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Neutral Vowels in Lokaa Harmony[*]
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0.   Key Significance

This paper discusses the neutral vowels in Lokaa [lokəə] harmony, [i, u, ə, a]. By neutral I mean a segment which has no harmonic counterpart. Such segments are either transparent or opaque. Lokaa harmony is important in three crucial respects. First, while it is rare to find a language which has both transparent and opaque vowels in its harmony, Lokaa does.[1] The high vowels [i, u] are transparent to harmony; the low vowel [a] is opaque, and the status of the mid vowel [ə] is indeterminate. Secondly, though Lokaa has an eight-vowel inventory the vowels [a] and [ə] have not "re-paired" (Bakovic 2000, 2003). They do not alternate, as we find for example in the neighboring language Igede (Bergman 1971, Armstrong 1983), or in Wolof (Ka 1994) which has an identical vowel system. Thirdly, the historic ATR contrast found in Benue-Congo high vowels (Stewart 1971, Williamson 1973) shows up when high vowel stems take mid-vowel prefixes, though the high vowels can only be [+ATR] on the surface. That is, the ATR merger of high vowels in Lokaa is not complete.

As van der Hulst and Smith (1986) note, languages which have ATR-harmony do not always have two fully symmetrical sets of vowels. However, the behavior of the so-called neutral vowels varies from one language to another. Furthermore the number of vowels in an inventory is not a true predictor of the number of neutral vowels that a language has. In Yoruba, a seven-vowel system, the neutral vowels include both high vowels [i, u] and the low vowel [a] (Archangeli and Pulleyblank 1989, Pulleyblank 2002, and others). All three vowels are opaque. Wolof (Ka 1994) on the other hand has an eight-vowel inventory, which is identical to that of Lokaa. However it has two high vowels [i, u] which are neutral and transparent.

This paper begins with a basic illustration of Lokaa harmony in section 1, using only nonhigh vowels. In section 2, I discuss the domain of harmony, and the status of compounds. In section 3 I turn to the high vowels. Section 4 discusses transparency, and section 5 discusses opacity. The analytic framework is Optimality Theory (Prince and Smolensky 2004). Within this framework, I will employ McCarthy's (2004) headed span theory, as extended to transparency by O'Keefe (to appear). Both of these are introduced in section 1.1.

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[*] Lokaa [lokəə] is an upper-cross language (of the Benue-Congo family) of Southeastern Nigeria. Some of its immediate neighbors are Legbo, Kohumono, Agoi and Mbembe. Lokaa is spelt as Lokạạ in the orthography. Earlier descriptions of the vowel harmony can be found in Iwara (1982, 1994, 1995), and in Akinlabi and Iwara (2004). Some of the facts discussed here are also in the latter paper. However the analysis proposed here differs from the proposals in that paper. I am grateful to members of my assimilation seminar of Fall 2005, especially Michael O'Keefe and Daniel Altshuler, for comments and discussions.

[1] Steinberger and Vago (1987) report that Bari, an Eastern Nilotic language with a ten-vowel system, has both opaque and transparent vowels in its ATR harmony. Because of the idiosyncratic properties of the "transparent" vowel, van der Hulst and Smith (1986) refer to the vowel as "pseudo-neutral".

1. Vocalic Structure and Basic Harmony

Lokaa is an eight-vowel language with [i, u, e, o, ɛ, ɔ, ə and a]. The vowels appear to split into two harmonic ATR sets, as in (1).

(1) Lokəə Harmonic sets.

[+ATR]			[-ATR]	
i	u			
e	ə	o	ɛ	ɔ
		a		

Assuming the classic definition of neutral vowels as stated above, there are four neutral vowels in (1), since there are four vowels that have no harmonic counterparts. The vowels [i, u, ə] have no [-ATR] counterparts, and the vowel [a] has no [+ATR] counterpart.

However, the harmonic sets can be illustrated with non-central mid vowels, which have harmonic counterparts in each set. For reasons of clarity, we will focus on non-high vowels in this section, abstracting away from high vowels, because they involve additional complications. High vowels are discussed in section 3. In the Lokạạ nouns in (2), noun stems with [-ATR] vowels take only [-ATR] noun class prefixes, and noun stems with [+ATR] vowels take [+ATR] prefixes.[2]

(2) Stems and Noun class prefixes

[+ATR] roots			[-ATR] roots		
lè-kó	L-H	'war'	lɛ̀-dɛ́	L-L	'greeting'
lò-tè	L-L	'song'	lɔ̀- tɛ́	L-H	'giant ant'
é- kòò	H-LL	'friendship'	ɛ́-kɔ̀	H-L	'cloth'
ò-də́m	L-H	'a man'			
			ɔ̀-dáŋ	L-H	'fufu'

In these examples, the nouns in each row belong to the same noun class, and the vowel quality difference in the class prefix is completely a function of the ATR specification of the stem vowel. These data are straightforward, and they can be easily accounted for by assuming constraints enforcing agreement of ATR features within a particular domain, including the prefix-stem domain seen here. I turn to McCarthy's (2004) Headed Span theory to explain these and other facts of the harmony.

1.1 Headed Span Theory Analysis

McCarthy's (2004) Headed Span theory is a theory of both local and non-local feature assimilation. In this theory, McCarthy proposes that the segments of a word are exhaustively parsed into spans for each distinctive feature.[3] Each span of the feature [F] has a head segment, and it is the head segment's value for [F] that

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[2] Throughout this paper we will adopt the following methods of transcription: a long vowel is transcribed as a sequence of identical vowels, tones are indicated with both diacritics and letters or with diacritics alone.

[3] Some features of McCarthy's (2004) Headed Span theory are also shared by Cole and Kisseberth's (1995) Optimal Domains theory. I will not go into a comparison of the theories here.

determines the pronunciation of the other segments in the span. A featural *span* is defined as a constituent whose terminal nodes are segments in a contiguous string.

McCarthy posits four constraint-types:

(i)   A markedness constraint that is violated by adjacent [F]-spans. This constraint replaces the ALIGN or AGREE constraints of other theories of spreading.

(ii) Faithfulness constraints requiring input [αF] segments to head [αF] spans in the output. They are Span Theory's alternative to IDENT.

(iii) Markedness constraints requiring certain segment types to head spans with a particular [F]-value. These constraints are essentially feature cooccurrence restrictions.

(iv) Markedness constraints requiring the head segment to lie at a particular edge of a span. These constraints produce directionality effects similar to ALIGN.

