ATR Vowel Harmony: new patterns and diagnostics

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1 Introduction

Formal phonological models rely on typology to inform representations, cognitive biases, acquisition patterns, and the role of functional pressures. Typological studies of harmony patterns have led to innovative theoretical insights into the nature of harmony. These include consonant harmony (Hansson 2010, Rose & Walker 2004), nasal harmony (Walker 2000), round harmony (Kaun 2004, 2005) and Advanced Tongue Root (ATR) harmony (Casali 2003, 2008, 2016). In this paper, I build on Casali's typological observations about ATR harmony through a large-scale study of the vowel inventories of African languages with and without ATR harmony. I make three key points: 1) presence of ATR harmony is correlated with contrast for ATR among high vowels, but not necessarily with contrast for ATR among mid vowels; 2) Acoustic (F1) differences between vowels is weakest among high vowels and this property drives harmony; 3) ATR harmony exhibits different patterns in Nilo-Saharan and Niger-Congo phyla.

2 ATR harmony characteristics

ATR harmony involves agreement among vowels for the position of the tongue root. Articulatory studies using X-Ray (Jacobson 1980), MRI (Tiede 1996), and ultrasound (Gick et al 1996, Allen et al 2013, Hudu 2014) have provided evidence that the position of the tongue root differs in pairs of vowels transcribed as being distinguished for ATR. Other articulatory properties include tongue body height, pharyngeal constriction/expansion, epiglottic constriction, and voice quality differences, probably induced by laryngeal displacement. The main acoustic difference between pairs of vowels that differ in ATR is F1: [+ATR] vowels have lower F1 than [-ATR] vowels (Starwalt 2008). Other possible differences are F2, F1 bandwidth, center of gravity and spectral tilt. In terms of phonological behavior, ATR harmony systems exhibit cross-height harmony effects (Stewart 1967), in which high vowels can trigger morpheme alternations in non-high vowels and vice versa. In addition, vowels in roots typically show agreement for ATR. Finally, in some languages, there is evidence for dominance of one value of ATR in harmony (Casali 2003, 2016) - a morpheme, usually a suffix, triggers harmony on the root for a particular ATR value.

In some languages, there are contrasts for ATR among equal sets of vowels at all vowel heights resulting in a 10-vowel system. Bongo, a Central Sudanic (Nilo-Saharan) language of South Sudan (Kilpatrick 1985) has such a system: /i ɪ u ʊ e ɛ o ɔ ɨ a/. (1a-e) illustrates ATR agreement within roots. (1f-g) shows ATR alternations in the root triggered by the [+ATR] possessive suffix /-í/ (cf. 1d,e) and (1h-i) illustrates the diminutive prefix alternating its ATR value depending on the ATR feature of the root vowels.

(1) **Bongo ATR harmony**

a.	kébì	'rope'	f.	bùdɔ̀-í	'your husband'
b.	bírù	'bat'	g.	tírì-í	'your lip'
c.	pìlɛ̀gɔ̀	'species of bird'	h.	gì-kúŋgú	'baby baboon'
d.	bɔ̀dɔ̀	'husband'	i.	gì-má	'small child'
e.	tárà	'lip'			

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Many other languages have a 9 vowel system /i ɪ u ʊ e ɛ o ɔ a/ with a single low vowel that has no harmonic counterpart, or only an allophonic [+ATR] version of a low /a/.

In other languages, the vowel system lacks contrasts among mid vowels, but does have contrasts among high vowels. These languages have 7-8 phonemic vowels. Dagik, a Kordofanian (Niger-Congo) language spoken in Sudan (Vanderelst 2016) is one such language with a phonemic system of 8 vowels: /i ɪ u ʊ ɛ ɔ ə a/. Dagik shows harmony within roots (2a-d) and morpheme alternations, such as the imperative morpheme (2e-i). ATR harmony produces [+ATR] allophones [e o ə ạ] of the [-ATR] vowels /ɛ ɔ ə a/.

(2) **Dagik ATR harmony**

a.	ʊkːɔ	'dance'	e.	sikː-u	'bury-IMP!'
b.	ulːo	'move down'	f.	sɪp-ʊ	'toss-IMP!'
c.	kəndʊ	'sugar cane'	g.	pɛt̪ː-ʊ	'listen-IMP!'
d.	kəndu	'palm tree'	h	sɔð-ʊ	'break-IMP!'
			i	wak-ʊ	'suck-IMP!'

