Phonology **15** (1998) 77–101. Printed in the United Kingdom
© 1998 Cambridge University Press

*Phonetic realisation of downstep in Bimoba**

Keith L. Snider
Summer Institute of Linguistics, Cameroon/Canada Institute of Linguistics at Trinity Western University

0 Introduction

Few phonological phenomena have so captured the attention of theorists and continued to baffle them as the phenomenon of tonal downstep. Downstep is the lowering of the tonal register that sometimes occurs between adjacent, otherwise identical tones. It is cumulative, and successive occurrences of the phenomenon result in ever lower settings of the tonal register. The present work reports on an instrumental study of downstep in Bimoba, a Gur language spoken in the Northern Region of Ghana. So far as I am aware, the present work is the only description in existence of tone in Bimoba.

Bimoba is a good candidate for a study of downstep, because it is a 'three-tone' language in which both Low tones (floating and non-floating) and Mid tones cause High tones to be downstepped. A number of phonological studies (based on auditory impressions only) of three-tone languages with downstep of High tone have claimed that the difference in pitch between a High and a following Mid is equivalent to that between a High and a following downstepped High. These include Supyire (Carlson 1983), Babanki (Hyman 1979), Moba (Russell 1986) and Kagoro (van de Kolk 1992). This issue is important to tone theorists because a number of proposals on the theory of downstep formally equate a downstepped High with one type of Mid tone. These include Clements

* The data for this study were obtained during and following a tone workshop conducted by the Summer Institute of Linguistics in Yaoundé, Cameroon (30 September–8 November 1996). I am indebted to Mr Siat Kanturib, my Bimoba language consultant, for his time and patience, to the Bimoba literacy committee for temporarily releasing him from his normal duties so that he could participate in the workshop, to Sonia Hine for sharing with me from her extensive knowledge of Bimoba and, finally, to the Stuart K. Hine Foundation for a travel grant which made it possible for both Siat and Sonia to travel to the workshop. The paper has profited from discussions with Steven Bird, and written comments from Sue Glidden, Robert Hedinger, Mark Karan, Connie Kutsch Lojenga, Myles Leitch and two anonymous *Phonology* reviewers. I am particularly grateful for extensive written comments from Bruce Connell, Bob Ladd and David Odden. The usual disclaimers apply.

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

(1983), Hyman (1986, 1993), Inkelas (1987) and Snider (1990). On the other hand, a number of other proposals account for downstep with phonetic implementation rules. These include Pierrehumbert (1980), Poser (1984), Beckman & Pierrehumbert (1986) and Pierrehumbert & Beckman (1988). 'If register shift is indeed a rule of phonetic implementation, there is no reason, a priori, for the interval of register shift to be equivalent to that found between two phonemic tones' (Snider 1990: 470). So far as I am aware, no instrumental study has ever addressed this issue. The present study therefore undertakes to help fill this lacuna, and concludes that in Bimoba a Mid tone is phonetically indistinguishable from a downstepped High tone in comparable environments.

A second issue of interest to phonologists concerns whether (or to what extent) Lows descend in alternating sequences of Low and High beyond that which can be attributed to declination, the gradual lowering over the course of an utterance of the 'phonetic backdrop against which the phonologically specified local F0 targets are scaled' (Connell & Ladd 1990: 2). Based mainly on studies reported in Hombert (1974), Schuh (1978: 238) concludes that 'LO tones descend in pitch much more slowly than intervening highs, *if they descend at all* [italics mine]... A better formalization... would seem to be one which progressively lowers HIs while leaving LOs constant'. The present work does not support this conclusion, but rather supports the conclusions of another more recent study on Yoruba, Laniran (1993), that the pitch of Lows does descend significantly. One unexpected result of the present study supports Connell & Ladd's (1990) findings for Yoruba (also confirmed by Laniran 1993) that there is a raising of High tones before Low tones.

Stewart (1965, 1983) coined the terms AUTOMATIC DOWNSTEP to refer to downstep when the Low tone is non-floating and NON-AUTOMATIC DOWNSTEP to refer to downstep when the Low tone is floating. A third issue of interest to phonologists is whether the degree of downstep which is attributable to automatic downstep is the same as that which is attributable to non-automatic downstep. Since both phenomena involve low tones, and both result in a downward shift in register, most theories of downstep formally equate, in one way or another, non-automatic downstep with automatic downstep. If both phenomena lower the tonal register to the same degree phonetically, those theories that formally equate the two are justified. Instrumental support for or against formally equating the two is, however, greatly lacking. The two instrumental studies known to me that address this issue, Liberman *et al.* (1992) and Laniran (1992)[1] come to opposite conclusions for Igbo. On the one hand, Liberman *et al.* (1992: 89) conclude that in Igbo automatic downstep 'imposes a significantly greater degree of lowering' than does non-automatic downstep. On the other hand, Laniran (1992: 49) concludes that for Igbo:

> an analysis that models both automatic and non-automatic downstep as a register lowering rule is able to show that the two phenomena are

[1] My thanks to Bruce Connell for drawing the Laniran study to my attention.

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

treated the same in the phonetics, that is, with or without an overt L tone, an H tone is downstepped by the same amount.

The present study also investigates this issue, and concludes that in Bimoba a High tone that is downstepped by a floating Low *is* phonetically indistinguishable from one that is downstepped by a non-floating Low tone. Together with the Laniran study, this supports those theories that formally equate the two types of downstep.

The paper is organised as follows. §1 describes the phonology of downstep in Bimoba, §2 presents the instrumental study itself and §3 discusses the implications of the study for formal theories of downstep.

1 Downstep in Bimoba

This discussion outlines the most important phenomena of the tonal system of Bimoba, in order to make clear why the instrumental study focuses on the specific issues it does.

Bimoba is an SVO language with a noun class system and a verb class system. Each noun in the language can be classified according to its concord markers. These include subject, direct object, numeral and various demonstrative suffixes. Since some noun classes share the same subject markers, and some share other concord markers, it is not possible to classify any given noun on the basis of any one marker alone, but rather on the total combination of markers distinctive to its class. Similarly, each verb in the language can be classified according to which combination of tense/aspect suffixes characterises its class.[2] In order not to unduly complicate this report, the verbs in the study were restricted to that class which takes *-í* in what translates as the present tense, and *-ì* in what translates as the past tense. The verbs were further restricted to those roots that end in /t/. The purpose of this restriction was to generate a construction that included a floating Low tone in the verb phrase: in the case of the past tense *-ì*, the segmental /t/ is deleted when it follows root-final /t/, which leaves the Low tone of *-ì* floating.

As stated above, Bimoba distinguishes three level-tone phonemes, High, Mid and Low. These are best demonstrated by placing them in contrast with a High tone at their left edge, as in (1). (In the glosses throughout this paper, NC = noun class, AM = associative marker, PRES = present tense and PAST = past tense.)

[2] Most morphemes in the language are monosyllabic. For a more complete description of Bimoba morphology see Hine (ms).

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

(1) a. gbát-úk ŋmít-í gbát-úk 'a bushbaby is cutting a bushbaby'
bushbaby-NC cut-PRES bushbaby-NC
[¯ ¯ ¯ ¯ ¯ ¯]
[gbá túk ŋmí rí gbá túk]

b. gbát-úk māt-í gbát-úk 'a bushbaby is squashing a bushbaby'
bushbaby-NC squash-PRES bushbaby-NC
[¯ ¯ _ _ _ _]
[gbá túk mā ↓rí gbá túk]

c. gbát-úk gòt-í gbát-úk 'a bushbaby is looking at a bushbaby'
bushbaby-NC look.at-PRES bushbaby-NC
[¯ ¯ _ _ _ _]
[gbá túk gò ↓rí gbá túk]

For the three sentences of (1), the verb roots are High, Mid and Low-toned, respectively. Whenever verb root-final /t/ is followed by a vocalic tense/aspect marker, it is realised as [r]. In (1b, c), the High-toned object is downstepped by the preceding Mid and Low-toned verbs, respectively.