Three of the above types of constraints are stated in (3) below, with an informal explanation of the role of each of them after the constraint. The fourth type (iv) will not be utilized in the discussion of Lokaa harmony presented here.

(3) Harmony Constraints (McCarthy 2004):

   a.   *A-SPAN(F)
        Assign one violation mark for every pair of adjacent spans of the feature [F].
        (Explanation: *Prefers having just one F-span per domain. Forces harmony.*)

   b.   FAITHHEADSPAN(αF)
        If an input segment x_I is [αF] and it has an output correspondent x_O, x_O will head a [αF] span.[4]
        (Explanation: *Equivalent of IDENT.*)

   c.   HEAD([βG, γH, …], [αF])
        Every [βG, γH, …] heads a [αF] span.
        (Explanation: *All (classes of) segments are capable of heading some F-assimilation span.*)

O'Keefe (to appear) provides the following ATR specific formulations of the constraints in (3).

(4) ATR specific headed span constraints:

   a.   *A-SPAN(ATR):   No adjacent ATR spans.

   b.   FAITHHEADSPAN(+ATR):   If an input segment x_I is [+ATR] and it has an output correspondent x_O, x_O will head a [+ATR] span.

   c.   FAITHHEADSPAN(-ATR):   If an input segment x_I is [-ATR] and it has an output correspondent x_O, x_O will head a [-ATR] span.

   d.   HEAD([-high], [+ATR]): Nonhigh vowels head [+ATR] spans.

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[4] O'Keefe (to appear) notes that FAITHHEADSPAN(αF) is a conjunction of markedness (*head a span of value αF*) and faithfulness (*preserve values of αF*). Therefore, in this paper a violation mark will be assigned only if both parts are violated.

    e.   HEAD([-high], [-ATR]):   Nonhigh vowels head [-ATR] spans.

In addition, O'Keefe (to appear) argues that it is necessary to adapt the idea of "stem control" (van der Hulst and van de Weijer 1995, McCarthy and Prince 1995, Bakovic 2000) to headed span theory, to account for the fact that affixes harmonize with stems. This achieves the directionality effect in stem-controlled harmonies. The stem control faithfulness constraint is stated in (5).

(5) FAITHSTEM(ATR)

If an input segment x_I is in the stem, has value [αATR] and it has an output correspondent x_O, x_O will have value [αATR].[5]

The forms in (2), with nonhigh vowels, can be derived as follows. The harmonic spans are enclosed in parentheses, and the head of a span is underlined. I indicate the stems in bold. In these tableaux, I demonstrate that the assumed underlying ATR specification of the affix is irrelevant by assuming an input form opposite that of the stem.

(6)

    a.   Deriving a form with [-ATR] mid stem vowel: ɛ́ - kɔ̀ H-L 'cloth'

          /e - **kɔ**/ →   [ɛ́kɔ̀]H-L   'cloth' (assuming prefix is [+ATR])

e - **kɔ**	*A-SPAN	FAITHSTEM (ATR)	FAITHHEAD (+ATR)	HEAD([-high], [±ATR])[6]
(e̱)(kɔ̱)	*!			**
(e̱)(ko̱)	*!	*		**
(e̱ko)		*!		***
☞ (ɛko̱)			*	***

    b.   Deriving a form with [+ATR] mid stem vowel: é- kòò H-L 'friendship'

        / ɛ́ - **kòː**/ → [ékòː] H-L   'friendship' (assuming prefix is [-ATR])

ɛ́- **kòː**	*A-SPAN	FAITHSTEM (ATR)	FAITHHEAD (-ATR)	HEAD([-high], [±ATR])
(ɛ)(ko̱ː)	*!			**
(ɛ)(kɔ̱ː)	*!	*		**
(ɛkɔː)		*!		***
☞ (éko̱ː)			*	***

The above tableaux and constraint ranking, which account for regular harmony in forms containing mid vowels only, can be justified as follows. In forms with mid vowels only, there can only be one harmonic span. *A-SPAN enforces this restriction.[7] A comparison of the first and (optimal) last candidates in each of

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[5] Note that this is the standard traditional definition of faithfulness to stem segments, and that it differs from FAITHHEADSTEM, which in addition requires all stem vowels to head spans.

[6] HEAD([-high], [±ATR]) is two constraints HEAD([-high], [+ATR]) "Nonhigh vowels head [+ATR] spans", and HEAD([-high], [-ATR]) "Nonhigh vowels head [-ATR] spans", and forms are evaluated for both of them.

[7] In this conception *A-SPAN is more like *STRUC, which keeps structures to a minimum, rather than other assimilation constraints like ALIGN or AGREE. This observation is due to Michael O'Keefe.

tableaux (6a) and (6b) confirms that complete harmony beats faithfulness to ATR specification of the prefix. This is seen in the single violation of FAITHHEADSPAN of the optimal candidate in each tableau, which results from changing the assumed ATR value of the prefix. Secondly, the fact that the affix (mid) vowel rather than the stem (mid) vowel changes implies the dominance of FAITHSTEM(ATR) over FAITHHEADSPAN. Both of these facts justify the ranking in the tableaux, summarized in (7).

(7) Ranking for regular harmony in forms with mid vowels only:
     {*A-SPAN, FAITHSTEM(ATR)} >> {FAITHHEADSPAN (+ATR), FAITHHEADSPAN (-ATR), HEAD([-high], [±ATR])}

In summary, in forms with only mid vowels *A-SPAN ensures that there is only one ATR-span, and FAITHSTEM(ATR) ensures that the ATR feature is that of the stem. Everything else is secondary.

2. Domain of Harmony

In Lokaa, the domain of harmony is the prosodic word (PrWd), which consists of a stem (cf. "stem" in Bakovic 2000, 2003; Pulleyblank 2002) and a preceding clitic or affix. This domain covers, in a noun, both the stem and its prefix, and in a verb, a prefix (or pronoun clitic) and its radical. The forms in (8a) and (8b) illustrate the "clitic plus verb" domains, and those in (9) show the "prefix plus noun stem" forms (see also the examples in (2)).

