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*Surface underspecification of tone in Chichewa**

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In Chichewa, a Bantu language spoken mainly in Malawi, there is a contrast between high and low tone, as illustrated by such minimal pairs as *mtengo* 'price' *vs.* *mténgo* 'tree'. But there is a strong asymmetry between the two tones in their phonological behaviour: high tone is phonologically active, while low tone is phonologically inert. Tone changes occur in Chichewa only if there is a high tone present in the phrase; a phrase composed only of low-toned morphemes is always realised unchanged with all low tones. The tonal phonology of the language can be described completely without reference to low tone (Kanerva 1989), as is typical for the Bantu languages (Stevick 1969).

I argue in this paper that this asymmetry is due to underspecification. The contrast in Chichewa is a privative one between high tone and no tone. Low tone is phonologically inert because it is simply the absence of tone. In particular, low tone is absent from surface representation. Syllables that are not specified as high-toned are assigned F0 by a non-linear transition function, as proposed for English intonation by Pierrehumbert (1980).

1 Surface underspecification

Considerable evidence has accumulated to indicate that the surface phonological representation is underspecified, i.e. that some elements of the representation lack target values for some features. The phonetic value for an element lacking a target value depends on the phonetic values of surrounding targets.

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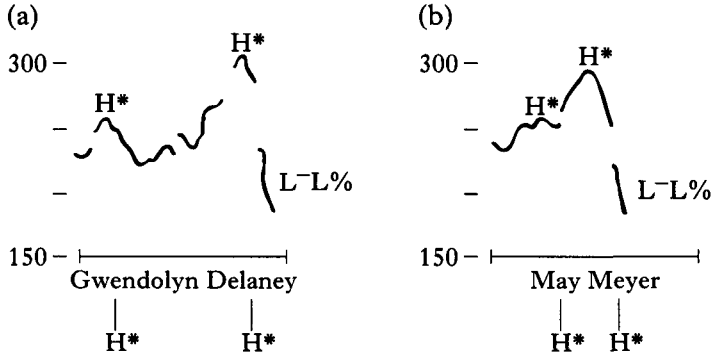
Cohn (1993), for example, considered nasal airflow as a physical manifestation of the feature [nasal] in English. She found, as one would expect, that a nasal stop has high nasal airflow throughout most of its duration, and an oral stop has no nasal airflow throughout most of its duration. Nasal airflow in a vowel, on the other hand, is determined by neighbouring consonants. In a vowel between two oral consonants, there is no nasal airflow. But if there is a nasal consonant on one side of the vowel and an oral consonant on the other, the nasal airflow during the vowel goes smoothly from the level for the preceding consonant to the level for the following consonant. Cohn argues that the vowel lacks a specification for [nasal], and its value for nasal airflow is determined by a straight-line transition between the specified nasal target values on either side.

Other arguments for surface underspecification in the literature include Pierrehumbert (1980) on tone in English, Pierrehumbert & Beckman (1988) on tone in Japanese, Davison (1992) on tone in Northern Mandarin, Keating (1988) on place of articulation in English consonants, Cohn (1993) on nasality in Sundanese, Huffman (1993) on nasality in Yoruba, van Bergem (1994) on vowel features in Dutch and Choi (1995) on vowel colour in Marshallese. In each of these cases, the authors argue that the relevant target specification is lacking in some elements of surface representation, and that the relevant phonetic value is assigned by a transition function. Such a possibility is also frequently assumed in the literature on coarticulation, e.g. Menzerath & de Lacerda (1933) and Öhman (1966).

Such work has important consequences for both phonology and phonetics. For phonology, it provides evidence against the idea that the phonological representation is fully specified, which was first assumed in Chomsky & Halle (1968), and has been revived recently in such works as Smolensky (1993), Calabrese (1995) and Beckman (1997). For phonetics, the evidence for surface underspecification means that a default or transitional phonetic interpretation must be available for stretches of the surface representation that are unspecified.

Most of the works arguing for surface underspecification have posited a simple transition function consisting of a linear interpolation between the specified values on either side. However, linear interpolation is not the only transition function evident in speech. Pierrehumbert (1980: 71) proposed that H* accents in English display a non-linear transition, in which 'the F0 falls until it is time to start aiming for the next H* level'. In the F0 contour in Fig. 1a, for example, the F0 peaks correspond to H* pitch accents. In between the H* peak on *Gwéndolyn* and the one on *Deláney*, F0 dips markedly, rather than following a straight line from peak to peak. Pierrehumbert argued that this F0 dip between H* pitch accents is not due to an intervening low tone. She found that the dip only occurs when the two H* pitch accents are separated by a sufficient number of syllables, as in (a). There is no appreciable dip between the two H* pitch accents when they are aligned with adjacent syllables, as in *Máy Méyer* in (b). According to Pierrehumbert's interpretation of these cases, it is

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(excised from the context 'I think you should discuss it with __.')

Figure 1
From Pierrehumbert (1980).

already time at the end of the first H* to 'start aiming for the next H* level' (cf. Bruce 1977 on Swedish).

The H* pitch accent contrasts in English with bitonal pitch accents that do have a low tone, e.g. L + H* or L* + H. The dip associated with the low tone in such a bitonal pitch accent is not dependent on the interval between peaks (Pierrehumbert 1980), and is timed with respect to the stressed syllable (Pierrehumbert & Steele 1989). These bitonal pitch accents can also be distinguished from the unmarked H* in their pragmatic interpretation (Pierrehumbert & Hirschberg 1990).

Curving transitions as in Fig. 1a have been described as 'trough transitions' by other authors. Engstrand (1988) noted that in slower productions of VpV nonsense words by Swedish speakers, the tongue lapses toward a neutral central position during the labial stop closure, between the gestures associated with the two vowels. A similar transition was found in English labial gestures by Gay (1978), Perkell (1986) and Boyce (1990), and in laryngeal gestures by Munhall & Löfqvist (1992). The velic height data described by Keating (1990) show a similar trough pattern in the case of a vowel between two nasals.

One can think of these transitions in terms of articulatory gestures within the model of Browman & Goldstein (1990). Each target can be expressed in terms of a gesture that requires a movement from a neutral position to a peak displacement and then back to neutral. Such gestures are schematised in Fig. 2, where the x-axis represents time and the y-axis represents displacement from neutral position. If two gestures involving the same articulator are separated in time, then there will be a period between the two gestures in which the articulator maintains neutral position. This is a trough transition, illustrated in Fig. 2a. If the two gestures overlap, it can be the case that the articulator is called upon to start moving to the second peak before it has finished the cycle of the first gesture back to neutral position. The more overlap there is, the less of the

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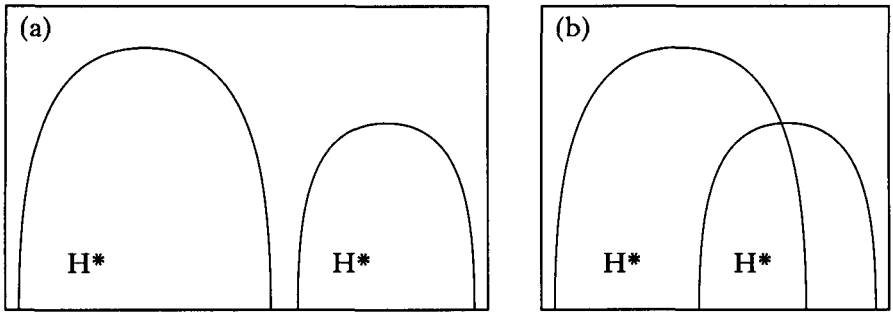


Figure 2
a) no overlap; b) overlap.

movement toward neutral position will be evident between the two peaks, until the first peak's offset covers the whole rise portion of the second peak. At this degree of overlap, there is no dip in between the two gestural peaks and the transition is linear, as in Fig. 2b. According to this characterisation, the distinction between trough and linear interpolation depends on the relative phasing of the two gestures. The transition tends toward a linear shape the more the two gestures overlap, and it tends toward a trough shape the more the two gestures are separated in time.

