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*Low vowels and transparency in Kinande vowel harmony**

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This paper addresses theoretical issues confronting cross-height harmony systems through an experimental study of Kinande, a Bantu language of the Democratic Republic of Congo. Using a combination of acoustic analysis and lingual ultrasound imaging, we evaluate previous proposals concerning the phonetic correlates of the harmonic vowel feature and the transparency of low vowels. Results indicate that (i) although a multivalued scalar acoustic feature in F1/F2 space is not adequate to distinguish all vowel categories in Kinande, the cross-height feature does correlate acoustically with F1, (ii) the cross-height feature of Kinande involves systematic tongue-root articulations and (iii) low vowels in Kinande are not neutral to harmony in the way reported in earlier work, but exhibit significant and systematic tongue-root advancement and retraction according to the dictates of harmony.

1 Introduction

While cross-linguistic surveys (e.g. Maddieson 1984) show that the most common vowel systems have a very small number of vowel heights, typically 'high'/'mid'/'low', many languages exhibit vowels with more differentiated heights. When confronted with multiple vowel heights, significant issues arise as to the analysis of such contrasts (see, for example, Clements 1990, 1991). Phonologically, there may be patterns to demonstrate that certain sets of vowels form classes with certain other vowels. Phonetically, issues arise as to the correlates of the features describing such classes, both acoustically/auditorily and articulatorily. Issues also

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arise as to the number of features required, both in the case of specific languages and cross-linguistically.

In this paper, we use acoustic analysis and ultrasound imaging to address several issues concerning the analysis of vowel 'height' in Kinande, a Bantu language of the Democratic Republic of Congo. The case is of interest because it involves a set of intertwined phonetic and phonological questions in a vowel system exemplifying typical cross-height harmony.

Phonologically, the system is fairly well understood (Valinande 1984, Schlindwein 1987, Steriade 1987, Hyman 1989, Clements 1990, 1991, Mutaka 1990, 1995, Archangeli & Pulleyblank 1994, 2002). It is established in such work that Kinande exhibits a cross-height pattern of vowel harmony (in the sense of Stewart 1967, etc.), and there is general agreement that the language exhibits seven vowels underlyingly and at least nine vowels on the surface.

(1) *Kinande vowel system*

underlying

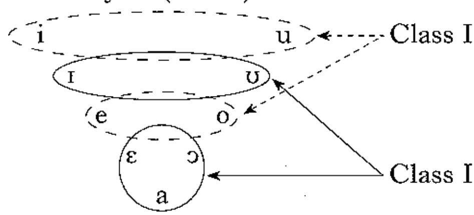
i u

ɪ ʊ

ɛ ɔ

a

surface (*take 1*)



The phonological classification seen in (1) is based on vowel-agreement patterns of a harmonic type, agreement where the harmonic classes include vowels of differing basic heights.

Certain issues regarding the vowel system of Kinande are unresolved, however. A broad question arises as to how to characterise the harmonic feature, the feature distinguishing between Class I and Class II vowels. While some work assumes that the feature is one of tongue-root advancement/retraction (e.g. Schlindwein 1987, Hyman 1989, Mutaka 1990, 1995, Archangeli & Pulleyblank 1994, 2002), Clements (1990, 1991) proposes that the feature distinguishing between classes such as these is a particular instantiation of a hierarchical aperture feature used for all vowel-height distinctions, where the feature [open] distinguishes vowels on the basis of the size of the pharyngeal cavity volume or the width of the tongue constriction. It would also be possible that all distinctions based on vowel height/F1 depend on a single multivalued feature (Ladefoged 1971, Lindau 1978).[1] In assessing the appropriateness of particular approaches to feature definition, it is striking that we are lacking relevant articulatory data on the relevant vowels. While phonological analyses have

[1] Both Ladefoged and Lindau actually assume that a vowel-height scale has maximally four values, and this can be cross-cut by some version of a feature like [ATR].

been proposed for a large number of cross-height systems (e.g. Archangeli & Pulleyblank 1994 and references therein), there exist articulatory studies on only a handful of languages. It is important for the establishment of an adequate feature system, therefore, that additional languages be examined articulatorily to test whether cross-height patterns do indeed involve such articulations. In moving towards a resolution of this issue for Kinande, we also move towards a better understanding of feature definitions in general.

A specific question involves the phonetic realisation of the low vowel /a/ in a Class I context. Work on Kinande is divided (see below) as to whether there is a Class I counterpart to the vowel /a/, primarily because the phonetics of the low vowel in a harmonic context is unclear. If the low vowel has a Class I counterpart then it is a harmonic target; if it does not have a Class I counterpart then it is transparent to the transmission of harmony. This question is essentially a phonetic one, but a phonetic question that has a direct impact on the phonological analysis. It is noteworthy in this regard that many cross-height harmony systems involve non-low vowels only; in such cases, low vowels appear impervious (either transparent or opaque) to cross-height harmony (see, for example, Archangeli & Pulleyblank 1994, Pulleyblank *et al.* 1995). Is this because universally low vowels cannot have an advanced tongue root value (Goad 1993)? Is it the case that low vowels can be phonetically advanced but not phonologically advanced, that advanced 'low' vowels are actually phonologically mid (Kaye *et al.* 1985)? Further questions arise concerning the transparency of vowels that do not exhibit variants for each harmonic class. In particular, do we find systems where a vowel that is incompatible with the harmonic feature acts as transparent to the transmission of that feature through a harmonic domain? While much work has assumed or argued that such transparency is possible (see Archangeli & Pulleyblank 1994 for discussion and references), work such as Gafos (1996) and Ní Chiosáin & Padgett (2001) has argued that all featural spreading must involve strictly string-adjacent sequences – ruling out the possibility of transparency to spreading. Where long-distance agreement is attested, such work must postulate a completely different, non-spreading, mechanism (Rose & Walker 2004).