(8) Third person pronoun before [+ATR] and [-ATR] verb stems.
     a. ɔ̀-nɛ̀n   ímàà   **ó-kə́ə̀**   bɛ́   kɛ̀   'The man has seen them'
         man   the   he-saw   them   has
         ɔ̀-nɛ̀n   ímàà   **ɔ̀-kpàà** lè-kòì   'The man beat a drum'
         he-beat   drum
     b. é tóó   'it had'   ɛ́ dɔ́ɔ̀   'it slept'
         ó mléé   'he entered'   ɔ́ mɛ̀ɛ̀   'he swallowed'

(9) Noun class prefixes plus noun stems:
     é-fém   'crocodile'   ɛ̀-tɛ̀   'dagger'
     ò-tèm   'Igbo trader'   ɔ̀-yɛ̀   'funnel'
     kò-póó   'cup'   kɔ̀-bɔ́ɔ́   'hand'

In (8a) the instructive examples are the forms **ó-kə́ə̀** "he-saw" as compared to **ɔ̀-kpàà** "he-beat". The form of the third person proclitic varies depending on the ATR specification of the vowel of the verb stem. The same is true of the examples in (8b). If we take these examples of clitic+verb stem with those of class prefix+noun stem in (9), it is clear that the domain of harmony can be characterized as the prosodic word. The proposal that the harmony domain is a PrWd is further supported by the fact that this is also the domain of a "tonal complex" in Lokaa, as argued in Akinlabi and Liberman (to appear).

2.1 Compounds

Compounds may juxtapose two or more noun stems with vowels from different harmonic sets; for this reason, they appear to be outside the domain of harmony. It is useful to note the following points:

(i) Compounds are head-final. In a compound of two nouns, the second noun stem determines the nominal class of the entire compound by dictating the shape of nominal prefix.

(ii) However, it is the first noun stem that determines the harmonic class of that prefix (Iwara 2003, Hyman 2004).

The following examples show compounds that are formed with nouns from different nominal classes and different harmonic sets. The prefixes are in boldface to show that the compound takes the (noun) class of the second noun.

(10)

a. **lè**-bóó-kpà 'climbing rope'   **lɛ̀**-kpɛ́-kòòl 'leopard's neck'
    kè-bóó + **lè**-kpà   ɛ̀-kpɛ́ + **lè**-kòòl
    rope   bag   leopard   neck

b. **kó**-də́m-bɔ́ɔ́ 'right hand'   **ɛ̀**-bɔ́ɔ́l-jə́ú   'royal necklace'
    ò-də́m + **kɔ̀**-bɔ́ɔ́   ɔ̀-bɔ́ɔ́l + **è**-jə́ú
    man   hand   chief   rope

c. **lè**-kó-táà   'war boulder'   **lɛ̀**-nɔ̀mà-bə̀ 'deep seat'
    lè-kó + **lè**-táà   kɛ̀-nɔ̀mà + **lè**-bə̀
    war   stone   seat   hole

Using the last example **lɛ̀**-nɔ̀mà-bə̀ (L-LL-L) 'deep seat' as illustration, we propose that nominal compounds have a nested structure consisting of a prosodic word within a prosodic word, and that the prefix is phonologically closer to the first noun. This structure can be represented as in (11).

(11) [[**lɛ**-nɔma]$_{WD}$ bə]$_{WD}$

If the domain of vowel harmony is the prosodic word, then we must conclude that the vowel of the first stem is opaque to harmony. This is completely expected if the domain of harmony is the first (lower) prosodic word, and if the second stem falls outside of the harmony domain. All of the compound forms in (10) illustrate this point. Note that in each case, the (initial) vowel of the first noun stem is a mid vowel, which as we have shown in (2) triggers and undergoes harmony. The formal account of the above forms is the same as that proposed in tableaux (6a) and (6b) for the forms in (2), except that the second stem will constitute an [F]-span domain by itself.

3. High Vowels

The Lokaa vowel system reveals an asymmetry that is commonly found in ATR harmony systems: high vowels have no [-ATR] counterparts. Therefore some [-ATR] stems take high vowel prefixes, which are invariant in their ATR specification. However, it is obvious that Lokaa used to have [±ATR] distinction in high vowels, which was present in Benue Congo (Stewart 1971, Williamson 1983). This historical fact is revealed by the varied behavior of high vowels in stems. However, all high vowels (prefix or stem) are now [+ATR].

3.1 Disharmonic High Vowel Prefixes

The forms in (12) show that high vowel prefixes are invariantly [+ATR] before [+ATR] stems in the first column, and [-ATR] stems in the third column.

(12) Disharmonic high vowel prefixes

í - kpé	'lawsuit'	ì - tàŋ	'hat'
lì - tè	'songs'	yì - dɛ́	'sleep/dream'
kú - té	'musical instrument'	kú - bàaŋ	'door'
lì - tó	'intestines'	lì-wàá	'leaves'
		yì - tɔ̀	'he-goat'

The standard Optimality Theoretic approach to this phenomenon, named "harmonic non-pairing" by Bakovic (2003), is the use of co-occurrence or "grounding" constraints (Archangeli and Pulleyblank 1994). The constraint *[HI, -ATR] (Archangeli and Pulleyblank 1994, Bakovic 2003) in (13) below says that high vowels 'prefer' not to be [-ATR].

(13) *[HI, -ATR]

An output segment is not simultaneously specified for [+high] and [-ATR].

In addition, we also need "head" constraints, which state that high vowels can head their own harmony spans, just like mid vowels.

(14) HEAD([+high], [+ATR]): High vowels head [+ATR] spans.
    HEAD([+high], [-ATR]): High vowels head [-ATR] spans.

If we take *[HI, -ATR] with the constraints enforcing harmony, *A-SPAN and headedness constraints, it is obvious that disharmonic high vowel prefixes occur because *[HI, -ATR] is inviolable in Lokaa, and therefore dominates the constraints enforcing harmony.

The rankings that derive disharmonic high vowels can be explained as follows (recall that the dominance of both *A-SPAN and FAITHSTEM(ATR) FAITHHEADSPAN has been justified in the preceding section):

(i) Stem vowel cannot be changed in favour of affix vowel:
     FAITHSTEM(ATR) >> HEAD([+hi], [±ATR]): (yìtɔ̀) versus *(yìto̱)

(ii) High vowels must be [+ATR]:
     *[HI, -ATR] >> HEAD([+hi], [±ATR]):   (yìtɔ̱) versus *(yɪ̱tɔ̀)

(iii) High vowel prefixes form one span with the stem:
     *A-SPAN >> HEAD([+hi], [±ATR]):   (yìtɔ̱) versus *(yì)(tɔ̱)

Tableau (15) illustrates the derivation of yì - tɔ̀ 'he-goat', assuming that the prefix is hypothetically [+ATR].