Some languages do not show contrasts among high vowels, but do show contrasts among mid vowels, resulting in 7-8 vowel systems. An example is the Akure dialect of Yoruba, a Defoid (Niger-Congo) language of Nigeria (Bamgbose 1967, Przezdziecki 2000), which has a phonemic 7 vowel inventory /i u e ɛ o ɔ a/. Harmony is shown for subject clitics and for other particles that precede the verb root. Harmony produces allophones [ɪ ʊ] of the high vowels /i u/ (3f).

(3) **Akure Yoruba ATR harmony**

a.	ó kí	's/he greeted'	e.	ó tú ti jó	'it has burnt again'
b.	ó dé	's/he arrived'	f.	ɔ́ tʊ́ tɪ bɛ́	'it has burst again'
c.	ɔ́ jɛ	's/he eats'			
d.	ɔ́ á	's/he came'			

It is often assumed that a 7 vowel system that lacks high vowel contrasts is the prototypical ATR vowel system. Mahanta (2008), citing Stewart (1971) notes that "in most commonly occurring vowel harmony systems, the distinctions between the high vowels merge too (/i/ with /ɪ/, and /u/ with /ʊ/), creating seven-vowel systems." Obikudo (2008) also notes "Most languages that are characterised by ATR vowel harmony have reduced vowel systems lacking /ə/ and often /ɪ ʊ/ as well, yielding nine and seven vowel systems." Such observations, which are primarily based on West African languages, have led to markedness constraints penalizing high [-ATR] vowels, the vowels that are lacking in such systems. For example, Archangeli & Pulleyblank (1994) proposed the HIGH/ATR constraint, and Bakovic (2000) and others adopt *[+high]/[-ATR]. Nevertheless, Casali (1995, 2002) has questioned the assumption that [ɪ ʊ] are 'poor' vowels that are marked. Casali's (2003) survey of 110 Niger-Congo and Nilo-Saharan languages with ATR distinctions reveals that most (72/110) languages actually have high [-ATR] vowels. More than half of the languages, 60, show a contrast for both high and mid vowels (labeled 5-Ht), 12 languages show a contrast for high but not mid (4Ht(H)) and 38 show a contrast for mid but not high (4Ht(M)). Therefore, there seems to be nothing particularly problematic about high [-ATR] vowels. Nevertheless, if an inventory is missing a set of vowels, it is more likely to be the high vowels in his survey. Casali notes, however, that the distribution of the 'missing vowel' systems is skewed genetically in his sample as follows. 2IU-2EO refers to contrasts for both heights, 2IU-1EO to contrast for high only and 1IU-2EO to contrast for mid only. We ignore the low vowels in this classification system; they present different analytical challenges.

Table 1: Distribution of vowel systems from Casali (2003)

	2IU-2EO	**2IU-1EO**	**1IU-2EO**	**Total**
Nilo-Saharan	17 (68%)	7 (28%)	1 (4%)	25
Niger-Congo	43 (50.5%)	5 (6%)	37 (43.5%)	85

Nilo-Saharan ATR languages show a strong preference for 2IU systems, whereas Niger-Congo languages reflect a more balanced distribution. Furthermore, the one Nilo-Saharan language reported in Casali (2003) to have 1IU-2EO system is Kaba, a Central Sudanic language, based on personal communication with Jim Roberts. Yet, Keegan (2012) reports a 1IU-1EO system and no ATR harmony for Kaba. Casali (2008:503) comments on the distribution in Table 1 hat 1IU-2EO languages are "extremely common and widespread (though seemingly more so in West and Central than in East Africa", whereas 2IU-1EO are less common, but "it is at least conceivable that they may prove more common than the other type in East Africa."