In this paper, we address these issues confronting cross-height harmony systems through an ultrasound study of Kinande, a Bantu language of the Democratic Republic of Congo. We show that (i) a multivalued scalar acoustic feature in F1/F2 space is not adequate to distinguish vowel categories in Kinande, (ii) the cross-height feature of Kinande does indeed involve systematic tongue-root articulations and (iii) low vowels in Kinande are not neutral to harmony in the way reported in earlier work, but exhibit significant and systematic tongue-root advancement/retraction according to the dictates of harmony.

The paper is organised as follows. As background, in the following section, we sketch the relevant aspects of Kinande phonology, establishing our hypotheses concerning featural representations and the transparency of low vowels. In the subsequent three sections, we present three experiments conducted to test these hypotheses. We conclude by considering the theoretical implications of our study.

2 Kinande vowel harmony

Contrastively, Kinande exhibits the seven vowels exemplified in the root vowels of (2).[2]

(2) [+ATR] *association restricted to high vowels in Kinande*

	root vowel			
a.	[i]	e-rį-lįb-a	[ɛ̀rìlí̋ːbà]	'to cover'
b.	[ɪ]	e-ri-lim-a	[ɛ̀rìlɪ̋ːmà]	'to cultivate'
c.	[ɛ]	e-ri-hek-a	[ɛ̀rìhɛ̋ːkà]	'to carry'
d.	[a]	e-ri-kar-a	[ɛ̀rìká̋ːrà]	'to force'
e.	[ɔ]	e-ri-boh-a	[ɛ̀ríbɔ̋ːhà]	'to tie'
f.	[ʊ]	e-ri-hum-a	[ɛ̀rìhʊ̋ːmà]	'to beat'
g.	[u]	e-rį-hųk-a	[ɛ̀ríhű̋ːkà]	'to cook'

While there is general agreement that Kinande has seven underlying vowels, there is some controversy over the phonological analysis of the height of these vowels. According to a view based on the features [high], [low] and [ATR], there are four underlying high vowels /i ɪ ʊ u/, two underlying mid vowels /ɛ ɔ/ and one underlying low vowel /a/ (Valinande 1984, Schlindwein 1987, Steriade 1987, Hyman 1989, Mutaka 1990, 1995, Archangeli & Pulleyblank 1994, 2002).

In opposition to such approaches where several distinctly defined features contribute to the overall determination of vowel height, Clements (1991) develops a proposal where vowel height is defined by a single recursive feature dividing up an 'abstract phonological "space"'. The core idea is that 'vowel height constitutes a uniform phonetic dimension' (Clements 1991: 39), divided up into subregisters by a hierarchically organised register feature. We expand on Clements' proposal shortly, noting here just that he assumes four heights distinguished underlyingly: height 1 /i u/, height 2 /ɪ ʊ/, height 3 /ɛ ɔ/ and height 4 /a/.

Consider the impact of vowel harmony. When a vowel is to the left of one of the highest vowels /i u/, it exhibits a raised variant. This has already been observed in (2), where the high vowel [ɪ] of the infinitival prefix /rɪ-/ undergoes harmony when it appears to the left of either [i] (2a)

[2] Orthographic representations indicate 'advancement' of vowels by a subscripted cedilla. Only in transcriptions have we included tone: a grave accent indicates low tone; an acute accent indicates high tone; a double acute accent indicates a phrasal high tone, a high that is present only when the word is phrase-final (see Mutaka 1990).

or [u] (2g). More generally, this harmonic raising can be seen in agentive forms where a suffixal /-i/ induces harmony on preceding vowels. The examples in (3) show the same roots seen in (2), with the addition of the agentive suffix:

(3) *High and non-high harmonic targets*

	root vowel	*agentive*		
a.	[i]	o-mų-lįb-į	[ɔ̀mùli̋ːbì]	'coverer'
b.	[ɪ]	o-mų-lįm-į	[ɔ̀mùli̋ːmì]	'farmer, cultivator'
c.	[ɛ]	o-mų-hęk-į	[ɔ̀mùhe̋ːkì]	'porter, carrier'
d.	[a]	o-mų-kar-į	[ɔ̀mùkə̋ːrì]	'forcer'
e.	[ɔ]	o-mų-bǫh-į	[ɔ̀múbőːhì]	'tier'
f.	[ʊ]	o-mų-hųm-į	[ɔ̀mùhűːmì]	'beater'
g.	[u]	o-mų-hųk-į	[ɔ̀múhűːkì]	'cook (N)'

The high, Class I/height 1 vowels /i u/ are unaffected by harmony (3a, g); the high, Class II/height 2 vowels /ɪ ʊ/ neutralise with /i u/ (3b, f). In all other cases, vowel harmony is non-structure-preserving (3c–e). Anticipating the results of § 5, we transcribe the low vowel as distinct when in a harmonic context (3d). Also observable in (3) is the iterative nature of harmony: all eligible vowels to the left of a harmony-inducing vowel exhibit a raised variant. Note, however, that the initial 'augment' vowel only undergoes harmony optionally, not as part of the regular harmonic process (this optional application is not indicated in the transcriptions here).[3]

With this background, we may now examine the main points we treat experimentally. The first issue concerns the nature of the harmonic feature. Consider three hypotheses concerning the nature of the relevant vowel features. Whether viewed as a single, multivalued feature (Ladefoged 1971, Lindau 1978), the interaction of hierarchical aperture features (Clements 1990, 1991) or the interaction of independent height and tongue-root features (Stewart 1967, Lindau 1979, etc.), all approaches predict that vowels will differ according to values of the first formant.