Whenever a Low or Mid tone lowers a High tone, the question arises whether the phenomenon in question is actually downstep or a local lowering. In order to answer this question, it is necessary to see whether tones that follow the lowered tone continue to contrast with the lowered tone in the same manner as they do when that tone is not lowered. The argumentation for the sentences in (1) is therefore as follows. These examples show that High, Mid and Low all contrast after a High tone; that is, the High-toned verb is realised at the same pitch as the preceding High-toned (*gbát-úk*), and the Mid and Low-toned verbs are realised at correspondingly lower levels of pitch. In (1b, c), the underlyingly High-toned present tense *-í* is lowered. If this lowering is in fact downstep, we would expect any High tone that follows it to be realised at the same pitch level as *-í*, and any Mids and Lows that follow it to be correspondingly lower. With respect to the first case, (1b, c) show that when another High tone follows *-í*, it is realised at the same pitch level as *-í*. (2) shows that a Mid that follows an *-í* that has been lowered by a preceding Mid is indeed correspondingly lower.

(2) gbát-úk māt-í tō-ók 'a bushbaby is squashing a colleague'
bushbaby-NC squash-PRES colleague-NC
[¯ ¯ _ _ ___]
[gbá túk mā ↓rí tō↓ók]

In (2), the High tone of *tō-ók* 'colleague' is also downstepped to the level of the preceding Mid. It is difficult to verify whether a Low following a

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

High that is lowered by Mid would also be correspondingly lower, because, as may be seen in (3), and as is argued below, a High tone (or a sequence of High tones) is raised before a Low tone. (3a) also demonstrates a postlexical rule of High-tone spread that spreads a High tone across a word boundary and raises the pitch of *pò* to the level of the preceding High-toned *rí* (cf. [pòrùk]).[3]

(3) a. gbát-úk māt-í pòr-ùk 'a bushbaby is squashing a spider'
bushbaby-NC squash-PRES spider-NC
[¯ ¯ _ ¯ ¯ _]
[gbá túk mā rí pó rùk]

b. tō-ók gòt-í gbát-úk 'a colleague is looking at a bushbaby'
colleague-NC look.at-PRES bushbaby-NC
[/ _ – – –]
[tōók gō ↓rí gbá túk]

In (3a), the underlyingly High-toned *-í* is raised above the level of the preceding Mid-toned *māt* because it is followed by Low-toned *pòr-ùk*. Similarly in (3b), the underlyingly High-toned *-ók* is raised above the level of the preceding Mid-toned *tō* because *-ók* is followed by Low-toned *gòt*. Examples (1) and (2) show us then that when a High tone is lowered by a preceding Mid, it is indeed a case of register lowering, because any Highs and Mids that follow the lowered High are also correspondingly lowered.

We now look at the lowering of High tones that is caused by preceding Low tones, as in (1c), to verify that this is also a case of register lowering.

(4) a. gbát-úk gòt-í tō-ók 'a bushbaby is looking at a colleague'
bushbaby-NC look.at-PRES colleague-NC
[¯ ¯ _ – ___]
[gbá túk gō ↓rí tō↓ók]

b. gbát-úk gòt-í pòr-ùk 'a bushbaby is looking at a spider'
bushbaby-NC look.at-PRES spider-NC
[¯ ¯ _ – – _]
[gbá túk gò ↓rí pó rùk]

In (4), it is clear that when a High tone is lowered by a preceding Low tone, a following Mid or Low is also correspondingly lower.

[3] The environment for the rule of High-tone spread is complicated and it is beyond the scope of this report to elaborate on it beyond saying that it does not apply when the Low in a High–Low–High sequence is singly linked, as in (1c) and (3b).

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

So far, we have looked only at examples of automatic downstep in which the Low tone that triggers the downstep is not floating. In Bimoba, floating Low tones also trigger non-automatic downstep, as may be seen in (5).

(5) gbát-úk ŋmít-ɨ̀ gbát-úk 'a bushbaby cut a bushbaby'
bushbaby-NC cut-PAST bushbaby-NC
[– – – – –]
[gbá túk ŋmít ˡgbá túk]

As noted above, the segmental /t/ of the past tense suffix is deleted when it follows root-final /t/. This leaves the Low tone of the suffix floating. Although this Low is floating, it nevertheless causes a following High tone to be downstepped.

A second source of floating Low tones in Bimoba is a floating Low 'boundary tone' that is assigned to the right edge of most noun phrases. Whether a noun phrase is assigned a boundary tone or not depends upon the head noun – most nouns require it, but a few, like *gbátúk* 'bushbaby' and *tōók* 'colleague', do not. For words that end in Low tone, like *pòrùk* 'spider', it is impossible to know whether or not they are followed by a Low boundary tone. Due to OCP constraints, a Low tone in Bimoba that is followed by a floating Low behaves the same as one that is not followed by a floating Low. The following examples illustrate the nature of the boundary tone (BT).[4]

(6) a. jɔ̄-ɔ̄-` 'man'
man-NC-BT
[⟍]
[jɔ̄ɔ̀]

b. jɔ̄-ɔ̄ pēē-n̄-` 'white man'
man-NC white-NC-BT
[– ⟍]
[jɔ̄ɔ̄ pēèn]

c. jɔ̄-ɔ̄ pēē-n̄-¯ jɔ̄-ɔ̄ pēē-n̄-` 'white man's white man'
man-NC white-NC-AM man-NC white-NC-BT
[– – – ⟍]
[jɔ̄ɔ̄ pēēn jɔ̄ɔ̄ pēèn]

Throughout the examples in (6), all tones, including the floating Mid associative marker (AM) in (6c), are Mid, except for the floating Low boundary tone that is consistently assigned to the right edge of the noun phrase. This Low tone docks onto the final syllable of the phrase, where it combines with, in the case of the examples in (6), the lexical Mid tone.

[4] For enlightening discussions on the phenomenon of boundary tones, see Hyman (1990), Mutaka (1990) and Black (1995).

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

Together, the two are realised as a Mid-falling tone. When the head noun is High-toned, a Low boundary tone reveals its presence by raising the preceding High tone (or sequence of High tones) and by downstepping any following High tones. This may be seen in (7).

(7) bá-á- ` ŋmít-ì gbát-úk 'father cut a bushbaby'
father-NC-BT cut-PAST bushbaby-NC
[¯ – _ _]
[báá ˡŋmít ˡgbá túk]

The introduction outlines three issues of importance to phonologists. The first, whether a downstepped High is phonetically indistinguishable from a Mid tone, rests on the assumption that there is, in fact, a Mid tone. A serious contender to the present analysis would be an analysis in which the 'Mid' is really a downstepped High; i.e. a High tone that is preceded or perhaps followed by a floating Low tone. If the Mid were in fact a High tone preceded by a floating Low, represented as (L) throughout the paper, one would expect that sequences of 'Mids' – (L)H (L)H (L)H – would be downstepped relative to each other since floating Low tones downstep High tones otherwise. But they are not; sequences of Mid tones merge and are all realised at the same phonetic pitch (cf. (6c)). A second argument against the Mid being a High that is preceded by a floating Low is that Mid tones do not spread onto underlyingly Low-toned syllables and thus do not follow the High-tone spreading rule, as they would if they actually were High tones. Compare these next examples.

(8) a. ā-gòt-ì pòr-ùk 'you (SG) looked at a spider'
2SG-look.at-PAST spider-NC
[– _ _ _]
[ā gòt pò rùk]

b. gbát-úk gòt-ì pòr-ùk 'a bushbaby looked at a spider'
bushbaby-NC look.at-PAST spider-NC
[¯ ¯ ¯ _ _]
[gbá túk gót pò rùk]

c. bá-á- ` ŋmít-í pòr-ùk 'father is cutting a spider'
father-NC-BT cut-PRES spider-NC
[¯ – – – _]
[báá ˡŋmí rí pó rùk]

In (8a), the Mid tone doesn't spread, whereas in (8b), the High tone does spread. In (8c), we see that even when the High is downstepped, it still spreads. I therefore conclude that the Mid is not a High tone that is preceded by a floating Low tone.

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

In order to reassure the reader that *ā-* in (8a) is indeed Mid-toned, as opposed to High-toned, it is contrasted with *gbát-úk* in (9).

(9) a. ā-ŋmít-í pòr-ùk 'you (SG) are cutting a spider'
2SG-cut-PRES spider-NC
[– ¯ ¯ ¯ _]
[ā ŋmí rí pó rùk]

b. gbát-úk ŋmít-í pòr-ùk 'a bushbaby is cutting a spider'
bushbaby-NC cut-PRES spider-NC
[¯ ¯ ¯ ¯ ¯ _]
[gbá túk ŋmí rí pó rùk]

Mid contrasts with High before a High tone that is followed by a Low tone.