Casali's (2003) survey established that 2IU systems (both 2IU-2EO and 2IU-1EO) are not uncommon at all, and he notes the propensity for Nilo-Saharan to favor 21U systems. However, his survey leaves some unanswered questions. First, what is the correlation between inventory structure and *presence* of harmony? Casali's research focuses on whether a particular inventory shows [+ATR] or [-ATR] dominance, not whether a particular inventory actually has ATR harmony or not. Second, what is the relationship between inventory structure, harmony and genetic/areal affiliation? With 25 Nilo-Saharan languages, it is hard to determine if the correlation he notes is robust or not. Other researchers have also conducted surveys of vowel systems in Africa. Williamson (2004) provides an overview of West African types, but without numbers. Clements & Rialland (2008) survey vowel inventories of 100 languages in the Sudanic belt, and note "It is usually the case, outside Bantu, that if an African language has two sets of high vowels it has ATR harmony as well." This statement is used to infer ATR vowel harmony from vowel inventories, but they only provide numbers for the vowel inventories, and no detailed information on whether the languages in their survey actually have harmony or not. For the Sudanic belt, they report 22 2IU-2EO languages, 6 2IU-1EO languages, 46 1IU-2EO languages, 25 1IU-1EO languages and 1 1IU-0EO language. More recently, Rolle, Faytak & Lionnet (2016, 2017), based on a survey of over 600 languages, have noted that there appear to be two distinct zones of ATR harmony in the Macro-Sudan Belt, a West African zone, and an East African zone, with a central ATR-less zone around the Central African Republic. This distribution fits with Casali's suggestion that East Africa may be different in terms of ATR harmony properties.

3. Typological Survey

In order to more thoroughly explore the typology of ATR harmony, I examined the vowel inventory and harmony properties of 524 languages from the Niger-Congo and Nilo-Saharan language phyla in the Macro-Sudan Belt (on this area, see Güldemann 2010). This survey is based on the list of languages in Casali (2003), my own database that was originally based around Nuba Mountains languages (Rose 2016), and the large database known as ALFA (Areal Linguistic Features of Africa (Rolle, Lionnet & Faytak 2016, 2017), into which my database is now folded.[1]

Assessing languages both with *and without* ATR harmony allows verification of two strong predictions:

(4) **Predictions about inventory and presence of ATR harmony**
If high vowels contrast (2IU) in a language, there will be ATR harmony
If high vowels do not contrast (1IU) in a language, there will not be ATR harmony

These predictions would appear to be easily falsified based on just the survey in Casali (2003), since he lists 38 1IU-2EO languages. However, Casali did not claim that all the languages had dynamic, active harmony, but rather that they showed ATR effects of some kind, which could be vowel coalescence, neutralization, or coocccurrence restrictions. In any case, strong claims are useful in that we can determine how well the data matches them.

In terms of coding the data, Rolle, Faytak & Lionnet (2017) distinguish between *strict* harmony and *trace* harmony in the ALFA database. Strict harmony involves active morpheme alternations and a system in which all vowels participate - that is, either a phonemic 2IU-2EO system or a 2IU-1EO or 1IU-2EO

[1] I am grateful to Nik Rolle, Matt Faytak & Florian Lionnet for sharing the ALFA database, which is an extensive collection of information on the vowel systems of African languages.

system with allophonic vowels. Examples would include Dagik as in (2) and Akure Yoruba as in (3). Trace harmony, on the other hand, involves root cooccurrence restrictions with no alternations, or systems in which the vowel inventory is missing contrasts and harmony is restricted to operate only between contrastive vowels. This typically involves harmony between mid vowels only in a 1IU-2EO system. In future research, it would be useful to separate the trace category into static cooccurrence restrictions and those with alternations, but at this point, such recoding is not complete.

Finally, researchers may use different criteria for transcribing vowels, and this could hamper making generalizations. In particular, determining whether vowels in the mid range are [ɪ ʊ] or [e o] is difficult (Casali 1995, 2003, Hyman 1999) and poses issues for 7/8 vowel systems. If fieldworkers transcribe a seven vowel system as 1IU-2EO rather than 2IU-1EO if there is no harmony to reinforce a high vowel transcription, this could skew the numbers in favor of 2IU with harmony versus 1IU without. It is not clear, however, if one transcription system would be favored over another if a vowel set is missing. In addition, some materials are written by African scholars who speak ATR-harmonic languages themselves, or by linguists who have years of experience living in a community and speaking the language - see Casali (2003, 2016) for extensive discussion of this point. It is also the case that if a language has dynamic harmony, it is usually clear which vowels are participating. The scale of the sample size in this paper should be large enough to correct for errors or mistrust of transcriptions.

3.1 *Nilo-Saharan* There were 105 Nilo-Saharan languages examined in the database. These are shown based on family groupings. Although we recognize that the internal classification of Nilo-Saharan is debated, the family grouping provides a useful breakdown for interested readers.