As a reviewer points out, one challenge for this unified view of transitions is the long linear F0 interpolation posited by Pierrehumbert & Beckman (1988) for Japanese. They found a linear transition from a high F0 level realising a high phrase accent to the low F0 level on the phrase-final syllable, realising the L% boundary tone. This linear transition covers up to eight syllables, which would seem to put it beyond the usual extent of laryngeal gestural overlap.

It might be relevant here that the second tone involved is a boundary tone. Pierrehumbert & Beckman found that L% had a lowering effect extending a number of moras from the end of a phrase (1988: 75). One way to model this would be to assume that the F0 lowering gesture associated with the boundary tone is one with a very gradual onset. Such an assumption would greatly increase the scope of gestural overlap for such boundary tones, reflecting the fact that boundary tones can have effects over a much longer period than lexical tones.

2 Low tone is phonologically inert in Chichewa

As stated above, high tone is phonologically active in Chichewa and low tone is phonologically inert. This asymmetry is evident in all the patterns of tone alternation and tone distribution in the language. These will be briefly surveyed in this section. In each case, we will find that there are strong restrictions on the distribution of high tones, but no restrictions on

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the distribution of low tones. For detailed analyses of the patterns, see Mtenje (1987), Kanerva (1989), Hyman & Mtenje (1995) and Myers & Carleton (1996).

2.1 Tone placement

There are a number of restrictions on the position of a high tone within the word or phrase. There are no such restrictions on the position of low tones.

2.1.1 *Phrase-final position.* A high tone cannot occur on the final syllable of a phrase. If a word with a final high tone occurs at the end of a phrase, the high tone is retracted to the second mora of the phrase-penultimate vowel, which is always lengthened (Kanerva 1989).[1]

(1) a.	mwaná uuyu	b. Mlónda ámaiwála mwaána.
	child this	watchman forgets child
	'this child'	'The watchman forgets the child.'

Where the word *mwaná* is not phrase-final, as in (1a), it has no long vowels and the high tone is on the final mora. But when the same word occurs in phrase-final position, as in (1b), the high tone occurs on the second half of the lengthened penult vowel.

There are no restrictions on the phrase position of low tones. A low tone can occur finally, medially or initially in a phrase.

Because these phrase-dependent processes are perfectly regular and can obscure some relevant distinctions, we will abstract away from them in all subsequent Chichewa transcriptions. These transcriptions thus reflect the pronunciation in phrase-medial position. The transcription given here differs from that in earlier work (e.g. Mtenje 1987, Kanerva 1989, Hyman & Mtenje 1995) in reflecting no processes of tone spread. See Myers (1998) and § 3.3 below for arguments that there is no tone-spread pattern in Chichewa.

2.1.2 *Tone placement in verb stems.* The verb stem consists of a verb root and a sequence of suffixes. The position of a high tone in the verb stem is restricted according to what kind of morpheme the tone belongs to.

A verb root in Chichewa can be high-toned, such as /tambalal/ 'stretch one's legs out', or toneless, such as /sangalal/ 'enjoy oneself'. However, the high tone of the root is not realised on the root itself, but on the last syllable of the stem, as in the imperative forms in (2).

(2) a.	*High-toned root*	b. *Low-toned root*
	Tambalal-á!	Sangalal-a!
	stretch out legs-TERM	enjoy-TERM
	'Stretch out your legs!'	'Enjoy yourself!'

[1] Abbreviations in the glosses: TERM = terminal verb marker; HABIT = habitual; SG = singular; PL = plural; OBJ = object; COMP = completed.

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Other high tones in the verb stem mark various inflectional distinctions. The present habitual and other tenses, for example, are characterised by a high tone on the stem penult, as in (3). (The absence of the high tone of the root on the final syllable of (3a) is due to Tone Reduction, to be discussed in §2.2.1.)

(3) a. *High-toned root*
Ndí-ma-tambalál-a.
1SG-HABIT-stretch out legs-TERM
'I stretch my legs out.'

b. *Low-toned root*
Ndí-ma-sangalál-a.
1SG-HABIT-enjoy-TERM
'I am happy.'

Other inflectional classes are marked by a high tone on the stem-final syllable (as in the subjunctive) or on the stem-initial syllable (as in the infinitive).

There are, on the other hand, no tenses marked by a low tone on a particular syllable, and there are no restrictions on the placement of low tones in the verb stem.

2.2 Tone dissimilation

When two high tones are juxtaposed within a phonological word or a close syntactic configuration, there is dissimilation. On the other hand, nothing happens when two low tones are juxtaposed, and there is no restriction on such sequences.

2.2.1 *Tone Reduction.* If two high tones are placed on adjacent syllables within the phonological word, the second high tone is deleted. Kanerva (1989: 25) refers to this process as Tone Reduction. It is an instance of a widespread pattern in Bantu languages known as Meeussen's Rule (Goldsmith 1984). For example, if a high-toned tense marker precedes a high-toned object marker, as in (4), the object marker (italicised here) is realised without high tone:

(4) Ndi-ná-*mu*-thandiz-a.
1SG-PAST-3SG OBJ-help-TERM
'I helped him/her (and continue).'

cf. Ndi-ná-a-*mú*-thandiz-a.
1SG-PAST-COMP-3SG OBJ-help-TERM
'I helped him/her (but no longer).'

The result of Tone Reduction is that there is no sequence of high-toned syllables in a Chichewa word. There is, on the other hand, no restriction on sequences of low tones.

Within a morpheme, there can be at most one high-toned syllable. Except for a few exceptional forms, no root has more than one high tone (Kanerva 1989: 14). This is stronger than the restrictions on successive morphemes, since the restriction within a morpheme also rules out two *non-adjacent* high tones. In contrast, there is no limit on the number of low-toned syllables in a morpheme.

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2.2.2 *Tone Shift.* In certain close syntactic configurations such as Noun + Determiner (Kanerva 1989), a word with the tone sequence HL cannot follow either HL or LH. Instead, a word that is generally HL, such as *wánga* 'my' in (5a, b), is changed to LH in this context, as in (5c, d). Kanerva (1989) refers to this pattern as Tone Shift (cf. Myers & Carleton 1996).