Next, let us consider an analysis in which the order of the constituents is reversed; i.e. 'Mid' is really a sequence of H(L), in which the (L) downsteps the preceding High. Again, if the Mid tone were really a sequence of H(L), one would expect that sequences of Mid tones would be downstepped relative to each other, since sequences of downstepped High tones are downstepped relative to each other. A second argument against this analysis is that the language does, in fact, have sequences of underlying H(L), but these sequences differ from Mids in that they are not all realised at the same phonetic pitch, as are adjacent Mids. Compare the sequences of underlying H(L)s in (10a), repeated from (7), with the sequences of underlying Mids in (10b), repeated from (6c).

(10) a. bá-á-ˋ ŋmít-ɨ̀ gbát-úk 'father cut a bushbaby'
father-NC-BT cut-PAST bushbaby-NC
[¯ ¯ _ _]
[báá ↓ŋmít ↓gbá túk]

b. jɔ̄-ɔ̄ pēē-ñ-¯jɔ̄-ɔ̄ pēē-ñ-ˋ 'white man's white man'
man-NC white-NC-AM man-NC white-NC-BT
[¯ ¯ ¯ ↘]
[jɔ̄ɔ̄ pēēn jɔ̄ɔ̄ pēèn]

I therefore conclude that the Mid is not a sequence of two tone phonemes, but is rather a phonemic tone in its own right. Before moving on to the instrumental study, it will be helpful to review the conclusions about Bimoba that have been reached so far: (i) Bimoba is a three-tone language, with High, Mid and Low tones; (ii) Low tones (floating or otherwise) downstep High tones; (iii) Mid tones downstep High tones; (iv) High tones are raised before Low tones.

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

2 Instrumental study

2.1 Method

The three issues around which the instrumental study is focused are summarised in the following questions:

(i) Do Lows and Highs descend in alternating sequences of Low and High beyond that which can be attributed to declination?

(ii) Is the degree of downstep which is attributable to automatic downstep the same as that which is attributable to non-automatic downstep?

(iii) Is the drop in pitch in a High–downstepped High sequence equivalent to that in a High–Mid sequence?

In order to answer these questions, I constructed a corpus of eight data sets consisting of twelve sentences and recorded ten tokens of each sentence as spoken by a single male native speaker of Bimoba.[5] After identifying the F0 for each syllable in a token, I calculated the mean F0 of the ten tokens for each syllable in each sentence. The F0 values and how they were determined appear in the appendix, together with the mean values for each sentence. Comparisons of F0 levels between syllables were based on percentage differences. For example, the percentage of difference in F0 between syllables A and B of a given utterance is expressed as 100−(B/A*100). Using percentage differences rather than absolute differences has essentially the same effect as expressing F0 on a semitone scale: both allow one to ignore differences in absolute F0 level when making comparisons. Then for each of the comparisons, I calculated the mean percentage of difference for each syllable pairing. The eight data sets appear in Table I, which shows the underlying and surface forms for each sentence.

Sentences 1 and 2, which are High-toned and Low-toned, respectively, were included in order to determine what, if any, pitch lowering could be attributed to declination, on the assumption that any lowering they would undergo would be due only to declination. Sentence 3 was compared with sentences 1 and 2 to see if Lows and Highs descend in alternating sequences of Low and High beyond that which can be attributed to declination. Sentence 4 was compared with sentence 5 to see if the degree of lowering which is attributable to automatic downstep is the same as that which is attributable to non-automatic downstep. Finally, the sentences in 6 and 7 were compared with those in 8 in order to see if there was any equivalence between a downstepped High and a Mid tone. In comparing across sentences, I used *t*-tests to assess the significance of differences. Note that in most cases, I was examining the *difference between differences*, e.g. comparing a mean difference in F0 of 22·4% in one sentence to one of 21·2% in another.

[5] The speaker, who is in his late thirties, has lived most of his life in Bunkpurugu, a Bimoba village in Ghana's Northern Region.

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

	underlying	*surface*	
1.	HH HH HH	gbátúk ŋmírí gbátúk bushbaby cut.PRES bushbaby	'bushbaby is cutting a bushbaby'
2.	LL L LL	pòrùk gòt pòrùk spider look.at.PAST spider	'spider looked at a spider'
3.	LL H LH LL L H	pòrùk ˈmón gòˈrí pórúk bɔ̀n ˈbík spider red look.at.PRES spider black small	'red spider is looking at a small black spider'
4.	HH L HH	gbátúk gòt ˈgbátúk bushbaby look.at.PAST bushbaby	'bushbaby looked at a bushbaby'
5.	HH H(L) HH	gbátúk ŋmít ˈgbátúk bushbaby cut.PAST bushbaby	'bushbaby cut a bushbaby'
6.	H(L) HH HH	báá ˈŋmírí gbátúk father cut.PRES bushbaby	'father is cutting a bushbaby
7a.	H(L) H(L) HH	báá ˈŋmít ˈgbátúk father cut.PAST bushbaby	'father cut a bushbaby'
7b.	H(L) H(L) MH	báá ˈŋmít tōˈók father cut.PAST colleague	'father cut a colleague'
7c.	H(L) H(L) LL	báá ˈŋmít pòrùk father cut.PAST spider	'father cut a spider'
8a.	HH MH HH	gbátúk māˈrí gbátúk bushbaby squash.PRES bushbaby	'bushbaby is squashing a bushbaby'
8b.	HH MH MH	gbátúk māˈrí tōˈók bushbaby squash.PRES colleague	'bushbaby is squashing a colleague'
8c.	HH MH LL	gbátúk māˈrí pórùk bushbaby squash.PRES spider	'bushbaby is squashing a spider'

[Table I]

2.2 Results

2.2.1 *Declination and downstep*. The first question posed in §2.1 is whether Lows and Highs descend in alternating sequences of Low and High beyond that which can be attributed to declination. Sentences 1–3 were designed to answer this question, and appear in Table II, together with their mean measurements.

Sentence 1 is all High-toned and shows an average decline in F0 over the course of the sentence of ·82 % per syllable. Sentence 2 is all Low-toned and also shows a gradual decline in F0 over the course of the sentence until the last syllable (E), which shows a drop of almost 10 Hz. Abstracting from the difference in F0 due to this final lowering (extremely common in Niger-Congo languages), the average decline in F0 for sentence 2 is 1·3 % per syllable. Since the rates of declination for High tones and Low tones are based on single sentences only (albeit ten tokens each), rates were not established for varying lengths of sentences. It is therefore not known how representative these rates of declination are for sentences that vary

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

	A	B	C	D	E	F	G	H	I
	142·3	143·3	139·7	137·3	136·3	136·5			
1.	gbá	túk	ŋmí	rí	gbá	túk			
	118·6	116·5	115·4	114·0	104·6				
2.	pò	rùk	gòt	pò	rùk				
	119·9	119·7	185·3	106·2	134·7	141·8	138·7	85·9	120·2
3.	pò	rùk	↓món	gò	↓rí	pó	rúk	bòn	↓bík

[Table II]

significantly in length from those of sentences 1 and 2. Following a suggestion from one of the reviewers, I will assume an equal rate of declination for both High and Low tones of 1 % per syllable.

One unexpected result of the present study was the discovery that High tones (or sequences of High tones) are raised before Low tones. As stated above, this is similar to Connell & Ladd's (1990) and Laniran's (1993) findings for Yoruba. Looking at Table II (see also Tables III and V below), we see that the first High tone (or sequence of High tones) in a sentence begins at a substantially higher F0 if it is followed by a Low tone (whether floating or not) than do those that are not followed by Low tones. Whereas High-toned words like *gbátúk* 'bushbaby' typically begin a sentence at around 143 Hz unless they are followed by a Low tone, High-toned words like *báá* 'father', which are followed by a floating Low boundary tone, typically begin a sentence at around 165 Hz. We can also verify this raising through other comparisons.