A possible distinction can be made acoustically between an approach based on a single multivalued feature and the approaches based on multiple features (whether multiple versions of [open] or articulatorily distinct features). In his discussion of vowel height, Ladefoged (1975), for example, defines height in terms of the value of the first formant. Consider the 'raising' induced by Class I vowels of Kinande. In a multivalued approach with a single height feature, this could involve a process

[3] Kinande harmony exhibits complex interactions with the morphology that are orthogonal to the concerns of this paper. For recent discussion, see Archangeli & Pulleyblank (2002).

subtracting a value from the relevant vowels.[4] For example, assuming that the four underlying vowel heights of Kinande are as in (4), allowing raising to subtract a value of [1] would produce the vowels in the right-most column; that is, [*n* high] → [*n*–1 high].

(4) *Multivalued features for 'height'*

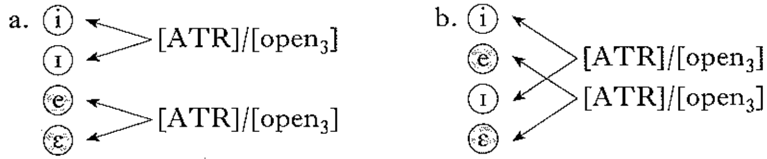
underlying		*surface: harmonically neutral*		*surface: with harmonic 'raising'*	
/i/	[1 high]	[i]	[1 high]	[i]	[1 high]
/ɪ/	[2 high]	[ɪ]	[2 high]	[i]	[1 high]
/ɛ/	[4 high]	[ɛ]	[4 high]	[e]	[3 high]
/a/	[6 high]	[a]	[6 high]	[ə]	[5 high]

Two points bear noting. First, the input values must be set up in such a way as to guarantee the correct number of surface distinctions; while [2 high] neutralises with [1 high], neutralisation does not take place with the two other starting heights. That is, we could not assume underlying forms of [1 high], [2 high], [3 high] and [4 high] and obtain the desired surface distinctions. Second, the raised version of /ɛ/ (i.e. [e]) must be lower than unraised /ɪ/ (i.e. [ɪ]). The logic is as follows: [i] and [ɪ] neutralise under raising. This means that the unit by which the [high] feature decreases is the value for [high] for [ɪ] minus the value for [high] for [i]; let us refer to this value as [p high]. Let the value for /ɪ/ underlyingly be [q high] and the value for /ɛ/ underlyingly be [r high]. We know that $q < r$. Hence when raising takes place, it follows that $q - p < r - p$.

The acoustic predictions are different for the three approaches being considered (single multivalued feature; hierarchically organised [open] features; height and tongue-root features). For the two theories involving multiple features (multiple [open] features or height and tongue-root features), it is possible to have interleaved vowels as a result of raising. That is, if the acoustic effect of raising happens to be relatively large in a given language, then a raised 'mid' vowel could be 'higher' than a neutral 'high' vowel.

[4] This analysis would be required in a radical multivalued theory that did not postulate a tongue-root feature. In the actual proposals for a multivalued height feature, Ladefoged (1968, 1975) and Lindau (1978, 1979) combine a multivalued height feature with an independent feature corresponding to tenseness/laxness or pharyngeal volume. Since our focus here is on the necessity/lack of necessity for such a tongue-root feature, such a hybrid analysis would be comparable to the multi-feature account including [ATR]. The Kinande-type pattern is not discussed in Ladefoged or Lindau's work and it should be stressed that the need for underlyingly gapped height features ([1/2/4/6 high]) would only be necessary if a feature like [ATR] is not posited.

(5) *Schematics of the interaction between two 'height' features*



'high' (*clear*) vs. *'mid'* (*shaded*) *distinction dominates* [ATR]/[open$_3$] *distinction*

[ATR]/[open$_3$] *distinction blurs boundary between 'high'* (*clear*) *and 'mid'* (*shaded*)

Patterns such as (5b) are not surprising in systems involving a 'tongue-root' feature. Lindau (1979), for example, shows that such a pattern holds of Akan. If found in Kinande, a pattern like (5b) would demonstrate the insufficiency of a single, multivalued feature along the F1 dimension.

To summarise, we predict that acoustic interleaving may occur only if multiple features are involved. If there is a single, multivalued scale, then the acoustics of the vowel scale would have to be of the type in (5a).

A second issue surrounds the articulatory properties of the Class I/Class II distinction. In a theory with a multivalued height feature, there is no expectation that particular sets of heights be realised by any particular articulator. Any means of changing F1 can in principle be employed for any height values. In a theory with a hierarchically organised set of [open] features, the same is true; while there *could* be a particular articulator associated with a particular [open] feature ([open$_1$], [open$_2$], [open$_3$], etc.), there need not be any unique assignment of articulators to a particular [open] value. See Clements (1991) for discussion.