(5) a. wánga 'my'

b. munthu wánga 'my person'
person my

c. mwaná wangá 'my child'
child my

d. mkázi wangá 'my wife'
woman my

The high tone in the determiner is shifted to the right only if there is a high tone in the last two syllables of the preceding word.

There is no shift in a determiner with only low tones (e.g. *uyu* 'this'), or if there are only low tones in the last two syllables of the preceding word.

2.3 Tone spans

A sequence of high-toned syllables cannot occur within a phonological word (Myers 1998). Thus one finds two-syllable words with the tone sequence HL, as in *dzína* 'name', or LH, as in *mwaná* 'child', or LL, as in *munthu* 'person'. But there are no two-syllable words in which both syllables are high (*HH), and more generally there are no words containing a HH sequence. A representation of HH as a sequence of two high tones, as in (6a), is ruled out by Tone Reduction (§2.2.1), but such a sequence could also be represented with a single high tone associated with two syllables, as in (6b).

(6) a. H H b. H

σ σ σ σ

Since there are no sequences of high-toned syllables, a multiply associated high tone, as in (6b), must be forbidden. There is, on the other hand, no restriction on sequences of low-toned syllables within a phonological word.

2.4 Analyses of the tone asymmetry

We have surveyed the tone patterns in Chichewa and found that they all involve the distribution of high tones. Low tones are not restricted in distribution, and play no role in the distribution of high tones.

These asymmetries between H and L were noted by Mtenje (1987) and Kanerva (1989). They proposed that the underlying contrast is between H and the absence of H, and that L is inserted as a default tone after all other phonological rules have applied. L plays no role in the phonology

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according to this analysis because it is not introduced in the derivation until after all the other phonology has happened.

An alternative account of the asymmetry is possible within Optimality Theory (OT), based on the insights of Smolensky (1993). Smolensky observed that unmarked feature specifications, such as coronal place of articulation, tend to be phonologically inactive. The relative unmarkedness of coronal is expressed in OT by ranking the constraint against coronal specifications, *COR, below the constraints against labial and dorsal specifications. Smolensky noted that in OT phonological activity occurs when some markedness constraint crucially dominates a faithfulness constraint, i.e. a constraint that opposes changes to the input. Thus if *COR is ranked below the constraints on other place specifications, *COR is less likely to dominate a relevant faithfulness constraint and so less likely to trigger phonological activity.

Applying this view to tone in Chichewa, one could say that tone is fully specified, and the contrast in both the input and the output is between H and L. The constraint against low tones (*L), and any constraint ruling out low tone in some context, are ranked below all the relevant faithfulness constraints. Given such a ranking, nothing will happen where there are just L tones, since keeping the input unchanged is a higher priority than avoiding low tones. In this account, L plays no role in the phonology because it is relatively unmarked.[2]

I argue for a third account, according to which the contrast at all levels is a privative one between H and the absence of H. There is no low tone, except for the L% boundary tone at the end of phrases (Myers 1996). I will refer to this view as the SURFACE UNDERSPECIFICATION hypothesis. In this view, lexical L tone plays no role in the phonology of Chichewa because it doesn't exist in the language. This approach was proposed and motivated for Bantu in general by Stevick (1969), and has been assumed recently by Hyman & Mathangwane (1998: 211) for Ikalanga and Odden (1998: 267) for Yao. In OT terms, surface underspecification of low tones requires that the constraint against low tones (*L) is ranked above a faithfulness constraint, e.g. MAX-IO(T) against tone deletion, and above the constraint requiring that each syllable bear tone (Myers 1997).

All three accounts predict an asymmetry between H and L. But the surface underspecification hypothesis differs from the other two accounts in that it asserts that L is absent from surface representation and so cannot be a target for phonetic interpretation. I will argue in the rest of this paper that this is so: L is not a phonetic target in Chichewa. This evidence supports the surface underspecification account and provides evidence against the two accounts described here which require full surface specification.

[2] This account would have some difficulty with the fact that there are no tenses marked by a floating low tone (§ 2.1.2). If low tones are allowed, and floating tones in the input end up associated in the output, then it is unclear how one could get this result in terms of a low-ranked *L.

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3 Surface underspecification in Chichewa: an experiment

Our hypothesis is that all syllables in Chichewa that are not high-toned (aside from the phrase-final one) are toneless, and that their F0 values are assigned by a transition function in terms of the F0 values of surrounding high tones. To test this hypothesis, an experiment was conducted in which the number of toneless syllables between two high tones was systematically varied.

3.1 Materials and procedures

The materials for the study were three sentences of Chichewa, which differ just in the choice of matrix verb:

(7) a. Mlónda ámayámba kunyénya.
watchman begins to-goof-off
'The watchman begins to goof off.'
b. Mlónda ámayenéra kunyénya.
watchman must to-goof-off
'The watchman must goof off.'
c. Mlónda ámalepherétsa kunyénya.
watchman prevents to-goof-off
'The watchman prevents (someone) from goofing off.'

Each sentence has four high tones. The sentences differ from one another in how many syllables separate the two medial high tones. There is one syllable separating the second from the third high tone in (7a), as opposed to two syllables in (7b) and three syllables in (7c).

Loudness and speech rate were varied in order to induce a broad range in F0 values and in the time interval between peaks. The sentences were written on sheets of paper, each with instructions as to how loudly and quickly it was to be produced. There were three loudness levels: LOUD (as if shouting to a person out in the hall), NORMAL (as if speaking to a person across the booth) or SOFT (as if speaking quietly to a person right next to the speaker). Louder utterances tend to have a higher and broader pitch range than softer utterances (Liberman & Pierrehumbert 1984). There were two rates: NORMAL (as in normal conversation) or FAST (as fast as the speakers could speak while maintaining clarity). The sentences were recorded on a DAT tape recorder in a sound-treated booth.

Three speakers of Chichewa produced the sentences: SM, DJ and CJ. All three speakers are adult native speakers of Chichewa from Malawi. SM is a male from Nkhotakota in the Central region, DJ is a male from Blantyre in the South and CJ is a female from Mzuzu in the North.