If we compare, for example, the degree of lowering for downstepped Highs that are *not* followed by Low tones (e.g. syllable B of sentence 6 in Fig. 1 and Table III) with that for downstepped Highs that *are* followed by Low tones (e.g. syllable B of sentence 7a in Fig. 1 and Table III), we see that downstepped Highs that are not followed by Low tones are lowered substantially more than downstepped Highs that are followed by Low tones.

syllables	*difference*	95% *conf.*	*declination*	*diff-decl.*	
5D/B	25·4%	±0·9%	2%	23·4%	*downstepped High*
6B/A	25·7%	±1·5%	1%	24·7%	*downstepped High*
7B/A	13·6%	±0·7%	1%	12·6%	*downstepped High followed by Low*

[Table III]

This is because the downstepped Highs that have Lows following them have been raised by the following Lows, and the downstepped Highs that do not have Lows following them have not been raised. One may also

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

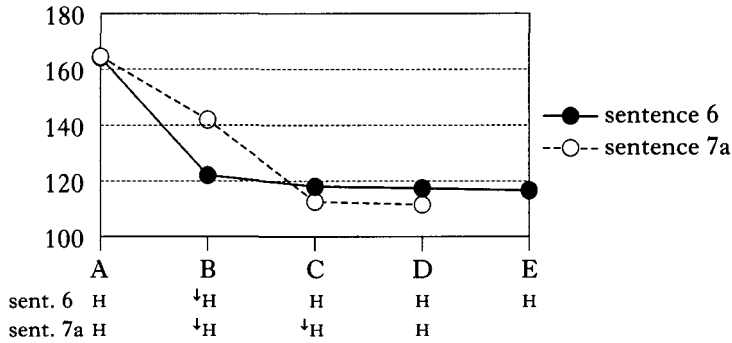


Figure 1
Downstepped High + High *vs.* downstepped High + Low

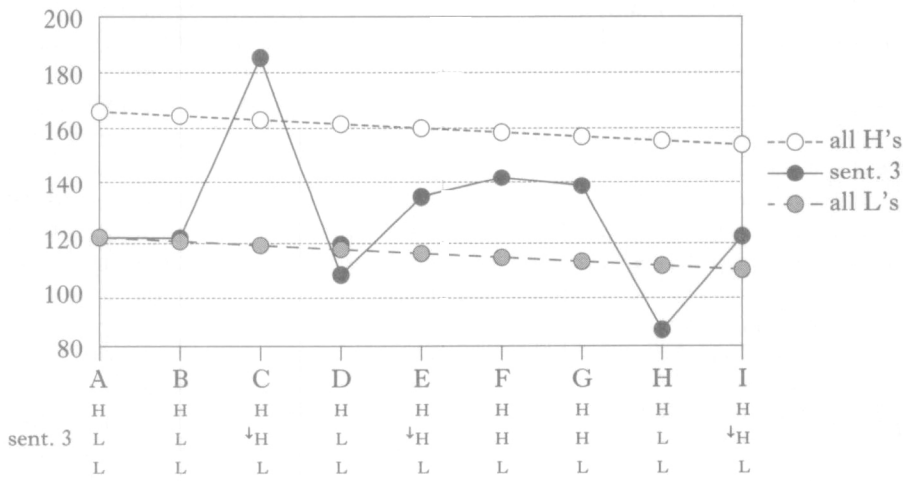


Figure 2
Automatic downstep *vs.* declination

compare the downstepped High of syllable D in sentence 5 (Fig. 3 below and Table III) with that of syllable B in sentence 7 (Fig. 1 and Table III), although the environment for sentence 5 is less comparable than that for sentence 6.[6]

Sentence 3 is a mixture of Highs and Lows. Notice that in this sentence, the second High tone does not reach its target until syllable F. Figure 2 shows sentence 3 against the backdrop of the assumed rate of declination (1 % per syllable). It is clear that the F0 of both Highs and Lows in

[6] The confidence intervals throughout the paper are based on a statistical formula that takes into account the sample size, the standard deviation and the desired level of significance (0·05 or 95 % for all confidence intervals in this paper). Because the confidence interval takes into account the standard deviation *and* the sample size, it is more useful than standard deviation alone.

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

sentence 3 declines much more rapidly than that which can be attributed to declination.

One might expect the first High tone in sentence 3, which is raised due to the following Low, to be realised at somewhere around 165·8 Hz, the mean beginning F0 of sentences 7a–c, which begin with a High tone followed by a Low. Since it is realised instead at 185·3 Hz (±4·6 Hz), which is considerably higher than that, I assume that this extra height is due to some factor or factors other than pre-Low raising. The difference in F0 between 165·8 Hz and the F0 of the final High of the utterance (120·2 Hz) is 45·6 Hz, a decline of 27·5%. The difference in F0 between 119·9 Hz (±3·3 Hz) and the F0 of the final Low of the utterance (85·9 Hz, ±1·8 Hz) is 34·0 Hz, a decline of 28·4%. This decline is slightly greater than that for High tones. Given that the figure of 165·8 Hz for the beginning of the High tone decline is only a postulated figure, and that the figure of 85·9 Hz for the end of the Low tone decline does not take into account any utterance-final lowering, it is perhaps safer to say that for Bimoba, the rate of decline for High tones in alternating sequences of Highs and Lows is roughly the same as that for Low tones, and that both are lowered considerably more than the 7% or 8% that one could attribute to seven or eight syllables of declination. This supports Laniran's (1993) findings for Yoruba.

2.2.2 *Automatic downstep* vs. *non-automatic downstep*. The second question posed in §2.1 is whether the degree of downstep which is attributable to automatic downstep is the same as that which is attributable to non-automatic downstep. Sentences 4 and 5 were designed to answer this question, and appear in Table IV, together with their mean measurements.

	A	B	C	D	E
	156·8	150·4	101·3	113·8	113·6
4.	gbá	túk	gòt	ˡgbá	túk
	152·6	151·5	151·2	113·0	113·6
5.	gbá	túk	ŋmít	ˡgbá	túk

[Table IV]

Sentence 4 includes a non-floating Low tone (syllable C) between High tones and sentence 5 includes a floating Low between the High tones of syllables C and D. The information in Table IV is displayed graphically in Fig. 3.

For sentence 4, the difference in F0 between syllables B and D is 24·2%. If we take into account declination, we can attribute a difference in F0 of 22·2% to downstep and raising, as shown in Table V.

For sentence 5 the difference in F0 between syllables B and D is 25·4%. Taking declination into account, we can attribute a difference in F0 of 23·4% to downstep and raising. Comparing sentence 4 with sentence 5,

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

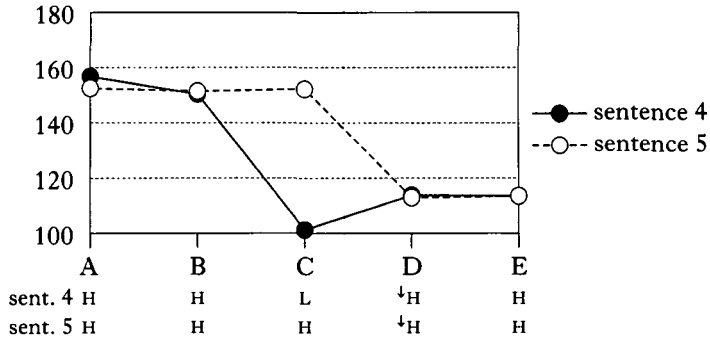


Figure 3
Automatic downstep *vs.* non-automatic downstep

syllables	*difference*	95% *conf.*	*declination*	*diff-decl.*	
4D/B	24·2%	±2·1%	2%	22·2%	*automatic downstep*
5D/B	25·4%	±0·9%	2%	23·4%	*non-automatic downstep*

[Table V]

one can see that the degree of lowering that is attributed to a non-floating Low tone, 22·2%, is very close to that attributed to a floating Low tone, 23·4%. A *t*-test showed this difference to be statistically non-significant. From this we conclude that the degree of lowering attributable to automatic downstep is the same as that attributable to non-automatic downstep.

2.2.3 *High–downstepped High* vs. *High–Mid*. The third question posed in §2.1 is whether there is any equivalence between the difference in F0 in a High–downstepped High sequence and the difference in F0 in a High–Mid sequence. The sentences in data sets 6–8 were designed to answer this question and appear in Table VI, together with their mean measurements.

The first two syllables of 7a–c are shared by all three sentences. For these sentences, the F0 of the first syllable of 7a is similar to that of the first syllables of 7b and 7c, and the F0 of the second syllable of 7a is similar to that of the second syllables of 7b and 7c. The same can be said for the first three syllables of 8a–c. In order to increase the level of confidence we can place in the mean measurements, I averaged the measurements of the shared syllables of all 30 tokens in 7, and all 30 tokens in 8. Statistical comparisons showed that there were no significant differences between the means averaged together in this way. Grand means based on 30 repetitions for the initial syllables of sentences 7a–c and 8a–c are shown in Table VII.