(6) *Harmonic vowels: the scalar height hypothesis*

underlying				*harmonised*	
[open$_1$]	[open$_2$]	[open$_3$]		[open$_3$]	
–	–	–	/i u/	–	[i u]
–	–	+	/ɪ ʊ/	–	[i u]
–	+	+	/ɛ ɔ/	–	[e o]
+	+	+	/a/	–	[ə]

In contrast, if a tongue-root feature is invoked, then the theory makes testable predictions about the vowel distinctions based on the postulated feature.[5]

[5] It should be kept in mind that Clements' (1990, 1991) proposal for vowel height is compatible with the postulation of a tongue-root feature that is independent of height. That is, although Clements' analysis of Kinande is formulated in terms of a hierarchical [open] feature, it would be possible to analyse Kinande differently, as having high/mid/low vowels determined by [open] with a cross-cutting tongue root feature. The crucial distinction between (6) and (7) is whether the harmonic feature

(7) *Harmonic vowels: the* [ATR] *hypothesis*

underlying		*harmonised*	
high advanced: [+high, −low, +ATR]	/i u/	[+ATR]	[i u]
high retracted: [+high, −low, −ATR]	/ɪ ʊ/	[+ATR]	[i u]
mid retracted: [−high, −low, −ATR]	/ɛ ɔ/	[+ATR]	[e o]
low retracted: [−high, +low, −ATR	/a/	[+ATR]	[ə]

To be specific, based on cineradiographic data, Painter (1973), Lindau (1979), Hall & Hall (1980), etc. suggest that there is an articulatory variable involved for some languages, namely the retraction/advancement of the tongue root or the overall constriction/expansion of the pharyngeal cavity. In a language like Akan, for example, one harmonic class of vowels exhibits tongue-root advancement as part of a generally expanded pharynx, while a second harmonic class of vowels exhibits tongue-root retraction as part of a generally constricted pharynx (Tiede 1996).

In addition to general questions concerning the acoustic and articulatory properties of the Kinande Class I *vs.* Class II distinction, specific questions arise about the analysis of low vowels. Schlindwein (1987) describes Kinande as having nine surface vowels, the seven underlying vowels described above plus the two advanced mid vowels seen in (3c, e). She does not consider there to be an advanced counterpart of the low vowel. Hyman (1989) raises doubts about this description. Though he initially postulates exactly the same set of surface vowels as proposed by Schlindwein, he ultimately suggests for theoretical reasons that [a] should be analysed as undergoing ATR harmony, but that 'in most circumstances a [+ATR] vowel /a/ is non-distinct, phonetically, from an /a/ lacking the ATR specification'. He notes that the advanced character of an /a/ in a harmonic context is observed when the advanced low vowel is lengthened; he cites the example /o-mʊ̨́-kal-i̧/ [ɔ̀múkə̀ːlì] 'woman'. Mutaka (1995) concurs with Hyman's description, adding that for advancement to be perceived in a low vowel the low vowel must be both long and low-toned. Interestingly, even though Hyman and Mutaka agree that there may be some phonetic advancement on low vowels, they differ in their phonological conclusions: Hyman treats low vowels as undergoers; Mutaka treats low vowels as transparent. Archangeli & Pulleyblank (1994) note the need for instrumental investigation of this question, tentatively treating low vowels as undergoers, with any potential masking of the phonological advanced–retracted distinction due to phonetic factors. In summary, depending on the description, low vowels have been considered to be phonetically unaffected by harmony (Schlindwein 1987) or phonetically affected in only a small, narrowly defined set of contexts (Hyman 1989, Mutaka 1995). At a phonological level, depending on the

is determined by a hierarchical [open_3] feature or by an independent tongue-root feature.

analysis, low vowels have been considered to be transparent (Schlindwein 1987, Steriade 1987, Mutaka 1995) or undergoers (Hyman 1989, Clements 1990, 1991, Archangeli & Pulleyblank 1994, 2002).

The resolution of these issues concerning the low vowel in Kinande bears on general issues. First, based on cross-linguistic patterns, it would not be surprising if low vowels in certain languages were unable to phonologically bear the value [+ATR] (see, for example, Archangeli & Pulleyblank 1994, Pulleyblank *et al.* 1995). This argument has specifically been made for Kinande in work such as Schlindwein (1987) and Steriade (1987). It is clear, however, that low vowels do not block the transmission of harmony in Kinande. In (3d), for example, the high vowel in the prefix is advanced as a result of harmony initiated by the high vowel in the suffix, despite the presence of a low vowel intervening between the two. Is it the case, therefore, that low vowels in Kinande undergo harmony and become advanced? Or is it the case that they remain retracted and act as transparent to the spread of [+ATR]? Work on harmonic systems such as Gafos (1996) and Rose & Walker (2004) would lead us to expect the former. Gafos argues that all harmonic spreading is local in the sense that no phonological elements are skipped during the transmission of harmony. While long-distance effects are possible, such work suggests that such cases are qualitatively different. For Kinande, since all non-low vowels are consistent with a harmony-as-spreading analysis, we would expect *all* harmony to be local and therefore that low vowels be targets, not transparent.

We present three experiments designed to test questions arising from these patterns. The first two experiments concern the nature of the harmonic feature in Kinande, and the third concerns the analysis of the low vowel, which has been variably analysed as undergoing harmony or being neutral to harmony in Kinande. Experiments are as follows.

Experiment 1 tests the hypothesis that the height features for a harmonic system such as Kinande can be based on a unidimensional acoustic scale, along the lines of a single multivalued feature for vowel height. If a unidimensional scale is possible, the vowels of Kinande should be along the lines of (5a), not, for example, along the lines of (5b). To test the plausibility of such a unidimensional analysis, we measured F1 and F2 for all vowels of Kinande, including low vowels in both Class I and Class II contexts. In addition to testing whether simple acoustic height (F1) is sufficient to characterise vowel height in Kinande, the acoustic investigation in Experiment 1 also tests whether there is a significant acoustic difference between low vowels in Class I *vs.* Class II contexts.

In Experiment 2, we test for an articulatory correlate for the vowel distinctions observed, specifically looking for whether the two harmonic classes can be categorised according to tongue-root articulation. Using ultrasound imaging, we measured tongue-root positions for all vowels (including low vowels), comparing tongue-root retraction in harmonically paired sets of vowels.

Finally, Experiment 3 examines specific questions raised by the behaviour of low vowels from Experiments 1 and 2, testing whether differences between Class I and Class II low vowels may be attributed to local phonetic interpolation or to phonological differences in feature value.