Table 2: Presence and absence of ATR harmony in Nilo-Saharan languages

	ATR harmony	**no ATR harmony**	**Total**
Saharan	3	1	4
Songhay	0	1	1
Surmic, Koman, Nubian, Temein, Daju Nyimang (E. Sudanic)	16	18	34
Nilotic (E. Sudanic)	24	3	27
Central Sudanic	20	12	32
Other (Fur, Kresh, Kunama, etc.)	2	5	7
Total	65	40	105

If we examine the breakdown of the languages with ATR harmony, all 65 of them have a 2IU system, while none has a 1IU system.

Table 3: Inventories of Nilo-Saharan languages with ATR harmony

	2IU-2EO	**2IU-1EO**	**1IU-2EO**	**1IU-1EO**	**Total**
Saharan	2	1[2]	0	0	3
Songhay	0	0	0	0	0
Surmic, Koman, Nubian, Temein, Daju, Nyimang (E. Sudanic)	12	4	0	0	16
Nilotic (E. Sudanic)	20	4	0	0	24
Central Sudanic	11	9	0	0	20
Other (Fur, Kresh, Kunama, etc.)	1	1	0	0	2
Total	**46**	**19**	**0**	**0**	**65**

[2] Anonby (2007) claims that Beria (Saharan) is 2IU-1EO with mid +ATR allophones based on vowel distribution in Jakobi & Crass (2004). I have therefore included it here as 2IU-1EO. Dazaga (Saharan) (Walters 2016), however, has marginal phonemes with /e o/, so I classify it as 2IU-2EO. Casali (2003) listed Dazaga (or Daza) as 2IU-1EO.

Of the 40 languages without harmony, 39 have a 1IU system, and only one language has a 2IU system without showing harmony. This language is Shilluk (Remijsen, Ayoker & Mills 2011), wherein ATR contrasts do not cause affix alternations, although they are employed for stem morphophonological alternations. It is also the case that 2IU-1EO inventories (19) (Table 2) are as common as 1IU-2EO inventories (18) (Table 3) in Nilo-Saharan.

Table 3: Inventories of Nilo-Saharan languages without ATR harmony

	2IU-2EO	**2IU-1EO**	**1IU-2EO**	**1IU-1EO**	**Total**
Saharan	0	0	0	1	1
Songhay	0	0	0	1	1
Surmic, Koman, Nubian, Temein, Daju, Nyimang (E. Sudanic)	0	0	7	11	18
Nilotic (E. Sudanic)	1	0	2	0	3
Central Sudanic	0	0	7	5	12
Other (Fur, Kresh, Kunama, etc.)	0	0	2	3	5
Total	1	0	18	21	40

The patterns exhibited in Nilo-Saharan are striking confirmation for the hypothesis that 2IU languages show ATR harmony, while 1IU languages do not. They also provide a partial answer to the suggestion that Casali (2003) made about Nilo-Saharan languages - that 2IU-1EO may prove more common than 1EO-2EO in East Africa. In fact, the number of languages with each of these inventories is even.

3.2 *Niger-Congo* There were 419 Niger-Congo languages examined in the database. These are also broken down by family groupings in the tables. Although there are hundreds of Bantu languages in Niger-Congo, we focused on those Bantu languages located within the Macro-Sudan belt for which there was reliable information, and did not consider those spoken in Southern Africa. Future research will need to include more Bantu languages.

Table 4: Presence and absence of ATR harmony in Niger-Congo languages

	ATR harmony	**no ATR harmony**	**Total**
Atlantic	13	15	28
Mande	8	12	20
Gur	34	14	48
Kru	16	1	17
Kwa	37	11	48
Benue-Congo	44	60	104
Ijoid	8	2	10
Dogon	4	0	4
Gbaya	10	2	12
Bantoid	3	26	29
Kordofanian	9	4	13
Ubangi	10	15	25
Adamawa	5	17	22
Northern Bantu (Zones A C D J)	36	3	39
Total	**237**	**182**	**419**

Those languages with ATR harmony are provided in Table 5. There are 155 languages with 2IU systems and ATR harmony, or 65% of the ATR harmony languages. Nevertheless, 35% are 1IU-2EO systems, a falsification of the prediction that 1IU systems do not correlate with ATR harmony.