Comparing downstepped Highs with Mids is not completely straightforward in Bimoba. This is because, as discussed above, High tones are raised before Lows independently of the downstepping process. Because

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

	A	B	C	D	E	F
	164·2	122·0	118·0	117·4	116·6	
6.	báá	↓ŋmí	rí	gbá	túk	
	165·5	142·0	112·6	111·5		
7a.	báá	↓ŋmít	↓gbá	túk		
	165·9	143·6	113·5			
7b.	báá	↓ŋmít	tō↓ók			
	165·9	143·8	96·1	87·4		
7c.	báá	↓ŋmít	pò	rùk		
	146·2	144·6	125·2	123·6	123·5	126·0
8a.	gbá	túk	mā	↓rí	gbá	túk
	147·3	145·9	127·0	126·9	113·7	
8b.	gbá	túk	mā	↓rí	tō↓ók	
	146·2	144·9	126·5	141·4	139·8	98·4
8c.	gbá	túk	mā	↓rí	pó	rùk

[Table VI]

	A	B	C	
	165·8	143·2		
7a–c	báá	↓ŋmít	...	
	146·6	145·2	126·3	
8a–c	gbá	túk	mā	...

[Table VII]

there is a Low tone between a High tone and a downstepped High, and because there is normally *not* a Low tone between a High tone and a Mid tone, the difference in F0 between a High and a downstepped High cannot be directly compared with the difference in F0 between a High and a Mid. The comparison can, however, be made indirectly in two ways.

The first is to determine the degree of lowering that occurs when a High tone is followed by a downstepped High that has also been raised by a following Low tone. This factors out the raising effect by ensuring that both Highs are raised, and helps to establish the true value for downstep in this environment. Once this degree of lowering is determined, it can be compared with the difference in F0 between a High and a following Mid. For sentence 7 (see also the discussion above), the difference in F0 that is unattributable to declination between a High and downstepped High that is followed by a floating Low is 12·6% (±0·7%, sentence 7, Tables VII–VIII).

In this case, both High tones have been raised by the Low tones immediately following each one (i.e. the first High is followed by a floating

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

syllables	*difference*	95% *conf.*	*declination*	*diff-decl.*	
7B/A	13·6%	±0·7%	1%	12·6%	*downstepped High*
8C/B	13·0%	±0·8%	1%	12·0%	*Mid tone*

[Table VIII]

boundary Low, and the second High is followed by the floating Low that resulted from deletion of the segmental part of the past tense suffix, -*ì*). I take the figure of 12·6% to be representative for downstep in this environment. This figure may then be compared with the percentage of lowering that is representative for the difference between a High tone and a following Mid. That figure, 12·0% (±0·8%, sentence 8, Table VIII), is virtually the same as that for downstep. A *t*-test showed this difference to be statistically non-significant.

The second way one can compare downstepped Highs with Mids in Bimoba is to determine the difference in F0 between a raised High (i.e. one followed by a Low tone) and a following Mid tone. In Bimoba, Low tones do not influence following Mids. This can then be compared with the degree of lowering that occurs when a High tone (raised by a following Low) is followed by a downstepped High that has *not* been raised by a following Low tone.

Syllables B and C of sentence 7a (Table IX; see also Fig. 4) provide an example of a raised High that is followed by a non-raised downstepped High.

syllables	*difference*	95% *conf.*	*declination*	*diff-decl.*	
7aC/B	20·6%	±1·1%	1%	19·6%	*raised High followed by downstepped High*
7bC/B	20·9%	±1·7%	1%	19·9%	*raised High followed by Mid*

[Table IX]

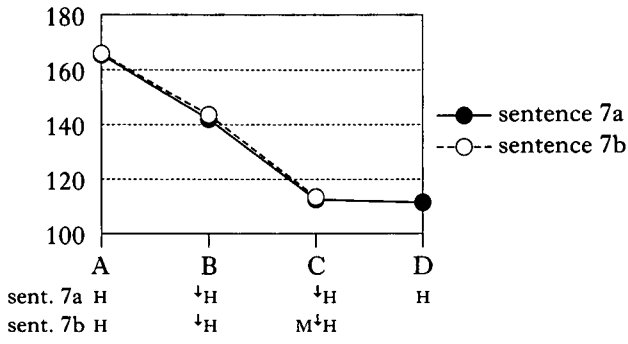


Figure 4
Downstepped High *vs.* Mid

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

The difference in F0 between these syllables that is unattributable to declination is 19·6 % (±1·1 %). Syllables B and C of sentence 7b provide an example of a raised High that is followed by a Mid. In this case, the High is raised due to the presence of a floating Low tone between the High and the Mid. The difference in F0 between these syllables that is unattributable to declination is 19·9 % (±1·7 %). Again, these figures are virtually the same. A *t*-test showed this difference to be statistically non-significant. From this we conclude that the downstepped High in Bimoba is phonetically equivalent to the Mid tone.

Before discussing the implications of the phonetic study for the theory, it will be helpful to review the conclusions about Bimoba that have been reached in this section.

(i) The phenomenon of downstep lowers subsequent High tones and Low tones to a degree that is unattributable to the phenomenon of declination.

(ii) The degree of lowering that is attributable to automatic downstep is the same as that attributable to non-automatic downstep.

(iii) The degree of lowering in a High–downstepped High sequence is equivalent to that in a High–Mid sequence in comparable environments.

3 General discussion

As stated in the introduction, there is a controversy between theories that account for the phenomenon of downstep in the phonetics component and theories that account for it in the phonology component. Although linguists have not yet fully explored the phonology–phonetics interface, a number of arguments have been put forward against accounting for register shifts in the phonetics component (see Ladd 1989, 1993, Inkelas & Leben 1991 and Snider 1990). We examine two of these here.

The first concerns the advisability of allowing phonetic implementation rules to effect phonological differences. For many tonal languages, the presence *vs.* the absence of (non-automatic) downstep represents a phonological difference. Therefore the application or non-application of the phonetic pitch-implementation rules that are allegedly responsible for downstep would be phonologically significant. By definition, however, the application or non-application of *phonetic* implementation rules is never *phonologically* significant.

The second argument against accounting for downstep in the phonetics component has to do with the type of features that are employed in the phonetics component. Most theories of tone employ binary or unary features in the phonology component to differentiate phonemic tone levels. But those that account for downstep in the phonetics component cannot equate the phonemic levels of the phonology component with those produced by downstep or upstep in the phonetics component. This is because the features employed in the phonetics component have non-

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

binary (scalar, or gradient) values and are therefore very different from the binary or unary phonological features that are used to distinguish phonemic tones in the phonology component.

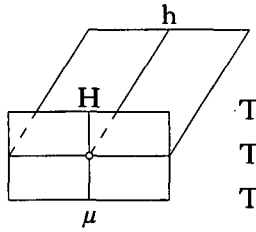
For those theories of tone that handle register differences and phonemic tone differences with separate feature systems (e.g. Pierrehumbert 1980, Poser 1984, Beckman & Pierrehumbert 1986, Pierrehumbert & Beckman 1988), there is no reason for the difference in F0 between a High and a downstepped High (a register difference) to be equal to that between a High and a Mid (a phonological difference). *Any* phonetic equivalence would be purely coincidental in these theories. On the other hand, if in undergoing downstep a High tone assimilates to a preceding Low in such a manner as to render the High *phonologically* identical to a Mid (i.e. so that it has the same feature representation as a Mid), the *phonetic* equivalence would not be coincidental. As stated in the introduction, studies of a number of languages that have three phonemic tone levels *and* the phenomenon of downstepped High have described the downstepped High as being phonetically identical to the Mid. Unfortunately, these studies lack instrumental support.

In order to demonstrate more clearly the relevance of the Bimoba study to formal theories of downstep, it will be helpful to present an overview of a theory that accounts for downstep in the phonology component.

3.1 Overview of Register Tier Theory

Register Tier Theory (henceforth RTT),[7] as set forth in Snider (to appear), assumes the following autosegmental features and tiers: the register features h and l on a REGISTER TIER, the tonal features H and L on a TONAL TIER, a TONAL ROOT NODE (TRN) TIER and a TONE-BEARING UNIT (TBU) TIER. These tiers have the geometric structure in (11).

(11) *Geometry of tone*



Register tier
Tonal tier
Tonal Root Node tier
Tone-Bearing Unit tier

Features on the Register tier and the Tonal tier are linked to structural nodes on the TRN tier. Geometrically, these tiers form separate planes

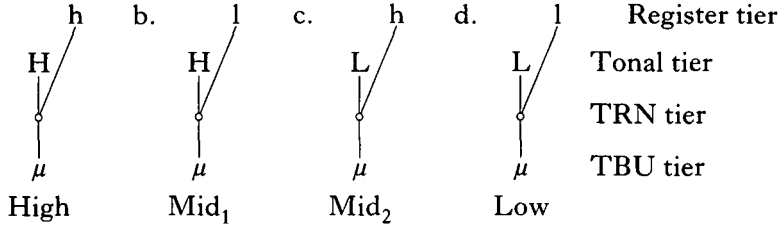
[7] Earlier versions of the theory include Inkelas (1987), Inkelas *et al.* (1987) and Snider (1990). The idea of a register tier was inspired by Yip (1980), and also advocated by Hyman (1985, 1986) and Pulleyblank (1986).