The DAT recording was redigitised and F0 measurements produced using the PLIB (Phonology Laboratory in a Box) pitch-tracking system. This is a PC-based autocorrelation program, designed by Anthony

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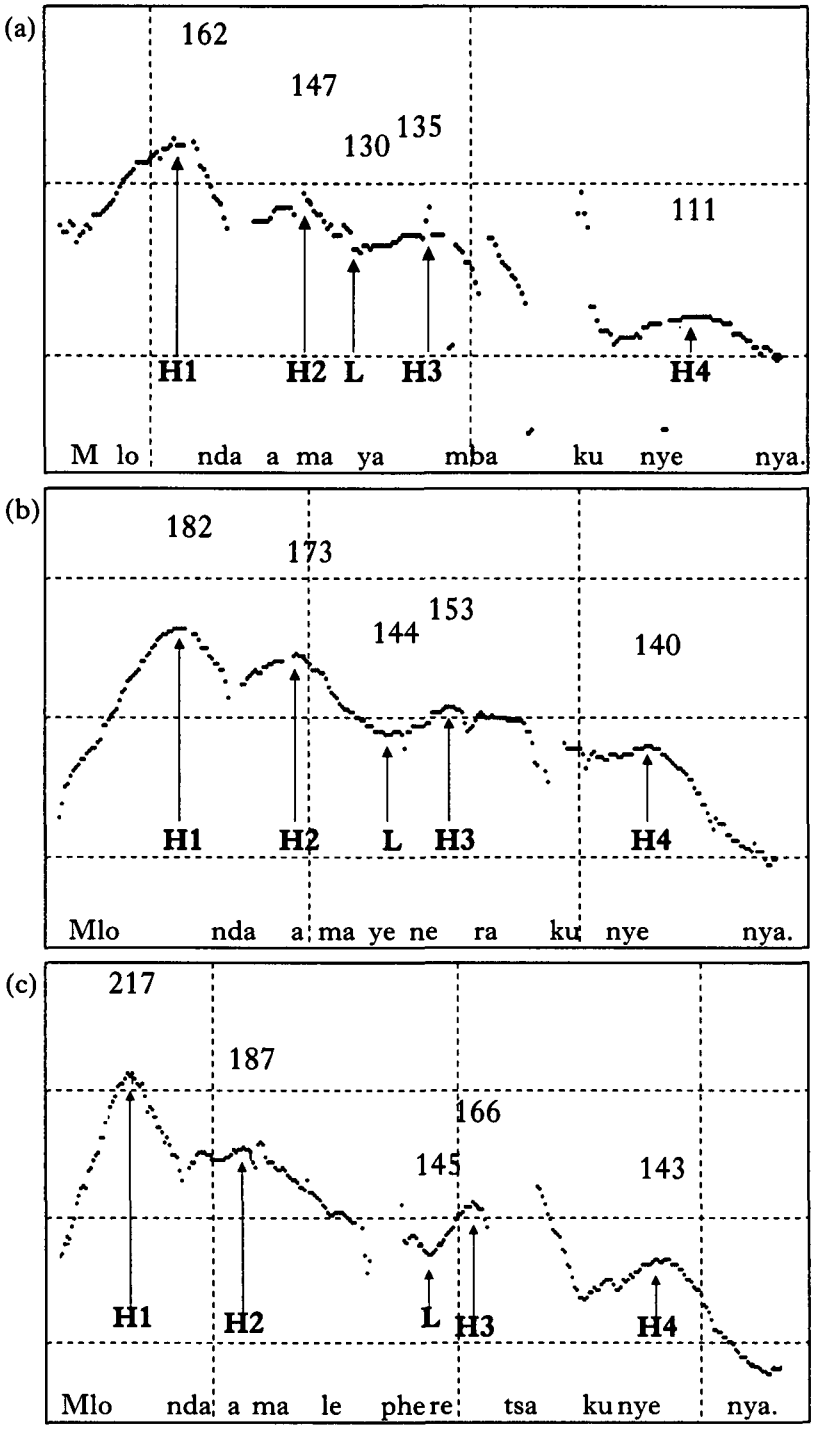


Figure 3
Sample pitch tracks for the three test sentences, as produced by speaker DJ.

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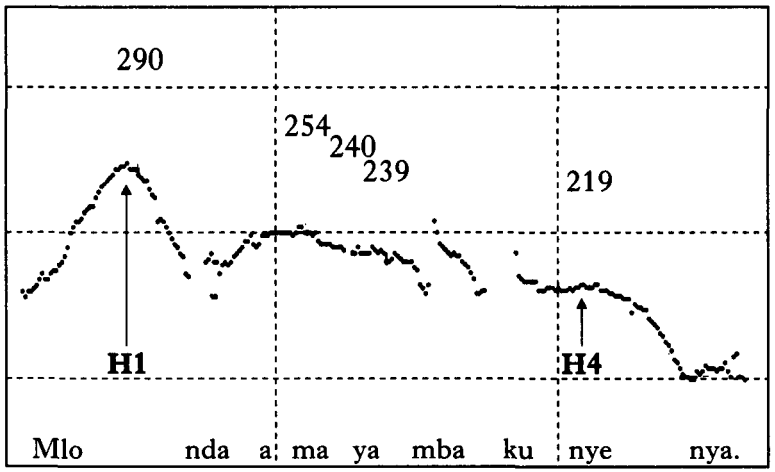


Figure 4
Example of pitch merger.

Woodbury on the basis of software by Mark Liberman and John McCarthy. The following points were measured for this study:

(8) a. H2 and H3: The local F0 maxima corresponding to the second and third high tones.
b. L: The local F0 minimum between H2 and H3.
c. T: The time interval between the offset of H2 and the onset of H3.

A high tone in the test sentences generally corresponded to a rise to a local maximum value, followed by a fall to a local minimum value. Local F0 maxima and minima were measured, excluding consonant effects.[3] The maximum value (H2 or H3) was sometimes found in a single timepoint (a pointed peak) and sometimes in a more extended plateau during which F0 was maintained at the same high level. Likewise, the lowest value between the two peaks could be in a single point (the tip of a sharp 'v') or a flat-bottomed valley floor. This distinction was important in the measurement of the interval T between peaks: the endpoints of this interval were the last instance of the maximal F0 value in H2 (= offset of H2) and the first instance of the maximal F0 value in H3 (= onset of H3).

Typical pitch tracks of the three test sentences, as produced by speaker DJ, are given in Fig. 3. Measurement points for H1–H4 and L are indicated, corresponding to the F0 numbers appearing over the F0 curves. It can be seen that there are four major peaks in F0 corresponding to the four high tones. In interpreting these pitchtracks it is important to note

[3] Consonants were indicated in the PLIB display by periods of low amplitude and low autocorrelation values. Rapid movements in F0 during a consonant or during the transition out of a consonant were considered to be segmental effects and were excluded from measurement. Measurements of local minima and maxima were made for the portions of the pitchtrack excluding these.

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that the F0 peak for a high-toned syllable usually is not attained until early in the next syllable. This phenomenon of 'peak delay' is discussed in more detail in §4.

3.2 Results

According to the hypothesis being tested, the peaks H2 and H3 represent target values, while the trough L represents a transition value. If this is true, L must be predictable as a function of H2, H3 and the interpeak interval T. In particular, the prediction is that the drop from H2 to L will increase as T increases.

3.2.1 *Peak merger.* According to the hypothesis, the depth of the dip between H2 and H3 is smaller the closer H2 is to H3. Thus there is a continuum of dip sizes correlating with a continuum of interpeak intervals, and the limiting case would be those cases in which H2 and H3 are so close together that there is no dip between them, as in Pierrehumbert's English example in Fig. 1b. In such a case, the dip from H2 to L would be 0 Hz, the distance between the two peaks would be 0 milliseconds, and H2 and H3 would be merged into one F0 peak.