Table 5: Inventories of Niger-Congo languages with ATR harmony

	2IU-2EO	2IU-1EO	1IU-2EO	1IU-1EO	Total
Atlantic	9	2	2	0	13
Mande	3	0	5	0	8
Gur	29	1	4	0	34
Kru	11	0	5	0	16
Kwa	27	0	10	0	37
Benue-Congo	27	1	16	0	44
Ijoid	8	0	0	0	8
Dogon	1	0	3	0	4
Gbaya	0	0	10	0	10
Bantoid	1	0	2	0	3
Kordofanian	3	6	0	0	9
Ubangi	2	2	6	0	10
Adamawa	4	0	1	0	5
Northern Bantu (Zones A C D J)	14	4	18	0	36
Total	**139**	**16**	**82**	**0**	**237**

Unlike Nilo-Saharan languages, there are very few languages with 2IU-1EO systems among Niger-Congo. Most of these are spoken in areas of contact with Nilo-Saharan languages, namely in the Nuba Mountains (Kordofanian), and the eastern Democratic Republic of the Congo or South Sudan area for Ubangi and Bantu (J, D) languages.

There are 182 Niger-Congo languages without ATR harmony in the database, and the overwhelming majority (97%) are 1IU languages (1IU-2EO or 1IU-1EO). Of these, most (69%) are 1IU-2EO languages. Therefore, even if 1IU-2EO as a vowel inventory does correlate with ATR harmony in 82 languages, 125 or 60% of 1IU-2EO systems show no harmony.

Table 6: Inventories of Niger-Congo languages without ATR harmony

	2IU-2EO	2IU-1EO	1IU-2EO	1IU-1EO	Total
Atlantic	0	0	7	8	15
Mande	1	0	9	2	12
Gur	0	0	12	2	14
Kru	0	0	1	0	1
Kwa	0	0	11	0	11
Benue-Congo	2	0	34	24	60
Ijoid	0	0	2	0	2
Dogon	0	0	0	0	0
Gbaya	0	0	2	0	2
Bantoid	1	0	21	4	26
Kordofanian	0	0	3	1	4
Ubangi	0	1	13	1	15
Adamawa	0	0	9	8	17
Northern Bantu (Zones A C D J)	0	0	1	2	3
Total	**4**	**1**	**125**	**52**	**182**

Furthermore, of the 82 1IU-2EO languages that show vowel harmony, 73 are classified as trace systems, whereas only 7 trace languages are attested for 2IU-2EO systems and none for 2IU-1EO. This indicates that the ATR harmony is more limited in 1IU-2EO systems.

Put together, the following distributions are observed. Harmony is far more likely to occur with a 2IU-1EO system than not, across both language phyla. Harmony is observed less often with a 1IU-2EO system than not, and is unattested in Nilo-Saharan.

Table 7: Inventories of 524 languages with and without ATR harmony

	2IU-2EO	2IU-1EO	1IU-2EO	1IU-1EO	Total
Harmony					
- Nilo-Saharan	46	19	0	0	65
- Niger-Congo	139	16	82	0	237
Total	185	35	82	0	302
No harmony					
- Nilo-Saharan	1	0	18	21	40
- Niger-Congo	4	1	125	52	182
Total	5	1	143	73	222

In conclusion, there are clear correspondences between inventory type and the presence of ATR vowel harmony. 2IU-2EO languages routinely have ATR harmony, where 1IU-1EO do not. A 2IU-1EO inventory with vowel harmony is a Nilo-Saharan pattern, as hinted at in Casali (2003), and confirmed with a larger sample of languages. It is also observed in eastern Niger-Congo languages such as Kordofanian, Ubangi and Bantu. 1IU-2EO does not correlate with harmony in Nilo-Saharan at all. In Niger-Congo, it shows a broader distribution, correlating with no harmony, trace harmony and occasionally strict harmony.