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

with respect to the TRN tier. Nodes on the TRN tier are, in turn, linked to moras (μ) on the TBU tier.

The features and geometry of (11) logically allow the specification of up to four level tones: High, Mid_1, Mid_2 and Low. Phonological representations for each tone appear in (12).

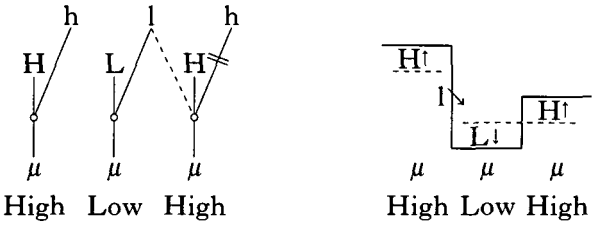
(12)



(13) below represents a typical automatic downstep environment, in which the second High of a High–Low–High sequence assimilates to the lower register of the preceding Low tone. It is therefore downstepped relative to the first High. Non-automatic downstep is treated identically to automatic downstep, with the exception that the Low tone of the construction is floating in the case of non-automatic downstep.

(13) *Downstepped High (automatic)*

a. *structural representation* b. *phonetic representation*



Lower-case h and l on the Register tier in (13a) respectively denote higher and lower registers, and these are represented in (13b) by the higher and lower dotted lines. Similarly, upper-case H and L on the Tonal tier in (13a) respectively denote high and low pitch relative to the current register, and these are represented in (13b) by the solid lines above and below the dotted register lines. In (13), the first TBU is realised with a H tone on its register. Because the second TBU is associated to a register l that is not linked to the preceding TBU, the L of this TBU is realised on a lower register than that of the preceding TBU. There is therefore a tonal difference *and* a register difference between the first and second TBUs. Since the third TBU is associated to the same register feature as the second TBU, the H of this TBU is realised on the same (lower) register

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

as that of the L of the second TBU. This means that the second High tone is downstepped relative to the first High. Compare the representation for Mid_1 in (12b) with that of the downstepped High in (13a). Phonologically, they are identical. This predicts that there are languages in which the two are phonetically equatable.

We turn our attention at this point to the phonological nature of downstep in Bimoba.

3.2 Phonological nature of downstep in Bimoba

From illustrations like (13) above, in which there is a register difference between a High tone and a following Low tone, one can see that RTT predicts that there will be languages for which the phenomenon of automatic downstep will lower to a degree that is unattributable to declination both Low tones and following High tones (in alternating sequences of Highs and Lows). As demonstrated in §2, this is in fact the case in Bimoba (and also Yoruba). The *fact* of this lowering is properly accounted for in the phonology component. To the extent that gradient features in the phonetics component are involved, it is to account for the *degree* of lowering in downstep.[8]

From the discussion on §3.1 above, it is clear that the features employed in RTT to account for automatic downstep are the same as those employed to account for non-automatic downstep. The prediction, of course, is that there exist languages for which the degree of lowering is the same in each case. As demonstrated in §2, the degree of lowering associated with automatic downstep in Bimoba is phonetically the same as that associated with non-automatic downstep.

I assume that the Mid in Bimoba has the structural representation of Mid_1 in RTT (i.e. H tone and l register). There are two facts about Bimoba that support this: (i) the phonetic realisation of the Mid tone and (ii) its phonological behaviour. With respect to (i), the phonetic equivalence of the Mid and the downstepped High strongly supports the claim that the Mid in Bimoba is Mid_1. With respect to (ii), the fact that Low tones do not downstep Mid tones (cf. §2.2.3) but Mid tones downstep High tones (cf. §1) is very much in keeping with the phonological behaviour of Mid_1. This is because the Mid_1 has a l register feature in its phonological make-up and is therefore ineligible to be a target for the *l*-spreading that is responsible for downstep of High (and Mid_2). The l of the Mid_1, however, can spread rightwards and downstep following High tones in the same manner as the l of Low tones. Taken together, the phonetic realisation of the Mid tone in Bimoba and its phonological behaviour strongly support analysing it as Mid_1.[9]

[8] A number of phonetic studies (e.g. Hombert 1974, Laniran 1993) show that in downstepping environments, Low tones descend more slowly than High tones. Recent work on European languages by Ladd (1996) suggests that differences like these may not require gradient features in the phonetics component, but may simply be attributable to the phonetics of pitch range.

[9] Of course, the Mid tone of some languages is Mid_2. The prediction for these

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

The facts of Bimoba call for a theoretical framework that treats downstep as a phonological phenomenon. The lowering of Low tones as well as High tones in downstepping environments, the phonetic equivalence of automatic downstep and non-automatic downstep, the phonetic equivalence of the downstepped High and the Mid tone, and the similarity in phonological behaviour between the downstepped High and the Mid all indicate that downstep is phonological.

Appendix A : Acoustic interpretation

Interpreting pitch contours is probably as much an art as a science. I will, however, try to indicate some of the more conscious criteria I used to establish the precise point in a TBU at which I measured the F0. To this end, I found Connell & Ladd's (1990) appendix on acoustic analysis very helpful. If the F0 was constant over the course of a syllable, or over a significant stretch of a syllable, I took the obvious measurement, using the Summer Institute of Linguistics' CECIL acoustic analysis application. Due to changes in phonological tone and perturbations caused by obstruents, however, the F0 was seldom constant over the syllable.

The reader will notice that many of the syllables in the corpus are flanked by obstruents. This was, to a certain degree, unavoidable. First, as explained above, verbs in the study were restricted to those that end in *t*, so as to produce an environment that included a verb-final floating Low tone. Secondly, the nouns *gbátúk* 'bushbaby' and *tōók* 'colleague' were chosen because they were virtually the only choices available that met the two following criteria: (i) The noun must belong to that very small class of nouns that are not followed by floating Low boundary tones. This was done in order to better control the phonological environment; (ii) The noun must be able to serve as subject of the clause in as semantically reasonable a manner as possible.

The presence of the obstruents perturbed the pitch trace to a certain extent, with voiced obstruents typically producing 'dips' in otherwise level contours, and voiceless obstruents producing 'breaks' in which the trace at the right edge of the break began at a substantially higher F0 and fell sharply to the level one would otherwise have expected the trace to have been realised at had the voiceless obstruent not intervened. These perturbations, for the most part, were identifiable for what they were and were ignored.

If a sequence of syllables had different phonological tones, I sought the target point for each tone and measured the peaks and valleys. This often aligned with the right edge of the voiced portion of the affected syllables. Finally, if a particular syllable was obviously functioning in a transitory manner between the peak of one tone and the valley of another, I chose the energy peak of the syllable as the point to read. In order to give the reader a better 'feel' for how I went about this, I have provided in Figs. 5 and 6 pitch traces for two tokens and indicated the points at which I measured the F0. The first trace is token 1.4 (the

languages is that the Mid does *not* downstep following High tones, the Mid *can* be downstepped by Low tones, and the Mid is not *necessarily* phonetically equatable with downstepped High.

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

fourth repetition of sentence 1), which is phonologically all High-toned, and the second trace is token 3.10, which has alternating sequences of underlying High and Low tones. Both tokens are representative of the mean values for each sentence.

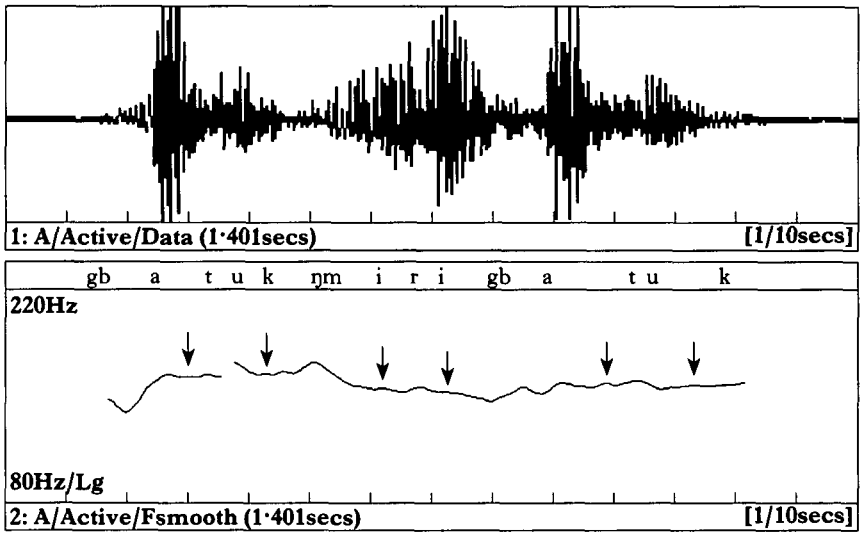


Figure 5
Token 1.4.