3 Experiment 1: testing for a scalar acoustic F1 feature for Kinande vowels

As discussed in §2, analyses of vowel height differ as to whether height can be accounted for by a single height feature based on F1 or whether multiple features are required, whether via [advanced tongue root] or a set of hierarchical aperture features. Under the assumption that relative height involves gradual scalar changes in the vowel space along a unidimensional scale, the theory predicts that [i u] will have the lowest F1, [ɪ ʊ] the next lowest, [ɛ ɔ] the next lowest, and so on. An experiment was designed to test the feasibility of such a scalar height feature in acoustic F1 space. If the scalar hypothesis is right, we expect to see discrete categories of vowels with F1 descending in the following order (unrounded vowels only): [a] (Class II), [ə] (Class I), [ɛ] (Class II), [e] (Class I), [ɪ] (Class II), [i] (Class I). Further, if the low vowel is both phonetically and phonologically transparent (see above) we should not expect /a/ to differ acoustically between Class I and Class II contexts.

3.1 Methods

3.1.1 *Subject.* A single adult male native speaker of Kinande (also an author of this paper) participated in this experiment. Clearly, our data would be more indicative of the larger Kinande-speaking population were we to have tested more, and more naive, subjects. However, given the small number of Kinande speakers in North America and the relatively new technology being employed, we were unable to test a larger number of subjects for the present study.

3.1.2 *Procedures.* All data were collected in a private home. The subject was seated on a solid chair without head stabilisation, and was asked to read words aloud from a typed list. Stimuli were designed to elicit the full vowel inventory of Kinande in both Class I and Class II contexts, and in consonantal contexts that would not impede or affect their production (i.e. surrounded where possible by labial and/or coronal obstruents). Additional stimuli were interspersed with these to address a variety of unrelated questions, and these sets served as distractors for each other. Each stimulus item was read aloud by the subject a total of nine times throughout the course of the experiment: three times each across three separate blocks. After removing errorful and/or unanalysable tokens (e.g. the third block was omitted from analysis for reasons concerning the ultrasound analysis described in detail below in Experiment 2), a total of 243 tokens were analysed: [i] 24 tokens; [ɪ] 24 tokens; [u] 21 tokens; [ʊ] 21 tokens; [e] 27 tokens; [ɛ] 24 tokens; [o] 27 tokens; [ɔ] 30 tokens; [ə] 24 tokens; [a] 21 tokens. Sample stimuli are given in (8); the spans including targets and triggers under consideration are enclosed in square brackets.

(8) *Sample stimuli*

infinitive	*applicative recent past*	
ɛ̀r[ísíː]gà	m[ótwàsígíː]rà	'leave'
ɛ̀r[ísɪ́ː]gà	m[ɔ́twàsígɪ́ː]rà	'sow'
ɛ̀r[ìsɛ́ː]gà	m[ɔ́twásɛ́gɛ̀ː]rà	'incise'
ɛ̀r[ísùː]bjâ	m[ótwàsùbíː]rjâ	'make revive'
ɛ̀r[ísʊ́ː]bà	m[ɔ́twàsʊ́bɪ́ː]rà	'revive'
ɛ̀r[ísɔ́ː]kà	m[ɔ́twàsɔ́kɛ́ː]rà	'cross'
ɛ̀r[ísáː]kà	m[ɔ́twàsákɪ́ː]rà	'remain'

Acoustic speech data were recorded digitally at 44 kHz, using a Sony Handycam Vision DCR-TRV900 (NTSC) digital video camera via a Shure SM58 microphone attached to a desktop stand resting on a table in front of the subject. The resulting audio signal was transferred to a Mac G3 computer and extracted using Adobe Premiere 5.0, and measurements were made using Praat 4.1 analysis software (www.praat.org). F1 and F2 were measured at vowel midpoints and recorded to a text file. These values were plotted and analysed using JMP IN 5.1 statistics software.

3.2 Results

Results are presented first in Fig. 1 as a bivariate scatterplot, with F2 (right to left) on the x axis and F1 (top to bottom) on the y axis, and with 95% confidence ellipses surrounding each vowel cluster. These results show Kinande vowels overlapping in F1, in the following order (in increasing order of F1): i (Class I), e (Class I), ɪ (class II), ɛ (class II)/ə (class I), a (class II).

ANOVA results indicate significant interactions among vowels along the F1 dimension [$F(9,235) = 139{\cdot}9158$; $p < 0{\cdot}0001$]. Table I shows post hoc interactions between specific vowel pairs for F1 (Student's t-test; $p < 0{\cdot}05$).

3.3 Discussion

The above results indicate that, although F1 is able to distinguish harmonic classes (white cells in Table I), vowel 'height' in Kinande cannot correspond to a unidimensional F1 scale. If the vowels of Kinande are analysed as belonging to three heights (high/mid/low), cross-cut by a tongue-root distinction, then it is not the case that 'high' vowels are