(15) yì - **tɔ̀**   'he-goat'

yi – tɔ̀	*[HI, -ATR]	*A-SPAN	FAITHSTEM (ATR)	FAITHHEAD (+ATR)	HEAD([+hi], [±ATR])
(yì)(tɔ̀)		*!			*
(yìto̲)			*!	*	**
(yɪ̀tɔ̀)	*!			*	*
☞ (yìtɔ̲̀)				*	**

As seen from the above arguments, alteration of the [+ATR] value of a high vowel prefix is disallowed. The question here is, does the high vowel belong in the same A-span as the [-ATR] mid vowel? The assumption above is that they do. The implication is that though *[HI, -ATR] disallows changing a high vowel to [-ATR], *A-SPAN forces high vowels to be in the same span with the mid vowel. Support for this position is that high vowels are transparent to harmony, as we will show in section 4.

3.2 Disharmonic Mid Vowel Prefixes

In the preceding section, we noted that high vowel prefixes are invariable, and they can occur with [+ATR] or [-ATR] stems. This is blamed on the co-occurrence constraint *[HI, -ATR], which forbids high vowels from being [-ATR]. However, mid vowel prefixes are ordinarily harmonic, usually agreeing with the ATR value of the stem vowel as seen in the examples in (2). The interesting issue that arises is that certain high vowel stems may take [-ATR] mid vowel prefixes, which are disharmonic.

This section argues that high vowels may be [+ATR] or [-ATR] in the input, but must be crucially [+ATR] on the surface because of undominated *[HI, -ATR]. However, the input [-ATR] specification of the relevant vowels remains floating on the surface, and is not deleted. The floating [-ATR] represents the incomplete fusion of historic [-ATR] high vowels with [+ATR] ones. (See Hoffmann 1973 for comparable mid vowel cases in Okpe.)

Before turning to the exceptional cases of high vowels in stems, it is important to establish what happens in the majority of cases. In most Lokaa nouns, stems with high vowels take [+ATR] class prefixes, while stems nonhigh [-ATR] vowels take the [-ATR] class prefixes as seen in (16):

(16) Prefix alternation before high vowel stems and [-ATR] mid vowel stems.
    a.   Class 3 singular [le / lɛ]:
        High vowel   Nonhigh [-ATR] vowel
        lè - tú 'head'   lɛ̀ – mà 'hole'
    b.   Class 5 singular [ke / kɛ]:
        kè - tí 'tree'   kɛ́ - kɔ̀ɔ̀l 'noise'
    c.   Class 6 plural [ye / yɛ]:
        yè - tí 'trees'   yɛ́ - kɔ̀ɔ̀l 'noises'
    d.   Class 11 singular [ko / kɔ]:
        kò-wú 'settlement' kɔ̀ - bɔ́ɔ́ 'hand'
    e.   Class 13 [lo / lɔ]:
        lò - wí 'water'   lɔ̀ - tɛ́ 'ant'

However, some high vowel stems take [-ATR] class prefixes like the [-ATR] mid vowel stems in (16):

(17) [+ATR] (harmonic) prefixes   [-ATR] (disharmonic) prefixes

    lè-tú   L-H 'head'   lέ kpì   H-L 'electric fish'

    kò-wú   L-H 'settlement'   kɔ̀-kpì L-L 'women's native pad

    kè tí   L-H 'tree'   kέ-yú   L-H 'riches'

    ó tì H-L 'ankle bell'   ɔ̀-kpí   L-H 'viper'

    yò-jí: L-H 'palm tree'   yɔ̀-yú   L-H 'beauty'

There are two possible analyses of the disharmonic data in (17). The first approach is to assume that the [-ATR] values of the mid vowel prefixes are not determined by the high vowel stems, and so the prefixes are underlyingly [-ATR]. The second possibility is to say that the [-ATR] values of the prefixes are, in fact, determined by the following high vowel stems, though they themselves are not [-ATR] on the surface. Evidence from compounds suggests that the second approach is the correct one. If these high vowel stems are placed in compounds, they still trigger [-ATR] prefixes for the entire compound.

(18)

    a.   **ɔ̀-kpí**   'viper'   **lè-tú**   'head'   **lὲ-kpí-tú** 'viper's head'

        cf:

        è-kpí   'rat'   **lè-tú**   'head'   **lè-kpí-tú** 'rat's head'

    b.   **kέ-yú**   'riches'   **ὲ-tó** 'family'   **ὲ-yú-tó**   'rich man's family'

        cf:

        lé-dù   'trash'   **ὲ-tó** 'house'   é-dù-tó   'trash-house'

    c.   lò-wí   'water'   **kὲ-waâ** 'drinking'   **kὲ-wí-waâ** 'water-drinking'

Several points are in order here. First, note that as shown in the compounds in (10), the stem that is closest to the prefix determines its ATR specification. Thus it makes sense to assume that "viper" and "rat" in (18a) trigger different ATR prefixes. This explains why "viper's head" retains a [-ATR] prefix while "rat's head" has a [+ATR] prefix. Otherwise it is odd that the last stem [-tú] "head" in both compounds selects different ATR specifications for different compounds. Secondly, as shown in the examples in (10) above, compounds are opaque to ATR propagation. Therefore, the [-ATR] specification of the prefix in forms like [ὲ-yú-tó] 'rich man's family' in (18b) cannot be from the last [-ATR] vowel (i.e. the second stem). The second stem vowel [-tó] is "outside" the domain of harmony, as we have shown. Finally, were the [-ATR] vowel of the prefix in this form from the last stem vowel [-tó], there will be no explanation for the [+ATR] prefix in forms like [é-dù-tó] 'trash-house', which has the same final stem.

We propose therefore that the disharmonic High vowel stems in (17) have an abstract or 'floating' [-ATR]. The floating [-ATR] will change the stem high vowels if they were to associate. But they don't associate because *[Hɪ, -ATR] is high ranked and inviolable in Lokaa. We propose that the prefixes of these stems harmonize with the floating [-ATR] of the stems, satisfying all higher ranked constraints calling for ATR agreement. But the stems themselves violate a constraint against having a floating feature on the surface, and a constraint against feature ([+ATR]) insertion. The constraint *FLOAT is stated in (19), and the derivation of [kὲ-yú] 'riches' is

provided in (20). In addition, we must also assume that the floating [-ATR] cannot be deleted, in satisfaction of MAX(ATR).