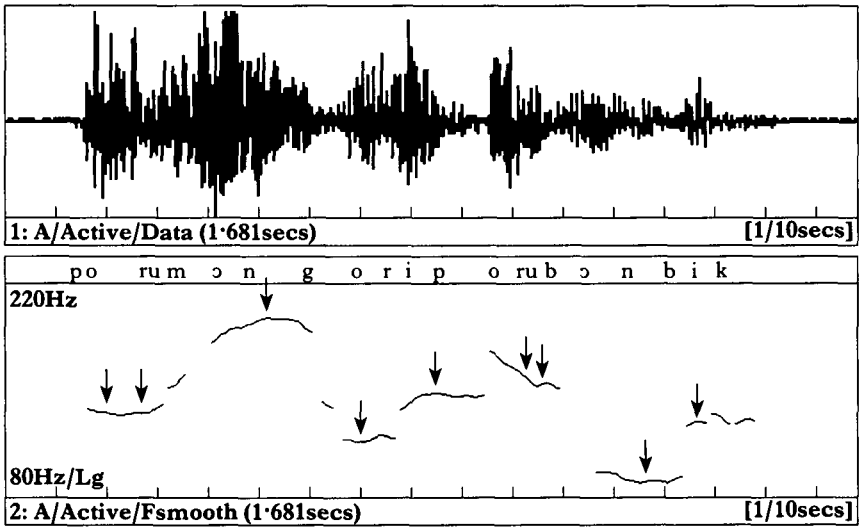


Figure 6
Token 3.10.

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

Appendix B : F0 of corpus tokens and mean values

	A	B	C	D	E	F
1.1	140·6	142·5	137·5	134·4	133·6	130·4
1.2	147·0	146·3	143·9	138·0	137·4	138·6
1.3	135·7	135·5	134·0	131·3	130·7	131·5
1.4	142·2	144·2	133·7	132·9	137·3	134·9
1.5	140·0	141·7	139·4	136·3	138·9	137·1
1.6	142·5	135·6	138·1	136·8	130·2	131·4
1.7	141·5	147·3	142·1	140·9	135·8	137·5
1.8	139·5	143·5	143·1	141·7	138·2	140·0
1.9	147·9	148·9	144·3	144·2	145·7	146·2
1.10	146·3	147·2	140·6	136·0	135·1	137·2
Mean	142·3	143·3	139·7	137·3	136·3	136·5
1.	gbá	túk	ŋmí	rí	gbá	túk

	A	B	C	D	E
2.1	114·2	112·2	110·1	113·0	103·5
2.2	117·3	111·9	109·8	108·4	101·1
2.3	127·3	118·3	115·3	115·4	112·1
2.4	112·6	112·6	111·4	106·8	94·7
2.5	117·1	117·4	117·9	111·7	106·7
2.6	116·4	109·8	110·5	117·2	91·8
2.7	117·0	120·3	118·0	116·9	98·0
2.8	122·6	120·2	119·9	117·3	111·0
2.9	121·7	121·4	123·7	118·7	114·4
2.10	120·1	121·2	117·0	114·7	112·2
Mean	118·6	116·5	115·4	114·0	104·6
2.	pò	rùk	gòt	pò	rùk

	A	B	C	D	E	F	G	H	I
3.1	122·6	122·1	185·7	108·9	140·2	140·9	141·5	83·5	122·0
3.2	114·2	113·6	175·0	103·0	131·1	134·1	134·9	79·6	116·5
3.3	114·3	112·4	177·0	103·0	133·6	139·5	136·9	85·4	120·4
3.4	118·0	118·0	182·8	105·6	132·7	151·2	143·4	88·4	122·7
3.5	119·1	118·7	178·2	108·3	132·7	136·7	136·7	86·1	114·2
3.6	116·5	115·7	180·7	102·8	133·0	136·4	134·7	84·9	121·8
3.7	128·6	129·4	194·6	109·4	137·4	146·7	140·5	83·9	124·2
3.8	129·4	129·4	197·7	104·1	135·7	149·8	140·2	90·0	119·6
3.9	114·8	114·6	191·4	108·9	138·0	137·9	137·2	88·0	121·7
3.10	121·9	122·8	189·5	107·5	132·6	144·5	140·7	89·1	118·8
Mean	119·9	119·7	185·3	106·2	134·7	141·8	138·7	85·9	120·2
3.	pò	rùk	↓mɔ́n	gò	↓rí	pó	rúk	bɔ̀n	↓bík

	A	B	C	D	E
4.1	158·3	158·1	95·8	111·3	111·9
4.2	150·3	146·8	106·0	112·8	110·9
4.3	159·9	151·7	96·2	113·2	111·6
4.4	183·5	179·6	114·8	125·2	125·4
4.5	148·2	140·3	92·8	107·5	111·4
4.6	137·2	136·7	102·5	104·3	103·7
4.7	154·6	149·5	104·0	120·4	123·9
4.8	162·9	150·5	104·4	120·2	114·8
4.9	161·0	143·4	102·7	112·4	115·8
4.10	151·8	147·8	94·2	110·6	106·8
Mean	156·8	150·4	101·3	113·8	113·6
4.	gbá	túk	gòt	↓gbá	túk

	A	B	C	D	E
5.1	158·1	159·4	158·3	118·4	117·0
5.2	144·3	145·6	147·3	108·7	108·9
5.3	147·1	146·7	146·6	113·3	113·2
5.4	152·5	152·6	149·5	110·0	111·0
5·5	146·5	139·9	144·4	106·7	108·8
5.6	143·8	145·3	141·7	111·0	109·6
5.7	159·3	160·8	157·5	118·1	119·1
5.8	168·3	162·2	159·3	119·9	120·6
5.9	157·9	151·7	161·3	112·2	115·6
5.10	148·2	150·6	146·1	111·5	112·5
Mean	152·6	151·5	151·2	113·0	113·6
5.	gbá	túk	ŋmít	↓gbá	túk

	A	B	C	D	E
6.1	178·9	132·2	128·3	131·8	131·6
6.2	170·3	131·7	121·4	117·3	116·7
6.3	164·4	117·4	116·0	114·7	110·9
6.4	152·8	116·1	111·1	109·8	112·1
6.5	157·2	117·9	114·7	112·2	117·1
6.6	159·2	118·6	115·9	113·4	113·3
6.7	165·9	125·3	121·1	117·9	113·5
6.8	162·1	124·2	118·0	120·0	117·2
6.9	167·4	116·1	114·7	116·4	110·9
6.10	164·2	120·2	118·9	120·7	122·2
Mean	164·2	122·0	118·0	117·4	116·6
6.	báá	↓ŋmí	rí	gbá	túk

	A	B	C	D
7a.1	173·5	143·6	111·9	110·6
7a.2	170·3	149·3	113·6	113·2
7a.3	160·2	138·2	112·3	110·6
7a.4	156·6	134·7	108·0	107·2
7a.5	165·4	139·4	110·0	110·1
7a.6	153·4	135·3	110·9	108·8
7a.7	167·2	144·1	115·3	115·0
7a.8	172·4	145·9	117·1	115·6
7a.9	164·0	142·9	112·1	111·8
7a.10	172·2	146·1	114·7	112·5
Mean	165·5	142·0	112·6	111·5
7a.	báá	↓ŋmít	↓gbá	túk

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

	A	B	C
7b.1	172·6	146·5	113·2
7b.2	168·9	146·8	111·9
7b.3	158·9	136·8	114·2
7b.4	159·1	137·5	112·3
7b.5	172·7	143·6	111·3
7b.6	164·3	144·1	111·3
7b.7	172·3	145·9	119·3
7b.8	159·3	142·2	115·6
7b.9	164·7	148·0	113·2
7b.10	165·7	144·8	113·0
Mean	165·9	143·6	113·5
7b.	báá	↓ŋmít	tō↓ók