There were many tokens in the dataset displaying such peak merger. An example of peak merger produced by speaker CJ is shown in Fig. 4. Note that in this case, unlike those in Fig. 3, there are not four clear peaks in F0. There are discernible peaks corresponding to H1 and H4, but it is impossible to distinguish the medial peaks H2 and H3.

The distribution of peak merger cases is summarised in Table I, in

sentence	*number of syllables between high tones*	*number of cases of peak merger*		
		SM	DJ	CJ
yamba	1	9 (5·9%)	68 (27·5%)	79 (32·5%)
yenera	2	0 (0·0%)	1 (0·6%)	0 (0·0%)
lepheretsa	3	0 (0·0%)	2 (0·8%)	0 (0·0%)

[Table I. Peak merger by sentence]

terms of the number of cases and the percentage of the total tokens of each sentence. A token counted as an instance of peak merger if it did not have a period of lower F0 values separating two periods of higher F0 values in the syllables between the second high-toned syllable in the sentence and the third. A token was not counted as an instance if there was any F0 fall followed by a rise in that region of the sentence. For all speakers, peak merger was rare (below a rate of occurrence of 1 in 100 tokens) except in the case of the *yamba* sentences (7a). In these sentences, where the two medial high tones are separated by only one syllable, peak merger was common, ranging from 6% to 33% of the total instances of the *yamba* sentences. It was especially frequent in the softer and faster conditions.

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It is important to note that there was no case of 'trough merger'. That is, there was no case of LHL which was realised with an extended trough. This is as we would expect from the perspective of the surface underspecification hypothesis. In HLH there are two targets that can be so close together that there is no transition period between them, but in LHL there is just one target, which cannot be impinged on by the surrounding non-targets.

3.2.2 *The depth of the F0 trough.* The hypothesis is that the F0 dip between H2 and H3 increases with the distance between those peaks. Tokens with peak merger were excluded from the dataset to be examined, since in these cases there is no local F0 minimum L or time interval T between two F0 peaks. We can think of such cases as representing an F0 dip of 0 Hz and an interpeak interval of 0 ms, but this interpretation would not correspond directly to measured values.

After excluding the cases of peak merger, as close as possible to 20 tokens per condition per sentence were randomly selected for each speaker to make up a balanced set. This yielded 20 tokens × 6 conditions × 3 sentences, making a total of 360 utterances. Some of the utterances had to be excluded due to various problems in recording or in measurement. The F0 peaks of the female speaker CJ, for example, frequently exceeded 500 Hz, which is the maximum F0 value that can be reliably measured using PLIB. This happened especially in the loud condition, to the extent that the entire condition had to be excluded in her case in order to maintain a balanced set of data. As a result, her dataset only includes 228 tokens. The dataset for speaker SM is missing eight tokens due to recording problems, yielding a total of 352 tokens. The speaker DJ had the complete set of 360 utterances.

One way to investigate the relation between the interpeak interval T and the F0 dip in this dataset is to look at how that dip varies across the three test sentences, which are distinguished by how many syllables intervene between the medial two peaks. The surface underspecification hypothesis predicts that the depth of the dip between the peaks will be greater for those sentences with more syllables intervening between the high tones. The extent of the dip was measured by subtracting L (the F0 value of the local F0 minimum) from H2 (the F0 value of the second F0 peak).

The mean values of the H2–L dip in each sentence for each speaker are given in Table II. It can be seen that for all three speakers the dip

sentence	*number of syllables between high tones*	*mean dip* (Hz)		
		SM	DJ	CJ
yamba	1	17·5	12·1	12·1
yenera	2	33·9	19·9	45·8
lepheretsa	3	42·8	32·4	57·2

[Table II. F0 dip (H2–L) by sentence]

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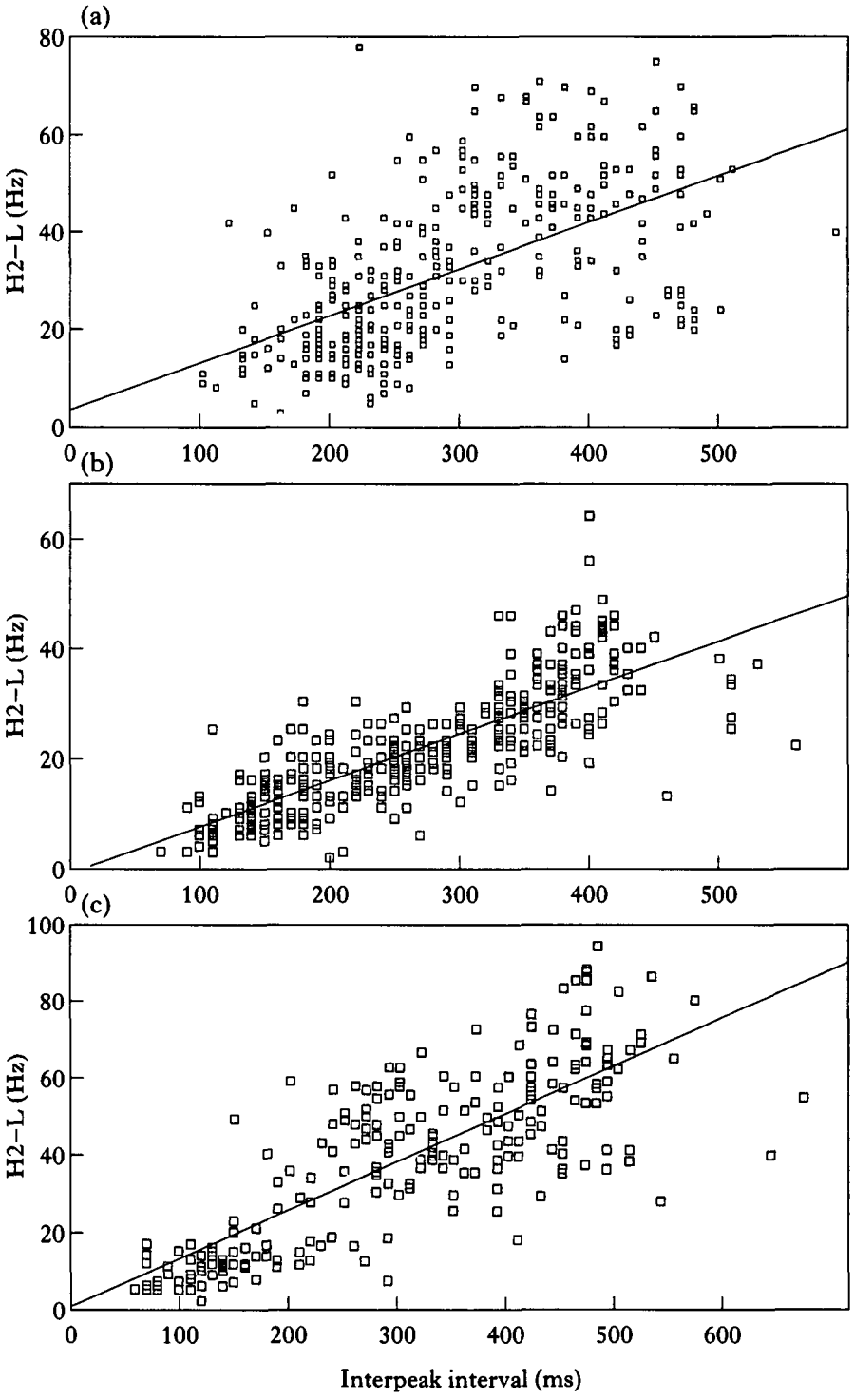


Figure 5
Scattergrams of H2–L * T. (a) speaker SM; (b) speaker DJ; (c) speaker CJ.