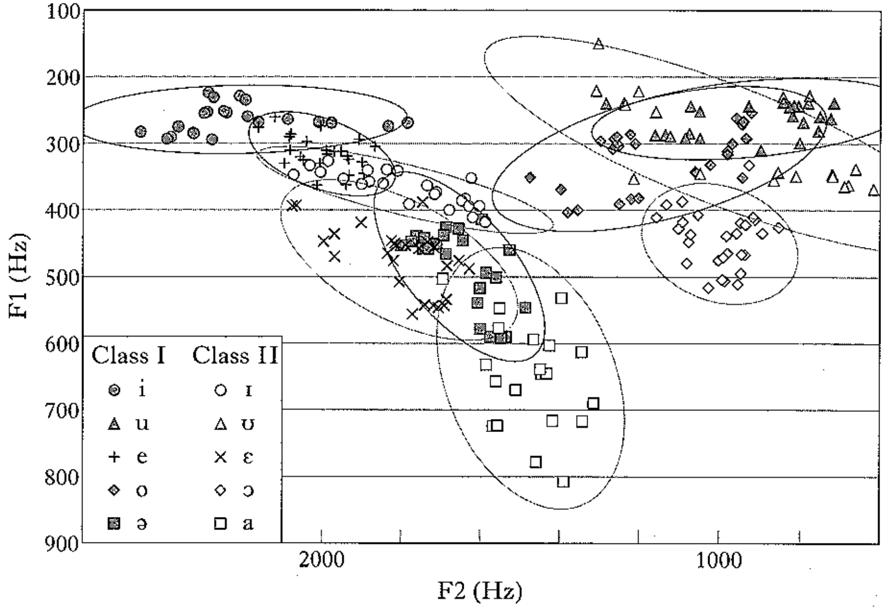


Figure 1
F1 × F2 scatterplot of all Kinande vowels, with 95% confidence ellipses.

	ɪ	ʊ	e	o	ɛ	ɔ	ə	a
i	S		S					
u		S		S				
ɪ			S*		S			
ʊ				NS		S		
e					S		S	
o						S	S	S
ɛ							S	NS
ɔ							S	S
ə								S

(white) comparisons concerning basic Class I/Class II distinctions
(light grey) comparisons concerning crossover across vowel heights
(dark grey) either not possible or not relevant
S significantly different (Student's t-test; $p < 0{\cdot}05$)
S* significantly different in a direction showing height crossover
NS not significantly different (Student's t-test; $p > 0{\cdot}05$)

Table I
Significance table for F1.

systematically distinguished from 'mid' vowels in terms of F1, nor is it the case that 'mid' vowels are systematically distinguished from 'low' vowels in terms of F1 (grey cells in Table I). Note in particular that the Class II 'high' vowel [ɪ] is significantly lower than the Class I 'mid' vowel [e] (cell marked S* in Table I). For the same reasons, it is not possible to distinguish the vowels of Kinande in terms of a single, scalar F1 feature; that is, there are not significant F1 distinctions between all members of a scale like /i ɪ e ɛ ə a/. Some dimension other than simple F1 must be invoked to account for the behaviour of Kinande vowels.

As a second point, we note that two low vowels are distinguished in Kinande: we see a significant difference in F1 values between the Class I and Class II low vowels. The articulatory correlates of the acoustic differences observed in this experiment will be examined in the next section.

4 Experiment 2: testing the [ATR] hypothesis

The previous experiment ruled out the possibility of a simple unidimensional acoustic feature for Kinande vowels. According to a theory where multiple distinctive features define vowel 'height', we discussed two hypotheses: the hierarchical [open] hypothesis and the [advanced tongue root] hypothesis. The [ATR] hypothesis makes the specific prediction that the Class I vowels of Kinande will have relatively advanced physical tongue-root positions compared to the corresponding Class II vowels. Further, based on their relatively discrete distribution in acoustic quality, we expect the low vowels to follow the rest of the vowels in reflecting this [ATR] distinction. The [open] hypothesis would be consistent with finding such tongue-root involvement but does not require it.

An ultrasound imaging study was conducted to test these predictions by measuring the relative positions of the tongue root across Kinande vowels.

4.1 Methods

The methods used in this experiment were identical to those of the previous experiment, except as follows.

4.1.1 *Procedures.* Lingual movements were imaged using an Aloka SSD-900 portable ultrasound with a UST-9102 probe fixed to a microphone stand and recorded simultaneously with the acoustic signal to the same camera described above at a standard video rate of 29·97 frames per second (about 33 Hz). Rather than constrain or track head movement, which was considered inappropriate for this field situation, three precautions were taken to ensure reasonable reliability of position data: (i) the subject was seated about 1 metre in front of typed stimuli, providing a visual focal point, contributing to head stabilisation (Stone 2005); (ii) a laser pointer projecting a crosshairs pattern was attached to a headpiece worn on the subject's head and aimed at a defined area on a nearby surface. The resulting signal was monitored visually throughout the experiment, giving experimenters a relatively accurate indication of shifts in head position (see Gick 2002); (iii) stimuli were randomised within three separate identical blocks, so that shifts in position across blocks could be measured, and affected data omitted (results indicated systematic differences in the third data block, presumably due to a shift in head position, and this entire block was omitted). In addition, all tokens in which the tongue root was not clearly visible were omitted. The resulting video ultrasound data were transferred to a Mac G3 using Adobe Premiere 5.0, and individual frames were extracted at the extrema of the tongue positions for all ten vowels; a total of 228 vowels were measured. Distances were measured from the ultrasound probe to the tongue root along a fixed angle (45 degrees) using the angle tool in NIH Image (version 1.60; http://rsb.info.nih.gov/nih-image/). This is illustrated in Fig. 2a with an example where the tongue root is advanced ([o]) and in Fig. 2b with an example where the tongue root is retracted ([ɔ]). The longer measurement line in Fig. 2b indicates a greater degree of tongue-root retraction.