(19) a.   *FLOAT: No floating autosegments.
    b.   MAX(ATR):   An input [-ATR] autosegment has a correspondent in the output.

(20) kɛ̀-yú   'riches'

	ke – yú	*[HI, -ATR]	*A-SPAN	FAITHSTEM (ATR)	MAX(ATR)	*FLOAT
a.	(kèyú)			*!	*	
b.	(kɛ̀yʊ́)	*!				
c.	(kè)(yú [-A])		*!			*
d. ☞	(kɛ̀-yú [-A])					*

Without a [-ATR] specification of the input, it is impossible for the prefix to surface as [-ATR], since the [ATR] value of the mid vowel prefix is completely predictable from that of the stem. Given the high ranking of both *[HI,-ATR] and FAITHSTEM(ATR) as seen in the preceding section the floating ATR cannot be deleted or phonetically realized as part of the stem high vowel.

The essential claim of this sub-section has been that cases of apparent disharmony involving mid vowel prefixes and high vowel stems are really not disharmony because the stem has a floating [-ATR] autosegment, proof of which are the compounds in (18). Otherwise it is not clear what the mid vowel prefixes are harmonizing with. As seen in the forms in (18), even when the prefix is supplied by another ([+ATR]) stem that is further away, the high vowel stem still turns the prefix to [-ATR].[8]

The issue that arises here is the phonetic status of the high vowel of the stem. Is the [-ATR] part of the high vowel? The answer here is that it is not. The high vowel is [+ATR] on the surface, and it is followed by a [-ATR] autosegment. (See Akinlabi 1996, Zoll 1996) for discussions of subsegmental units.) The idea therefore is that the high vowel of the stem behaves transparently to the floating [-ATR] autosegment. That the high vowel in this case is transparent is not surprising, as high vowels are in general transparent to any [-ATR] which is part of a following nonhigh vowel, as we discuss in detail in the next section.

The ranking required for the derivation of forms with disharmonic mid vowel prefixes is:

{*[HI, -ATR], *A-SPAN, FAITHSTEM(ATR), MAX(ATR)} >> *FLOAT.

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[8] For the sake of completeness, note that it is impossible to derive this form without assuming a stem with [-ATR], given as we have shown, that mid vowel prefixes always harmonize with the stem. This appears like imposing an input. This is however not the case; the only claim being made is that only inputs with a [-ATR] will surface this way, while inputs with [+ATR] will surface with [+ATR] prefixes. The alternative position, assuming that the prefixes themselves are [-ATR] collapses in the face of the data in (18), where [ATR] specification of the prefix must be assumed to come from the stem.

4. High Vowel Transparency

In section 3, we showed that high vowels [i] and [u] are disharmonic in both prefixes and stems, blaming this on co-occurrence constraints against high, [-ATR] vowels. This is however not the only the characteristic of high vowels in Lokạạ harmony. Though the high vowels themselves *do not* undergo harmony (they don't alternate), they are transparent to [-ATR] propagation when they occur as the first vowel of a disyllabic or trisyllabic stem.[9]

(21) Disyllabic noun stems with [+ATR] and [-ATR] class prefixes:

a.	è-sìsòŋ	'smoke'	*ɛ̀-sìsòŋ
	kò-fíyə̀	'brain'	*kɔ̀-fíyə̀
	lè-jìmə̀	'matriclan'	*lɛ̀-jìmə̀
	ó-yínə́	'story'	*ɔ́-yínə́
b.	ɛ̀-sísɔ̀ŋ	'housefly'	*è-sísɔ̀ŋ
	kɛ̀-títaŋ	'rafia bamboo splinter'	*kè-títaŋ
	lɔ̀-títaŋ	'rib'	*lò-títaŋ
	ɔ́-túːmá	'need'	*ó-túːmá

(22) Nouns derived from disyllabic verb stems

a.	fùkə́	'count'	kó-fùkə̀	'counting'	*kɔ́-fùkə̀
	túkə́	'run'	kè-túkə̀	'running'	*kɛ̀-túkə̀
	wìːyə́	'blow'	kè-wìːyə́	'blowing'	*kɛ̀-wìːyə́
	fìːlə́	'jump'	é-fìːlə̀	'high jump'	*ɛ́-fìːlə̀
b.	fúká	'gather'	kɔ́-fúkà	'gathering (people)'	*kò-fúkà
	fúká	'gather'	kɛ̀-fúkà	'gathering (things)'	*kè-fúkà
	lúːwá	'push'	kɔ̀-lúːwà	'pushing'	*kò-lúːwà
	tíká	'shift'	kɔ̀-tíkà	'shifting'	*kò-tíkà

(23) Disyllabic verb stems with proclitics

a.	yó dìbə̀	'we caught'
	yɔ́ píká	'we polished'
b.	yó kúdə́	'It split'
	yɔ́ mùːlà	'It dissolved'

(24) Trisyllabic noun stems with two high vowels

ɛ́-kpìlíbà	'cocoyam (sp.)'	*é-kpìlíbà
kɛ́-kílìkà	'kind of plant'	*ké-kílìkà

The examples in (21a) show that it is impossible to have a [-ATR] mid vowel prefix when the second stem syllable has a [+ATR] vowel, and (21b) shows that it is impossible to have a [+ATR] mid vowel prefix when the second vowel is [-ATR]. The near minimal pair of "smoke" and "housefly" is especially telling. The surface ATR specification of the prefixes of derived nouns in (22) cannot be explained

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[9] An objection might be raised that the stems in these cases have floating [-ATR] like those discussed in the last section. While there is no way to disprove such an argument because there is already a following [-ATR] vowel, within such an account it will be a colossal accident that the prefix is [+ATR] only when the stem high vowel is followed by a [+ATR] vowel, and it is [-ATR] only when the stem high vowel is followed by a [-ATR] vowel, and never otherwise.

unless the high vowels are transparent, since the verbs from which they are derived do not have these prefixes. The forms in (23) show proclitic ATR alternation depending on whether the second vowel of the verb is [+ATR] or [-ATR]. Finally the forms in (24) show two transparent high vowels in a trisyllabic stem.[10]

In its standard form, Headed Span theory (McCarthy 2004) requires every segment within a domain to agree in the harmonizing feature. Thus, within McCarthy's original proposal it is impossible to have a transparent segment; that is a segment which is neither a head nor associated with a head. O'Keefe (to appear) proposes that the requirement for every segment to agree with the harmonizing feature within the domain (a headed feature span) must be violable. That is, segments within the headed feature span do not have to agree with the feature defining this domain. He proposes that forms with transparent vowels should be analyzed as belonging to a single span with the head, violating the constraint requiring them to associate to a feature of the head.