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increases with the number of syllables between the high tones. These differences were significant for all three speakers: SM ($F(2, 349) = 116{\cdot}9$, $p < 0{\cdot}0005$), DJ ($F(2, 357) = 273{\cdot}0$, $p < 0{\cdot}0005$), CJ ($F(2, 225) = 282{\cdot}2$, $p < 0{\cdot}0005$). Post-hoc t tests using Bonferroni's adjustment show that the difference is significant (at the 0·05 level) for each pair of sentences.

We can also look at how the F0 dip correlates with the interpeak interval T. In the graphs in Fig. 5, the difference between H2 and L in each utterance is plotted against T. It can be seen that the H2–L difference tends to be greater when the interpeak interval is longer. The data-points cluster relatively tightly around the regression lines that summarise this linear relation.

These graphs suggest that the F0 minimum value L can be predicted by means of a transition function from the F0 value of the immediately preceding target H2 and the interval T between the surrounding targets. Stepwise multiple regression analysis of the data leads to the following models (where T is coded in seconds).

speaker	*equation*	R^2
a. SM	L = 0·89 (H2) – 102·7 (T) + 21·6	0·98
b. DJ	L = 0·98 (H2) – 83·0 (T) + 4·4	0·96
c. CJ	L = 0·80 (H2) – 132·1 (T) + 60·4	0·94

[Table III. Multiple linear regression analysis]

The equation for speaker SM in (a), for example, states that the value of L is 89 % of H2 minus 102·7 Hz per second of T plus a constant baseline value of 21·6 Hz. The R^2 values express the proportion of the variation in L that is accounted for by the equation: 94 %–98 %. These values show that the factors H2 and T account for nearly all of the variance in L.

For the three speakers, the time-dependent drop in F0, represented by the coefficient of the variable T, ranges from 83 to 132 Hz per second. This factor made a significant contribution to the model for each speaker: SM ($t(350) = -18{\cdot}2$, $p < 0{\cdot}001$), DJ ($t(358) = -25{\cdot}1$, $p < 0{\cdot}001$), CJ ($t(226) = -26{\cdot}7$, $p < 0{\cdot}001$).

The equations in Table III do not, of course, provide a complete model of the phonetic interpretation of low tones in Chichewa. They do not provide any information, for example, about how a low tone will be interpreted if it isn't between two high tones. The most important thing lacking is a representation of the bottom of the current pitch range (the 'reference line' of Liberman & Pierrehumbert 1984). F0 does not, of course, keep falling until it hits zero. Rather, it bottoms out when it hits the bottom of the current pitch range. This is not a significant factor in these models, because the interpeak intervals are relatively short, and the trough in question is relatively early in the sentence (and therefore far from approaching the bottom of the pitch range). In a general model of low tone in all contexts, the reference line would provide a strong limit to F0 falls.

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Moreover, because measurements were only made of the F0 minima and maxima, our linear model also gives no idea of the shape of the trough transition. There is some discussion of this issue in Pierrehumbert (1981), but she notes that 'the ear seems to be relatively insensitive to the shape of the curve between the targets' (1981: 989).

3.3 Discussion

We have seen that for all three speakers, the extent of the drop between F0 peaks depends on how much time separates the peaks, as predicted by the surface underspecification hypothesis. The longer the interpeak interval was, the greater the F0 drop was (§ 3.2.2). If the interpeak interval was too short, there was no drop at all (§ 3.2.1). We can account for these facts by assuming that there is no low-toned target in the interpeak interval. The dip in F0 depends on the extent of overlap between the laryngeal gestures associated with the two peaks: the greater the overlap, the less of a dip is apparent.

A similar pattern, as we noted above, is found in English with H* pitch accents (Pierrehumbert 1980, 1981). Prieto *et al.* (1995) reported the same pattern for F0 minima in Spanish: 'the value attained by the L point in Spanish is correlated with the temporal distance between accents. The larger the distance, the lower the L value is.'

These results can be contrasted with those of Arvaniti & Ladd (1995) for Modern Greek. They found that accented syllables in this language display a rise in F0 from a low point near the onset of the stressed syllable to a peak near the onset of the following vowel. To test the hypothesis that the accent was H*, they varied the number of syllables between accents, reasoning that if there was no L target the dip between the accentual peaks would be lower when there were more intervening syllables. They instead found that the F0 value of the trough was relatively invariant, unaffected by the number of syllables intervening between the peaks.[4] They concluded that there is an actual low target at the beginning of the accent, which they interpreted as a L*+H bitonal accent in contrast with the plain H targets in English, Spanish and Chichewa.

The results presented in this section raise questions about one tone rule for Chichewa posited in Kanerva (1989). This is 'Pre-High Doubling' (1989: 65), which spreads a high tone one mora to the right just in case there is a high tone following in the phrase:

(9) 

[4] Data for one of the three speakers in the study had a weak effect, in that the value for the L in the sentence with one syllable intervening between accents was significantly different than the sentence with four syllables intervening (the maximum number). But this speaker otherwise had no significant differences according to the number of intervening syllables (e.g. between one and two syllables).

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This has the effect of converting HL...H to HH...H, as in (10).

(10) a. *gal*ú uuyu 'this dog'
b. Tinabá *gál*ú uuyu. 'We stole this dog.'

According to these transcriptions from Kanerva, the first syllable of *galú* is raised to high tone when it occurs after a high-toned syllable, as in (10b). The proposed doubling rule is unusual in that it frequently creates violations of the Obligatory Contour Principle (Leben 1978, McCarthy 1986), which forbids sequences of identical elements (e.g. high tones).

Our study supports an alternative analysis of these cases. As formulated, Pre-High Doubling should apply repeatedly in our test sentences, since they include a number of underlying H...H sequences. But what we have found is not a categorical raising of L to H in these contexts, as (9) would predict, but rather a gradient pattern according to which L between two Hs is closer in F0 to those peaks the closer they are to each other. This is therefore not a *bona fide* case in which a phonological process creates violations of the Obligatory Contour Principle.[5]

4 Evidence from timing

Another asymmetry between peaks and troughs in the Chichewa F0 data is in their timing. The F0 peak of a high-toned syllable has a consistent timing relation with that syllable, while the F0 trough is timed with respect to the whole interpeak interval.