4.2 Results

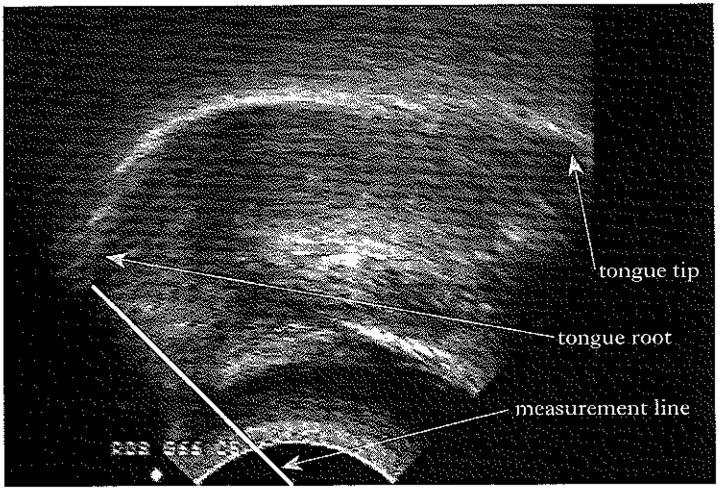
The results of this experiment indicate that the tongue-root position does vary systematically across Kinande vowels, with each Class I ([+ATR]) vowel exhibiting a significantly more anterior tongue-root position than its Class II ([−ATR]) counterpart, as shown in Fig. 3 (one-way ANOVA [$F(9,218)=88{\cdot}547$; $p<0{\cdot}0001$]; post hoc tests [Fischer's PLSD] indicate that all comparisons shown are significantly different within [±ATR] pairs [$p<0{\cdot}0001$]).

4.3 Discussion

The results of Experiment 2 are consistent with an analysis of Kinande in terms of the feature [ATR], showing that all vowels – including the low vowel – are indeed distinct in Class I *vs.* Class II contexts in terms of tongue-root position. Hence the results are consistent with an analysis of Kinande vowels as involving three basic heights, high/mid/low, cross-cut by a tongue-root feature. They would also be consistent with an analysis in terms of three [open] features; while it is possible that [$open_3$] involves the tongue-root movement specifically (see Clements 1991), such articulatory specificity is not required by such a feature.

An additional observation apparent in Fig. 3 is that high vowels are categorically distinct (showing no overlap between advanced and retracted sets), while non-high vowels exhibit considerable overlap between the

(a)



(b)

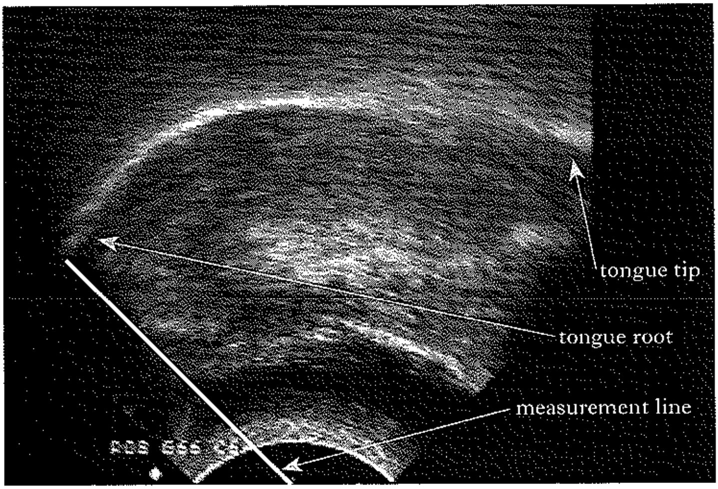


Figure 2

Diagrams of (a) an advanced back mid vowel [o] and (b) a retracted back mid vowel [ɔ], illustrating location and angle of measurement line superimposed on a typical ultrasound tongue-image frame. The irregular white arc dominating the image represents the upper surface of the tongue. The 45-degree line measures from the centre point of the transducer (bottom centre of frame) to the tongue-root surface.

advanced and retracted sets. This is interesting, since only high vowels employ this distinction contrastively in the Kinande lexicon. The implications of this observation are potentially far-reaching, but will not be explored further in this paper. However, this further supports the notion

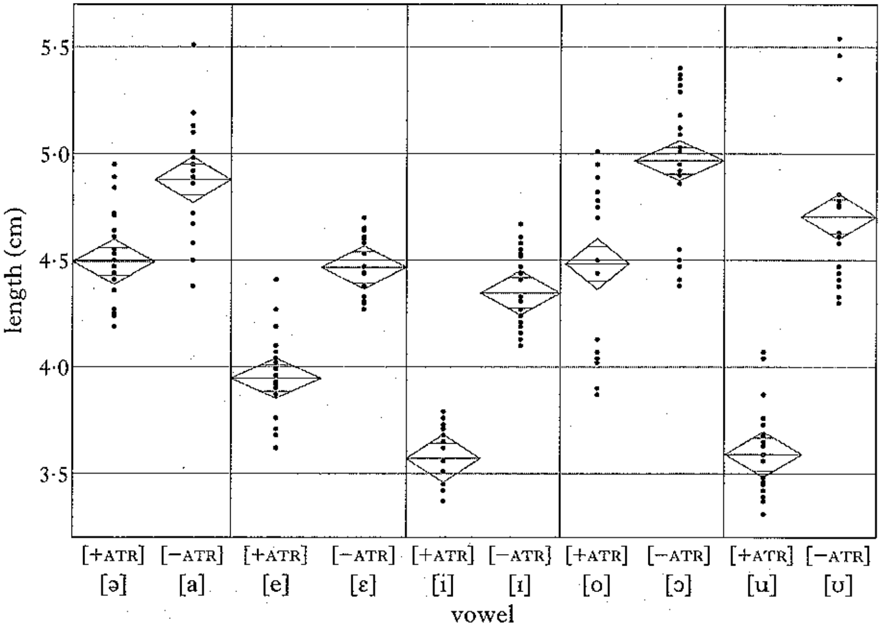


Figure 3
Univariate scatterplot of tongue-root distance from transducer for all Kinande vowels (higher values indicate a greater degree of retraction). Diamonds indicate 95% confidence intervals; diamond horizontal midlines indicate mean values for each vowel.

that low vowels in Kinande pattern like mid vowels both phonetically and phonologically. The phonological status of the [ATR] feature on low vowels is tested more directly in the following section.