O'Keefe proposes the constraint family, ASSOCIATEHEAD, which requires that segments share a specific feature of the head of the [F]-span in which they are located. A violation of this constraint while still remaining in the [F]-span implies transparency. The constraint is defined as in (25), and the ATR instantiation of it is defined as in (26).

(25) ASSOCIATEHEAD([βG, γH, …], [αF])
Every [βG, γH, …] must share the value of the head of the F-span in which it is located.

(26) ASSOCIATEHEAD([+hi], [ATR])
Every high vowel must share the value of the head of the ATR span in which it is located.

With this constraint, cases of transparency can then be analyzed as single spans. The ranking argument for Lokaa high vowel transparency is shown in (27), using a form like [ɛ̀-sísɔ̀ŋ] 'housefly'. The relevant tableau is in (28). Transparent vowels are in square brackets within the [F]-span.

(27) Ranking arguments for a transparent form.
*A-SPAN >> ASSOCIATEHEAD([+hi], [ATR])
    (ɛ̀s[í]sɔ̀ŋ) vs. *(esí)(sɔ̀ŋ)
*[HI, -ATR] >> ASSOCIATEHEAD([+hi], [ATR])
    (ɛ̀s[í]sɔ̀ŋ) vs. *(ɛ̀sísɔ̀ŋ)
FAITHSTEM(ATR) >> ASSOCIATEHEAD([+hi], [ATR])
    (ɛ̀s[í]sɔ̀ŋ) vs. *(ɛ̀sísòŋ)

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[10] In some recent works (Gafos 1996, Ní Chiosáin & Padgett 2001, Rose and Walker 2004, Benus 2005, and others), it has been proposed that all assimilation is local. Therefore there cannot be any transparent vowels in harmony. Archangeli and Pulleyblank (to appear) present interesting counterexamples to this claim. See their paper for discussion and criticism.

(28) ɛ̀ - sísɔ̀ŋ   'housefly'   *e- sisɔ̀ŋ

	è-**sísɔ̀ŋ**	*[HI, -ATR]	*A-SPAN	FAITHSTEM (ATR)	ASSOCIATEHEAD ([+hi], [ATR])
a.	(esí)(sɔ̀ŋ)		*!		
b.	(ɛ̀sɪ́sɔ̀ŋ)	*!			
c.	(ɛ̀sɪ̠̀soŋ)			*!	
d. ☞	(ɛ̀s[í]sɔ̀ŋ)				*

   If the root vowels cannot be changed, and if high vowels do not alternate, then the only choice left for them is to be transparent to [-ATR] or be opaque. In (28) the opaque candidate (a) loses because of a violation of *A-SPAN, the fully harmonic candidate (b) loses because of *[HI, -ATR], and candidate (c) loses because the stem vowel has been changed.

(29) Ranking for high vowel transparency:

   {*[HI, -ATR], *A-SPAN, FAITHSTEM(ATR)} >> ASSOCIATEHEAD([+hi], [ATR])

   As expected, high vowels are not transparent in compounds. This is so because the second stem falls outside the domain of harmony, as we argued in section 2.1. Note that in (30) the forms "bend" and "house" have [-ATR] prefixes in isolation. If the high vowels were transparent in the compounds we expect the prefixes to retain the [-ATR] specifications. (Recall from section 2 that the second stem determines the prefix, but the first stem determines its harmonic specification.)

(30) è-tí   +   kɛ̀-kú   →   kè-tí-kú
   'stick'   'bend'   'walking stick'
   lé-dù   +   ɛ̀-tɔ́   →   é-dù-tɔ́
   'trash'   'house'   'trash house'

   In summary, high vowel transparency may be seen in two types of forms in Lokaa. The first is when a floating [-ATR] survives in a stem with a [-ATR] high vowel as seen in (17) and (18), and when a [-ATR] vowel follows a high vowel in a bisyllabic form or longer, as in (21) – (24). The difference between these two is that in the forms in (17) the [-ATR] remain unassociated in the stem, whereas in the forms in (21) – (24), the feature [-ATR] is part of a nonhigh vowel. Therefore, all of the "disharmonic" forms in (17) violate ASSOCIATEHEAD([+hi], [ATR]), since they are being formally regarded here as "transparent" forms.

5.   The Low Vowel [a]

In this section, I turn to two features of the low vowel [a], namely its characteristics as a disharmonic prefix vowel and as an opaque stem vowel. The first characteristic linked to the constraint forbidding the feature [+ATR] from co-occurring with the feature [+low], and the second characteristic is linked to the fact that it must share the value of the head in which it is located.

5.1 Disharmonic [a] in prefixes

As a stem vowel the low vowel [a] triggers [-ATR] harmony. Only fully harmonic mid vowel prefixes (i.e. [-ATR]) can occur before it (in addition to the disharmonic

high vowel prefixes discussed in section 3.1). The three [+ATR] mid vowels [e, ə, o] cannot occur before [a].

(31) [a] as a stem vowel

  ὲ-fà   'power'
  έ-káàŋ   'dispute'
  ɔ̀-dáŋ   'fufu'
  yɔ̀-paá   'pieces'
  kɔ̀-káà   'crab'
  lὲ-mà   'hole'
  kέ-kpán   'overnight'

However, as a prefix vowel, [a] can be disharmonic with the stem vowel. In Lokaa, [a] can occur as a prefix to any following vowel stem vowel. Our interest here is in the [+ATR] stem vowels:

(32) [a] as prefix

  Nouns   Verbs
  à-tè   'songs'   á-teì   'you are singing'
  à-toó   'loads'   á-toówəí   'you are carrying'
  à-fiíl 'bush mangoes'   á-yéní   'you had'
  à-bə̀   'holes'   yá-toó   'they carried'

As in the non-alternating high vowels, the standard Optimality Theoretic approach to non-alternating low vowels is the use of co-occurrence or "grounding" constraints (Archangeli and Pulleyblank 1994). The relevant constraint here is *[Low, +ATR]. Again the idea of (33) below is that low vowels "prefer" not to be [+ATR].