Myers (1998) studied F0 peak timing in the *yenera* sentence in Chichewa in (7b). Two high-toned syllables were compared: the lengthened phrase-penultimate *nyé* and the earlier unlengthened syllable *né*. Measurements were made in Soundscope, using a spectrogram display synchronised with a pitchtrack display. The measure of F0 timing ('Peak Delay') was the time elapsed between the onset of the tone-bearing syllable (measured at the onset of the nasal murmur in the spectrogram) and the beginning of the F0 peak (i.e. the earliest of the local-maximum F0 values in the pitch track display). The duration of the tone-bearing syllable was also measured in the spectrogram, from the onset of the nasal murmur in the syllable onset to the drop in amplitude at the end of the vowel. Using multiple linear regression, Peak Delay was predicted in terms of the duration of the tone-bearing syllable ('Syll') and the phrase-position ('P'), which was coded 1 for a penult vowel and 0 otherwise. The results of the analysis are summarised in Table IV.

According to the R^2 values in Table IV, these simple models accounted for a substantial 56 %–75 % of the total variance in peak delay for each of

[5] Similar raising of L (either to H or to !H) between two H's has been reported in Tonga (Carter 1962: 2), Luganda (Hyman 1982: 4), Kongo (Carter 1980: 4), Kinyarwanda (Sibomana 1974: 20), Siswati (Rycroft 1982: 28), Makonde (Odden 1990: 165), Xhosa (Cassimjee & Kisseberth 1998: 108) and Akɔɔse (Hedinger 1985: 22). Quantitative data from these languages will be required to determine whether the effect in each case is categorical or gradient.

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speaker	*equation*	R^2
a. SM	Peak Delay = Syll × ((− 0·9 (P) + 1·4))	0·70
b. DJ	Peak Delay = Syll × ((− 0·61 (P) + 1·0))	0·56
c. CJ	Peak Delay = Syll × ((− 0·74 (P) + 1·1))	0·75

[Table IV. Peak Delay as a function of syllable duration and phrase position]

the three speakers. This indicates that the timing of the F0 peak with respect to syllable landmarks is regular.

The equations in Table IV express the alignment between the F0 peak and the tone-bearing syllable in the two positions. The equation for SM in (a), for example, states that the peak occurs at 140 % of the duration of the tone-bearing syllable in the general, unlengthened case (P = 0), which puts the peak at about the beginning of the following vowel. In the lengthened penult syllable (P = 1), on the other hand, the F0 peak occurs at 50 % of the way through the tone-bearing syllable. Similar patterns held for the other two speakers.

Such a pattern of F0 timing has been noted and analysed in a variety of languages. The F0 peak of a high-toned syllable occurs near the beginning of the next syllable in English (Silverman & Pierrehumbert 1990), Spanish (Prieto *et al.* 1995), Oneida (Grimm 1997), Navajo (de Jong & McDonough 1993), Czech (Bartels 1995) and Modern Greek (Arvaniti *et al.* 1998). The peak delay is significantly reduced in a lengthened syllable in English (Silverman & Pierrehumbert 1990), Spanish (Prieto *et al.* 1995) and Oneida (Grimm 1997).

The timing of F0 peaks with respect to syllable landmarks in Chichewa is thus regular and fits in with patterns found in other languages. When we turn to the timing of the F0 trough, on the other hand, we see a completely different picture. In the sentences under consideration, the low-toned stretch between H2 and H3 begins with the syllable *ma*. If the timing of low tones was analogous to that of high tones, then we would expect the beginning of the F0 trough, i.e. the location of the point at which the local F0 minimum is attained, to be timed with respect to that first low-toned syllable. Such a regular timing relation is found, for example, in the realisation of the low tone target in English (Pierrehumbert & Steele 1989) and Modern Greek (Arvaniti *et al.* 1998). In Chichewa, though, there is no relation between the F0 trough and the first low-toned syllable.

This point can be investigated most straightforwardly in our database in the *lepheretsa* sentence (7c), since the successive syllables in this sentence are easily distinguished in the amplitude displays in PLIB. In the sequence *ámalepherétsa*, the consonants *m*, *l*, *ph* (=[p^h]) and *r* are distinguishable as low-amplitude periods surrounded by the high-amplitude periods of the vowels.[6] The trough onset (i.e. the earliest timepoint

[6] In the *yenera* and *yamba* sentences, it is often very difficult to determine any kind of boundaries in the vocoid sequence *aye* and *aya*.

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of the local F0 minimum) occurred in this sentence in any one of the syllables intervening between the two high tones. The distribution by speaker is given in Table V, where each number represents the percentage of cases in which the trough onset occurred in that syllable in the set of *lepheretsa* utterances for the experiment reported in § 3. (The percentages for DJ add up to 99·9 %, rather than 100 %, due to rounding.)

speaker	*ma*	*le*	*phe*	*re*
a. SM	8·6	77·6	13·8	0·0
b. DJ	0·9	19·4	32·4	47·2
c. CJ	0·0	34·5	65·5	0·0

[Table V. Distribution of the trough onset (percentage of total occurrences)]

Where the trough onset tended to occur varied from speaker to speaker. The most common location was the syllable *le* for SM, *phe* for CJ and *re* for DJ. There was also a great deal of intraspeaker variation in the location of the trough onset, which often occurred in a different syllable in successive instances of the same condition.

If the trough onset is timed with respect to the tone-bearing syllable, we would expect the timing with respect to the syllable *ma* to be the same across the three sentences in our dataset, since that is the first syllable in the low-toned span in all three sentences. In fact, the trough was later in those sentences with more syllables in between the peaks. Let us define 'Trough Delay' as the measurement of the interval between the onset of /m/ (as indicated by the local minimum in RMS amplitude) and the trough onset. For SM, for example, the mean trough delay was 89 ms for the *yamba* sentence, 119 for *yenera* and 163 for *lepheretsa*. These differences among the three sentences were significant for all three speakers: SM ($F(2, 332) = 88{\cdot}2$, $p < 0{\cdot}001$), DJ ($F(2, 327) = 477$, $p < 0{\cdot}001$) and CJ ($F(2, 169) = 201{\cdot}3$, $p < 0{\cdot}001$).

The timing of the trough delay was not sensitive to the syllable *ma*, but rather to the interval T between the two F0 peaks. We can use linear regression to predict the trough delay from the interpeak interval T:

speaker	*equation*	R^2
a. SM	Trough Delay = 0·32 (T) + 31·8	0·37
b. DJ	Trough Delay = 0·80 (T) − 39·2	0·67
c. CJ	Trough Delay = 0·74 (T) + 10·3	0·64

[Table VI. Linear regression: Trough Delay by interpeak interval T]

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According to these models, the trough occurs at a relatively constant proportion of the period in between the peaks, regardless of what syllable that lies in. The R^2 values indicate that this single independent variable accounts for a significant percentage of the variance in trough delay (37–67%).

The F0 trough, then, is not timed with respect to the first low-toned syllable *ma*. Instead, its location is best predicted in terms of the whole interval between the two high tone peaks. This is unexpected if the trough is a realisation of a low tone that is associated with a sequence of syllables beginning with *ma*. It is expected, however, if there is no low tone target, and the trough is just a point that the F0 contour passes through on the path between the two high tone targets.