5 Experiment 3: the articulation of low vowels in [ATR] contexts

Although low vowels in the previous experiment exhibit a relatively advanced tongue root when preceding an advanced vowel, it is possible that such advancement is the result of phonetic interpolation (Pierrehumbert & Beckman 1988, Cohn 1990, etc.) rather than the phonological assignment of a [+ATR] value. Indeed, feature theories such as Goad (1993) and Kaye *et al.* (1985) prohibit the assignment of [+ATR] to a low vowel absolutely: any 'low' vowel exhibiting a phonological property of advancement must, in their theory, be phonologically non-low.

We conducted two subtests aimed at determining whether low vowels are phonologically targeted by advancement harmony. First, we tested whether the effect of an advanced vowel is maintained throughout a sequence of low vowels or whether a diminishing effect of advancement is exhibited as distance from the triggering vowel increases. Second, an additional test was conducted to control for the possibility that low vowels are being affected incidentally by intervening between a trigger to their right and an undergoing vowel to their left. That is, while the first subtest considers low vowels in the (schematic) context /i … a* … i/ (where an effect could be incidental), the second considers the context /a* … i …/, where any effect must be because low vowels are targeted. Thus this second test asks whether low vowels are themselves targeted by advancement harmony or whether they transmit the harmonic value without themselves being specifically targets.

5.1 Methods

The methods used in this experiment were identical to those of the previous experiment, except as follows.

5.1.1 *Procedures.* Stimuli for the first part of Experiment 3 consisted of words containing sequences of two adjacent low-vowel syllables preceding harmony triggers (12 token words, i.e. 24 token vowels), e.g. Class I: /mótwa̲sá̲kị́:re/ ‘we remained’ (Class I initial suffix /-irɛ/). We refer to the underlined vowel that is closer to the trigger vowel (i.e. the one on the right) as ‘a1’, and the adjacent vowel that is one syllable further from the trigger as ‘a2’. The second part of Experiment 3 considered the first two vowels in the word /ká̲ga̲sụ/ (a proper name) (22 token words, i.e. 44 token vowels).

5.2 Results

The results of the first part of this experiment (the /mótwa̲sá̲kị́:re/ type) show that there is no significant effect of distance from the trigger vowel, i.e. no significant difference between low vowels (‘a1’ and ‘a2’), as shown in Fig. 4 (Student’s t-test; $p > 0{\cdot}10$).

The second part of this experiment (the /ká̲ga̲sụ/ type) found the same effect (Student’s t-test; $p > 0{\cdot}10$) even when the leftmost vowel in the word was a low vowel.

5.3 Discussion

The results of Experiment 3 support the view that low vowels in Kinande bear the same phonological feature as distinguishes harmonic classes in the non-low vowels (either [ATR] or [$open_3$]). The effect appears to be categorical, not gradient. If the difference in tongue-root position between Class I and Class II low vowels (seen in Experiment 2 above) were the result of local, gradient phonetic interpolation, we would expect to see this effect diminish over time. However, as seen in the first part of

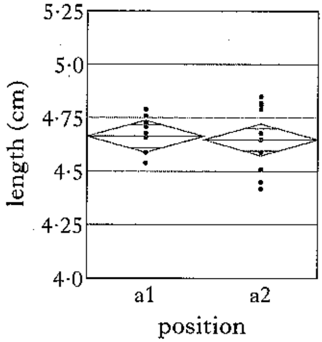


Figure 4
Univariate scatterplot of tongue-root distance from transducer for Kinande low vowels (higher values indicate a greater degree of retraction). 'a1' designates vowels closer to the [±ATR] trigger; 'a2' designates vowels adjacent to 'a1' vowels, but one syllable further from the trigger. Diamonds indicate 95% confidence intervals; diamond horizontal midlines indicate mean values for each vowel.

Experiment 3, this is not the case. If the difference were the result of phonetic carry-over linking one non-low vowel to another across intervening low vowels (i.e. transparency), we would expect the effect not to hold when there is no non-low vowel to the left of the low vowel sequence. The second part of Experiment 3 showed that this is not the case. Thus, it appears that both the low and mid vowels in Kinande bear a categorical feature, a feature that is phonologically assigned.

6 Conclusion

The experimental work reported on here served to test specific questions about a specific language. We saw that the cross-height harmony feature of Kinande acoustically manifests itself through F1, that the feature articulatorily involves relatively advanced and retracted tongue-root positions, and that low vowels are categorically affected by this feature.

The issues that these results bear on, however, are broader than this. Firstly, as the only imaging study of Kinande vowels, and one of only a tiny handful of such studies of languages purported to use distinctive tongue-root advancement and/or retraction, the present study adds to the collective knowledge of how such systems operate. The present results substantiate the notion that the [ATR] feature is a viable one, and they add to the large and growing body of evidence that phonological features are defined by combinations of phonetic correlates (see, for example, Halle 1983). Secondly, by using instrumental analysis to controvert a case of putative phonological and phonetic transparency in a long-distance harmony system, the present study suggests that a class of apparent cases of transparency may be found in this and other languages to emerge more straightforwardly from local assimilatory processes than has been previously thought. It is not being claimed that there exist no cases of phonological transparency; numerous examples exist in the phonological literature where it would be surprising to discover that transparency is an illusion; see Hansson (2001) and Rose & Walker (2004) for some recent discussion of a possible distinction between local and non-local patterns. However, further substantiation of even these cases using quantitative methods such as those employed in the present study will be essential in establishing a more accurate characterisation of these processes.

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