(33) *[Low, +ATR]   (Archangeli and Pulleyblank 1994, Bakovic 2003)
    An output segment is not simultaneously specified as [+low] and [+ATR].

If we take *[Low, +ATR] with the constraints enforcing harmony, *A-Span and FaithStem(ATR), disharmonic low vowel prefixes can be accounted for with the constraint ranking: *[Low, +ATR], FaithStem(ATR) >> *A-Span. This ranking says that harmony, that is, belonging to one headed span, can be dispensed with in favor of retaining the ATR value of the root and not having a [+ATR] low vowel. The following tableau (34) illustrates the derivation of à-tè 'songs'.

(34) à-tè   'songs'

à-tè	*[Low, +ATR]	FaithStem (ATR)	*A-Span
(ætè̱)	*!		
(atέ)		*!	
☞ (à)(tè̱)			*

In the above tableau, we have used *[Low, +ATR] to rule out [a] from assimilating in ATR, just as we did with *[Hi, -ATR]. However, we have in anticipation of the analysis of its "opaqueness" (van der Hulst and Smith 1986:235) assumed here that it does not form part of the same span as the stem vowel. For example, a candidate like (àtè̱) will beat every other one in this tableau. Only the (high) ranking of AssociateHead([+lo], [ATR]) can rule it out.

The account given above of the non-alternation of [a] sets the stage for the analysis of its opacity, to which we now turn.

5.2 Low Vowel Opacity

The preceding section shows that the low vowel [a] is disharmonic in prefixes in that it does not alternate. It can be prefixed to either a [-ATR] stem or a [+ATR] stem. We accounted for this behavior with the co-occurrence constraint *[LOW, +ATR], which requires that low vowels not be [+ATR]. This behavior parallels that of high vowels in prefixes. Unlike high vowels, however, the low vowel [a] is not transparent in stems. There are two issues that any analysis must account for. First, [a] does not alternate with [ə] even though both vowels occur in the system.

(35) è-bə̀ə̂m   'glue'
     ò-bə́ə́   'ghost'
     á-kpə̀n   'clump of raffia palm'

Secondly, [a] blocks [+ATR] propagation: nonhigh vowels occurring before the vowel [a] can only be [-ATR] and never [+ATR] in the prefix+stem domain, even if the second vowel of the stem is [+ATR].

(36) ɛ̀-kàpóóŋ   'pepper'
     kɛ́-taâkpoô   'grasshopper'
     ɛ̀-bládə̀l   'tick'

One interesting feature of Lokaa is that though it is an eight-vowel system, the vowel [a] has not "re-paired" with [ə] (Bakovic 2000, 2003). In a symmetrical eight-vowel system like Wolof (Ka 1994) or ten-vowel system like Igede (Armstrong 1983) [a] normally pairs with [ə]. But Lokaa has an asymmetrical eight-vowel system in which [a] and [ə] are unpaired. This results in a system in which [a] and [ə] are neutral (in addition to the high vowels). Bakovic defines harmonic pairing as follows:

(37) Definition: Harmonic pairing

A vowel *x* in a language L with a harmonic feature [±*hf*] is harmonically paired iff there is another vowel *y* in L's inventory and *y* differs from *x* only in terms of [±*hf*].

The Lokaa vowel [a] differs from [ə] in both the harmonic feature [±*ATR*], as well as the feature [low]. Re-pairing apparently results in a shift, in which the language re-classifies [ə] as a [low] vowel, as in Igede (Armstrong 1983), or in the entire vocalic system is split into high versus nonhigh, as in Wolof (Ka 1994, O'Keefe to appear). Neither of these has yet taken place in Lokaa.[11] Therefore the two vowels [a] and [ə] remain unpaired, hence the non-alternation.

We now turn to the second point, [a] opacity, using the same assumptions as we did for disharmony. We derive the opacity of [a] essentially by ranking *[LOW, +ATR] and FAITHSTEM(ATR) over *A-SPAN. However, this is not enough to derive opacity. As van der Hulst and Smith (1986:238) note, opaque segments are "blockers, non-undergoers and spreaders" (see also Clements and Sezer 1982). This ranking only achieves the "non-undergoing" nature of [a].

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[11] See Iwara (1994) who notes that a shift is underway.

Within Span theory the blocking and spreading characteristics of [a] require [a] to share the harmonic value of the head of the span and to head its own span. Both of these requirements must be superior to forming a single span with a head that has a different ATR value (O'Keefe to appear). These requirements are enforced by appropriate rankings of the constraints ASSOCIATEHEAD([+lo], [ATR]) and HEAD([+LO],[-ATR]), which are defined as in (38).

(38) a.   ASSOCIATEHEAD([+lo], [ATR])
          Every low vowel must share the value of the head of the ATR span in which it is located.

     b.   HEAD([+LO],[-ATR])
          Low vowels head [-ATR] spans.

To achieve [a] opacity, both of these must also dominate *A-SPAN. The next tableau shows the derivation of [ɛ̀-kàpóóŋ] 'pepper'. Though the tableau in (39) does not show a crucial ranking of ASSOCIATEHEAD([+lo], [ATR]) and *A-SPAN, a close examination shows that this ranking alone achieves [a] opacity.

(39) ɛ̀-kàpóóŋ   'pepper'

e̦ -**kapóóŋ**	*[LOW, +ATR]	ASSOCIATEHEAD ([+lo], [ATR])	HEAD([+LO], [-ATR])	*A-SPAN
a. (èkæpóóŋ)	*!			
b. (ɛkapɔ́ɔ́ŋ)			*!	
c. (èk[à]póóŋ)		*!	*	
d. ☞ (ɛ̀kà)(póóŋ)				*

The combined ranking of the constraints for overall harmony, high vowel transparency, and low vowel opacity is presented in (40).

(40) Low vowel opacity dominates high vowel transparency:
    *[LOW,+ATR], ASSOCIATEHEAD([+lo], [ATR]), HEAD([+LO],[-ATR]), FAITH STEM(ATR) >> {*A-SPAN, *[HI, -ATR]} >> *FLOAT, ASSOCIATEHEAD([+hi], [ATR]), FAITHHEAD(+ATR), FAITHHEAD(-ATR), HEAD([+hi], [±ATR])

In summary, the analysis presented above and the proposed ranking in (40) show that there is a crucial difference between the co-occurrence constraints and the ASSOCIATEHEAD constraints. The co-occurrence constraints control the inventory, and the different rankings of the ASSOCIATEHEAD constraints indicate whether or not they will form part of an F-span.