5 An alternative account

There is a plausible alternative account of the fact that the F0 dip tends to be less at shorter interpeak intervals, which relies on the notion of 'undershoot' (Lindblom 1963, Moon & Lindblom 1994). Undershoot occurs when a segment is so brief that the articulators fail to reach the segment target before they have to begin moving toward the next target. In such a case, the gesture undershoots the target, and the phonetic value of the undershot segment tends toward the phonetic values of surrounding elements, i.e. a 'blended' gesture intermediate between the two (Browman & Goldstein 1990).

In Chichewa, we could assume that there are low-toned targets, contrary to the surface underspecification hypothesis, but that at the shorter interpeak intervals there is not sufficient time to reach those targets. The laryngeal gestures corresponding to H2 or H3 overlap with the F0-lowering gesture of L, yielding a blended laryngeal gesture intermediate between the two. The result is that the F0 drop is less for shorter interpeak intervals. Bruce (1977) proposes just such an explanation for the fact that the dip between accents in Swedish is reduced as the temporal distance between the accents is reduced.

Undershoot is a well-motivated pattern, and it would account for the dependence of the F0 dip in Chichewa on the interpeak interval. But undershoot fails to account for other facts about low tone in the language. First, we have noted that H plays a role in Chichewa phonology, but L does not. This would require a separate explanation in the undershoot account, but follows without further stipulation from the hypothesis that L does not exist at any level in Chichewa. Second, we have seen that F0 peaks have a regular timing relation with respect to the tone-bearing syllable, while the F0 troughs do not. This follows in the surface underspecification account from the lack of a low tone target, but it would require additional stipulations in the account in which there are low tone targets.

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A third problem with the undershoot account is that it should apply to high tones as well as low tones. We would expect that the H would be undershot in LHL exactly as the L is supposed to be undershot in HLH. Overlap of the gestures corresponding to H and L should not only yield a higher version of L, but a lower version of H.

One test of this prediction is a comparison of the two different rates, since gestural overlap is expected to be greater at the faster rate (Gay 1981). The undershoot approach therefore predicts that at faster rates high tones will be lower in F0, since they will be subject to more overlap with neighbouring low tones. In fact, the opposite is the case. The F0 value of H2 was found to be significantly higher in the fast than in the normal speaking rate: SM ($t(347) = 2{\cdot}4$, $p = 0{\cdot}017$), DJ ($t(353) = 2{\cdot}2$, $p = 0{\cdot}029$), CJ ($t(226) = 4{\cdot}3$, $p < 0{\cdot}0005$).

The maximum gestural overlap would be in the cases of peak merger, as described in § 3.2.1. In these cases the F0 value of H2 should according to the undershoot account be lower than in cases with no peak merger, since the gesture for H2 overlaps maximally with that for L. To test this hypothesis we can't just take the F0 value of H2 as the dependent variable, since peak merger tends to be more frequent in the soft condition, which brings with it lower F0 values. Instead, the comparison was based on the quotient of the value of H2 divided by that of H1, in order to relativise the level of H2 to the ambient pitch range. Comparing H2/H1 for the cases of peak merger in the *yamba* sentence to cases of the same sentence with distinguishable H2 and H3, no significant differences were found between the two sets: SM ($t(65) = -0{\cdot}52$, $p = 0{\cdot}604$), DJ ($t(187) = -0{\cdot}06$, $p = 0{\cdot}953$), CJ ($t(97) = 0{\cdot}38$, $p = 0{\cdot}703$). Thus H2 was not significantly lower (relative to the pitch range) in the peak merger cases than in comparable cases without peak merger.

We can conclude that while an undershoot account could make sense of the dependence of the F0 trough on the interpeak interval, it cannot without further elaboration and stipulation account for the other asymmetries between high and low tone in Chichewa.

6 Conclusion

I have argued that there is no lexical low tone in Chichewa. The contrast in Chichewa is between high tone and no tone.

Three sorts of evidence have been adduced in support of this view. First, low tones play no role in the phonology of Chichewa. According to our hypothesis, this is because there are no low tones (except for L% boundary tones). Second, as predicted, the F0 values of the toneless syllables in this study depend on the F0 values of the surrounding H tones, and the amount of time between them. The F0 value of the F0 trough can thus be accurately predicted by means of a transition function between surrounding targets. Third, there is an asymmetry between peak and trough in terms of timing. The onset of the peak is aligned in a

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relatively invariant way with the end of the tone-bearing syllable. The onset of the trough, on the other hand, is not bound to any particular syllable, and in particular is not bound to the first toneless syllable.

Taken alone, each of these three results is consistent with an account in which the low tone is specified, but only the surface underspecification account predicts all three without further stipulation. The phonological inertness of L can be expressed, as we noted in §2.4, by making L the default tone, or by making it sufficiently unmarked in an OT analysis. But neither of these approaches to the phonological inertness of low tone can explain the phonetic asymmetries between H and L. On the other hand, §5 described an alternative account in terms of undershoot for the raising of L between two H's. But such an analysis could not by itself explain why there is no lowering of H between two L's, or account for the asymmetries between the two tones in timing and phonological activity. The assumption that non-high-toned syllables are toneless, on the other hand, accounts for all these facts without requiring any more assumptions.

Our findings have some general theoretical implications. First, they provide further support for the existence of surface underspecification, as in the papers cited in §1. All such cases provide evidence against the idea that the phonological representation is fully specified (Smolensky 1993, Calabrese 1995, Beckman 1997). Second, our results support the proposal that the transition between specified phonetic values can be non-linear, as suggested by Pierrehumbert (1980) and others. Third, we have shown that Chichewa does not have a phonological pattern raising low tone to high between two high tones, a pattern that would run counter to the Obligatory Contour Principle.

Since low tone is phonologically inert in most of the Bantu languages (Stevick 1969), it is likely that similar arguments would apply to these related languages. Pulleyblank (1986) has in fact proposed that low tone is the default in *all* two-tone systems. I would not argue, however, that low tone is absent from surface representation in all such systems. Low tone has been shown to be a phonetic target in such two-tone systems as English (Pierrehumbert 1980), Japanese (Pierrehumbert & Beckman 1988)[7] and Modern Greek (Arvaniti & Ladd 1995).

Moreover, there are two-tone languages in which high tone has been said to be phonologically inert. Some Bantu languages, such as Luba, have switched H and L so that L corresponds to Proto-Bantu H and *vice versa* (Guthrie 1967: 61). Nash (1992–94) shows that in one such language, Ruwund, low tone is phonologically active and H is inert. Sequences of low-toned morphemes dissimilate in Ruwund, while sequences of high-toned morphemes are left untouched – the mirror-image of the usual Bantu case as found in Chichewa. A similar state of affairs is found outside of Bantu in Igbo (Clark 1990) and Bambara (Creissels & Grégoire 1993).

[7] In Pierrehumbert & Beckman's analysis of Japanese, the L targets are the L of the HL accent and the L% boundary tone, while unaccented moras without an intonational tone are treated as toneless.

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It would be interesting to see whether this phonological asymmetry corresponds to a phonetic asymmetry, as we found in Chichewa.

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