	A	B	C	D
7c.1	172·1	145·9	89·2	88·6
7c.2	174·4	144·9	94·9	87·1
7c.3	159·4	139·7	100·2	87·1
7c.4	158·7	142·6	92·7	85·0
7c.5	168·3	145·7	97·9	88·5
7c.6	157·3	139·1	89·8	83·8
7c.7	165·0	142·9	98·4	82·2
7c.8	166·9	142·8	99·4	84·4
7c.9	163·0	142·3	99·9	89·2
7c.10	174·1	152·4	98·7	97·8
Mean	165·9	143·8	96·1	87·4
7c.	báá	↓ŋmít	pò	rùk

	A	B	C	D	E	F
8a.1	149·4	147·6	126·9	125·9	121·2	129·5
8a.2	149·5	152·1	132·0	129·8	127·6	128·0
8a.3	147·5	146·6	125·7	122·6	121·9	122·1
8a.4	136·3	137·2	121·7	123·1	122·2	125·9
8a.5	142·6	139·2	124·4	120·3	122·1	123·1
8a.6	148·4	146·3	124·1	124·2	128·4	125·9
8a.7	150·6	148·4	126·0	123·6	122·0	128·2
8a.8	145·7	143·5	126·4	122·9	123·2	127·9
8a.9	149·7	147·1	123·3	123·8	123·5	120·9
8a.10	141·9	138·4	121·4	120·2	123·3	128·1
Mean	146·2	144·6	125·2	123·6	123·5	126·0
8a.	gbá	túk	mā	↓rí	gbá	túk

	A	B	C	D	E	F
8b.1	147·0	149·3	132·2	131·1	115·9	
8b.2	148·5	145·0	130·9	129·0	110·1	
8b.3	152·1	145·0	130·3	131·0	118·1	
8b.4	152·3	149·0	127·1	128·2	115·2	
8b.5	138·7	137·6	120·3	119·4	109·8	
8b.6	141·1	137·9	123·6	123·1	110·3	
8b.7	146·8	148·6	128·0	126·9	112·5	
8b.8	149·3	150·1	130·0	131·6	116·5	
8b.9	148·2	149·3	124·5	125·5	114·7	
8b.10	149·4	147·1	122·7	122·8	113·9	
Mean	147·3	145·9	127·0	126·9	113·7	
8b.	gbá	túk	mā	↓rí	tō↓ók	

	A	B	C	D	E	F
8c.1	147·6	155·3	130·1	146·3	144·5	96·2
8c.2	147·7	148·6	128·4	139·1	145·1	101·1
8c.3	149·0	141·3	128·4	146·2	143·0	104·0
8c.4	146·0	138·4	123·0	138·9	138·2	96·2
8c.5	144·4	141·8	119·8	135·8	133·8	95·8
8c.6	148·0	143·9	123·1	136·6	132·1	96·2
8c.7	145·4	145·0	127·8	142·9	141·9	101·1
8c.8	148·5	147·7	129·7	149·3	143·1	99·5
8c.9	147·6	146·7	125·8	141·7	140·7	98·0
8c.10	138·0	140·3	128·5	137·2	135·5	95·8
Mean	146·2	144·9	126·5	141·4	139·8	98·4
8c.	gbá	túk	mā	↓rí	pó	rùk

REFERENCES

Beckman, Mary & Janet Pierrehumbert (1986). Intonational structure in Japanese and English. *Phonology Yearbook* **3**. 255–309.

Black, Cheryl (1995). Boundary tones on word-internal domains in Kinande. *Phonology* **12**. 1–38.

Carlson, Robert (1983). Downstep in Supyire. *Studies in African Linguistics* **14**. 35–45.

Clements, George N. (1983). The hierarchical representation of tone features. In I. Dihoff (ed.) *Current approaches to African linguistics*. Vol. 1. Dordrecht: Foris. 145–176.

Connell, Bruce & D. Robert Ladd (1990). Aspects of pitch realisation in Yoruba. *Phonology* **7**. 1–29.

Hine, Sonia (ms). Bimoba morphology. Summer Institute of Linguistics.

Hombert, Jean-Marie (1974). Universals of downdrift: their phonetic basis and significance for a theory of tone. *Studies in African Linguistics*. Suppl. **5**. 169–183.

Hulst, Harry van der & Keith Snider (eds.) (1993). *The phonology of tone: the representation of tonal register*. Berlin: Mouton de Gruyter.

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press

Hyman, Larry M. (1979). Tonology of the Babanki noun. *Studies in African Linguistics* **10**. 159–178.

Hyman, Larry M. (1985). Word domains and downstep in Bamileke-Dschang. *Phonology Yearbook* **2**. 47–83.

Hyman, Larry M. (1986). The representation of multiple tone heights. In Koen Bogers, Harry van der Hulst & Maarten Mous (eds.) *The phonological representation of suprasegmentals*. Dordrecht: Foris. 109–152.

Hyman, Larry M. (1990). Boundary tonology and the prosodic hierarchy. In Sharon Inkelas & Draga Zec (eds.) *The phonology–syntax connection*. Chicago: University of Chicago Press. 109–125.

Hyman, Larry M. (1993). Register tones and tonal geometry. In van der Hulst & Snider (1993). 75–108.

Inkelas, Sharon (1987). Tone feature geometry. *NELS* **17**. 223–237.

Inkelas, Sharon & William R. Leben (1990). Where phonology and phonetics intersect: the case of Hausa intonation. In John Kingston & Mary E. Beckman (eds.) *Papers in laboratory phonology I: between the grammar and physics of speech*. Cambridge: Cambridge University Press. 17–34.

Inkelas, Sharon, William R. Leben & Mark Cobler (1987). The phonology of intonation in Hausa. *NELS* **17**. 327–342.

Kolk, Kees van der (1992). *The three-level terraced tone system of Kagoro*. MA thesis, University of Leiden.

Ladd, R. (1989). Review of Pierrehumbert & Beckman (1988). *JL* **25**. 519–526.

Ladd, R. (1993). In defense of a metrical theory of intonational downstep. In van der Hulst & Snider (1993). 109–132.

Ladd, R. (1996). *Intonational phonology*. Cambridge: Cambridge University Press.

Laniran, Yetunde (1992). Phonetic aspects of tone realisation in Igbo. *Progress Reports from Oxford Phonetics* **5**. 35–51.

Laniran, Yetunde (1993). *Intonation in tone languages: the phonetic implementation of tones in Yorùbá*. Ithaca: Department of Modern Languages and Linguistics, Cornell University.

Liberman, Mark, J. Michael Schultz, Soonhyun Hong & Vincent Okeke (1992). The phonetic interpretation of tone in Igbo. In *Proceedings of the IRCS Workshop on Prosody in Natural Speech*. Philadelphia: University of Pennsylvania. 83–92.

Mutaka, Ngessimo (1990). *The lexical tonology of Kinande*. PhD dissertation, University of Southern California.

Pierrehumbert, Janet (1980). *The phonology and phonetics of English intonation*. PhD dissertation, MIT.

Pierrehumbert, Janet & Mary Beckman (1988). *Japanese tone structure*. Cambridge, Mass.: MIT Press.

Poser, William (1984). *The phonetics and phonology of tone and intonation in Japanese*. PhD dissertation, MIT.

Pulleyblank, Douglas (1986). *Tone in Lexical Phonology*. Dordrecht: Reidel.

Russell, Jann M. (1986). *Some tone perturbation rules in Moba*. Ms, Summer Institute of Linguistics, Lomé, Togo.

Schuh, Russell G. (1978). Tone rules. In Victoria A. Fromkin (ed.) *Tone: a linguistic survey*. New York: Academic Press. 221–256.

Snider, Keith L. (1990). Tonal upstep in Krachi: evidence for a register tier. *Lg* **66**. 453–474.

Snider, Keith L. (to appear). *The geometry and features of tone*. Dallas: Summer Institute of Linguistics & University of Texas at Arlington.

Stewart, John M. (1965). The typology of the Twi tone system. Preprint from the *Bulletin of the Institute of African Studies* **1**. 1–27.

Stewart, John M. (1983). Downstep and floating low tones in Adioukrou. *Journal of African Languages and Linguistics* **5**. 57–78.

Yip, Moira (1980). *The tonal phonology of Chinese*. PhD dissertation, MIT.

https://doi.org/10.1017/S0952675798003534 Published online by Cambridge University Press