This concludes the discussion of transparency and opacity in Lokaa. In section 6, I turn to the indeterminate nature of [ə].

6.   The Status of [ə]

This section presents the details of the characteristics of [ə], its patterning as a mid vowel, its interesting distribution within stems, and its bearing on the question of positional neutralization and harmony.

6.1 Harmony and the Distribution of the Vowel [ə]

The right to left distribution of [ə], in bisyllabic words, appears to be governed by vowel harmony, while the left to right distribution is governed positional privilege (faithfulness) and markedness considerations.

As already shown in the preceding sections, noun class prefixes and proclitics harmonize with noun stems and verbs respectively in their ATR specification, if they are mid vowels. The same distribution is true of the first vowel of an underived bisyllabic noun or verb stem, where the harmonic restrictions also hold.

[ə] patterns like any other mid vowel, as a stem vowel. As an ATR head (trigger), the vowels that can occur to its left are the same ones that can occur to the left of any other [+ATR] mid vowel, namely: [i, u, e, o, ə and a]. Explanatorily, these are the expected [+ATR] mid vowels [e, o] (41a), the [+ATR] high vowels [i, u] (41b), the disharmonic [a] (41c), or another [ə] (41d).

(41) Vowel distribution before [ə]

    a.   [ə] preceded by mid vowels [e, o]

pèːyə́	'learn'	*pɛ̀ːyə́
é-pléələ̀	'mud shelf'	*é-plɛ́lə̀
yòmə́	'lie down'	*yɔ̀mə́
kówə́	'show'	*kɔ́wə́

    b.   [ə] preceded by high vowels [i, u]

píːmə́	'inspect'
dìbə́	'catch'
túkə́	'run'
kúwə́	'squat'

    c.   [ə] preceded by [a]

ɛ̀-bládə̀l	'tick'

    d.   [ə] preceded by another [ə]

kpə̀nə́	'cover'
sə̀kə́	'put aside' (save money)

Given the above forms, we can assume that any vowel can precede [ə], subject to vowel harmony and with the restriction that the [ə] must head a harmonic span like any other mid vowel. The rest of the ATR analysis follows those proposed for mid vowels in the preceding sections.[12]

However, the left to right distribution of [ə] is more severely restricted. The vowel following a [ə] can only be [i], or else another [ə]. The following bisyllabic verb and noun stems illustrate the distribution.

(42) Vowel distribution after [ə]

    a.   [ə] followed by [i]

də̀lí	'take'
kə̀bí	'spoil'
ló-wə̀nì	'space'

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[12] Notice that the distribution in (41) cannot be analyzed as vowel reduction because (a) [ə] contrasts in with every other vowel in the language, (b) it can occur long or short like any other vowel in Lokaa, (c) its occurrence is not restricted to any syllable type, (d) the lone vowel of a monosyllabic noun stem can be [ə] and, (e) entire bisyllabic verb stems can be [ə].

    b.   [ə] followed by another [ə]
        təmə́   'push'
        kpə̀nə́   'cover'
        ke̍-təmmə́   'willow'

Notice that the restriction after [ə] is not reciprocated by [i], because [i] can be preceded by any other vowel in the language. This restriction is on [ə]. Harmonically, nothing interesting occurs here, since both vowels are [+ATR]. The left to right vowel distribution involving [ə] is dependent on markedness. [ə] must be followed by a less marked vowel [i][13], or a vowel of equivalent markedness [ə] (a copy of itself).

The conundrum here is that the left to right distribution of [ə] (and not any other vowel) appears to be controlled by markedness, supporting the positional markedness hypothesis of Beckman (1997) and others. However, harmony occurs in a right to left directionality, with [ə] also heading harmonic spans like any other mid vowel. Since positional privilege and markedness have been linked to vowel harmony (Beckman 1997), the question is whether the right edge has any privileges, or whether harmony is just directional (Hyman 2002, McCarthy 2004, Archangeli and Pulleyblank (to appear)). As Lokaa data clearly shows, vowel distribution is often intertwined with vowel harmony, but they can be separated (see Archangeli and Pulleyblank (to appear) for a similar point). Vowel distribution is often subject to positional privileges, but vowel harmony is subject to directionality. When both occur together, this distinction is often masked, as we see in Shona (Beckman 1997).

6.2 Transparent or Opaque?

The final question to be addressed here is the status of [ə] as a neutral vowel. Neutral vowels are often either transparent to harmony, as in the case of Lokaa high vowels, or opaque to harmony, as we have demonstrated in the case of [a]. But is [ə] transparent or opaque? The left to right distribution discussed above prevents any definite answer to this question. As we have just noted, [ə] is only followed by [i] or another [ə]. To test the transparency or opacity of [ə], we will need it to be followed by a [-ATR] vowel and be preceded by some prefix or clitic. This structure is impossible in Lokaa.[14]

7.   Conclusion

Unlike many languages with [ATR] harmony, Lokaa has four unpaired vowels [i, u, ə, a]. [i, u] are transparent while [a] is opaque. The basic aim of this paper was to describe the interesting phenomenon of high vowel transparency and low vowel opacity in Lokaa [ATR] harmony. In addition, the incomplete merger of the historic [+ATR] and [-ATR] high vowels now manifests in two forms of high vowel transparency: one in which a high vowel is transparent to a floating [-ATR]

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[13] There is overwhelming literature on the unmarkedness of [i], which I assume is quite convincing. See for example Pulleyblank (1988), de Lacy (2002), and others.

[14] There appears to be no forms with a floating [-ATR] [i] following a [ə]. This gap may suggest that [ə] is opaque, on the interpretation that these forms exist and that [ə] is simply preventing [-ATR] harmony. [ə] occurs as a prefix vowel in a few examples, but the stem vowel must be [ə].

autosegment, and another in which a high vowel is transparent to a following [-ATR] vowel. Finally, Lokaa has an interesting interaction between vowel harmony and another vowel distributional restriction, which is based on markedness.

Any theory of harmony must be able to accommodate these varied phenomena in the same language. We have shown that McCarthy's (2004) Headed Span Theory, taken with the extensions proposed by O'Keefe (to appear), does this. In addition, we have also shown that co-occurrence constraints have different roles to play in harmony than ASSOCIATEHEAD constraints. Co-occurrence constraints control the inventory, and the different rankings of the ASSOCIATEHEAD constraints indicate whether or not they will form part of a feature span.

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