4. Explaining the patterns

High [-ATR] vowels are not rare within ATR harmony languages**.** Moreover, markedness of /ɪ ʊ/ does not explain their ubiquity or their strong correlation with ATR harmony (Casali 1995, 2002). A wider sample of languages also shows that the apparent 'preferred' /i e ɛ a ɔ o u/ inventory is not actually a good predictor of the presence of ATR harmony. Some researchers have argued that vowel harmony aids perception (Suomi, 1983, Kaun 1994, 1995, Gallagher 2010, Kimper 2011) by extending a featural contrast over a domain. Kaun (1994, 1995) argued that vowels that are 'weak' bearers of lip rounding are more prone to trigger round vowel harmony. Vowels in perceptually weak positions have also been noted to trigger harmony (Walker 2011). McCollum (2015, 2016) maintains that the smaller the perceptual distance between harmonic pairs (for rounding), the more likely these vowels are to trigger harmony. With respect to ATR, Casali (2003:342) raises the role of perception, and observes that [ɪ ʊ] are perceptually confusable with [i u] and [e o] based on descriptions by fieldworkers. This may make 2IU systems more prone to ATR harmony due to the presence of [ɪ ʊ]. In this section, I discuss acoustic and perceptual evidence, and argue that it is the high vowels that drive ATR harmony. Their propensity to trigger harmony also fits with the behavior of 2IU-1EO systems in generating allophones, compared to 1IU-2EO systems, which do not.

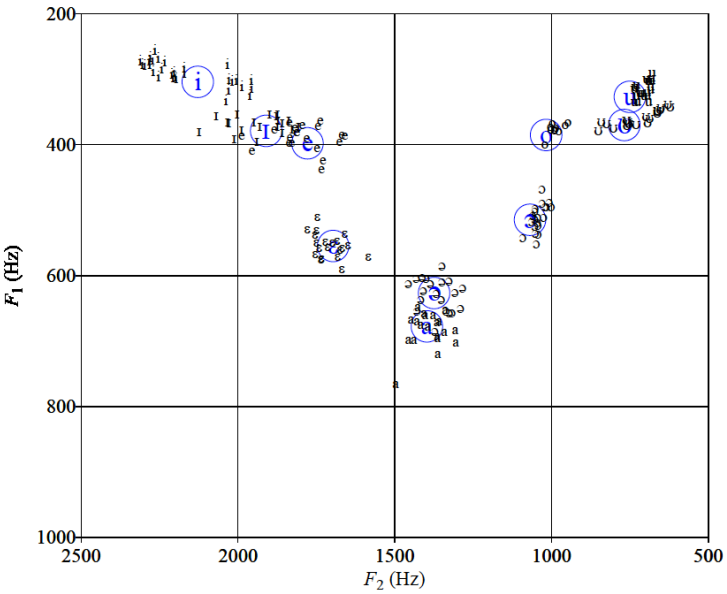
4.1 *Acoustics, perception and harmony* The most reliable acoustic cue for ATR distinctions is F1. In a study of eleven African languages, Starwalt (2008) examined a wide range of acoustic properties of ATR. Only F1 was consistent across speakers and languages. Other acoustic measures such as F2, F1 bandwidth, spectral tilt and center of gravity could also distinguish vowels depending on the language and vowel pairings. In the following chart drawn from Starwalt (2008), there are two languages with contrasts for both sets of vowels, Foodo and Ikposo, and two languages with contrasts for high vowels, Kinande and Lubwisi, but allophonic mid vowels, which could also be measured and compared. The F1 differences for high vowels are much smaller than those for mid vowels across all four languages.

Table 8: Starwalt (2008:426) - average F1 differences in Hz between vowel pairs

Inventory type	Language	i-ɪ	u-ʊ	e-ɛ	o-ɔ
21U-2EO	Foodo (Kwa)	149	133	178	174
	Ikposo (Kwa)	65	103	163	231
2IU-1EO [e o allophonic]	Kinande (Bantu J)	104	71	219	151
	Lubwisi (Bantu J)	134	111	210	168

The vowel space for one speaker of Kinande is illustrated below. The mid vowels are well separated from each other in terms of F1, but the mid [+ATR] vowels closely approximate the high [-ATR], which in turn show small F1 differences, and little F2 differences for the back vowel contrast.

Figure 1: Vowel space for 10 Kinande vowels - male speaker (Starwalt 2008)



Becker-Kristal (2010) also reports on the vowel systems of a wide range of languages. He notes the formant values for various different ATR-harmony languages. The following chart shows normalized F1 differences for five languages with 2IU-2EO systems, two Niger-Congo and three Nilo-Saharan. Data are from Fulop et al (1988) for Degema, Cahill (2007) for Konni, Guion et al (2004) for Maa, Demolin (1989) for Mangbetu and Yigezu (2002) for Baale.

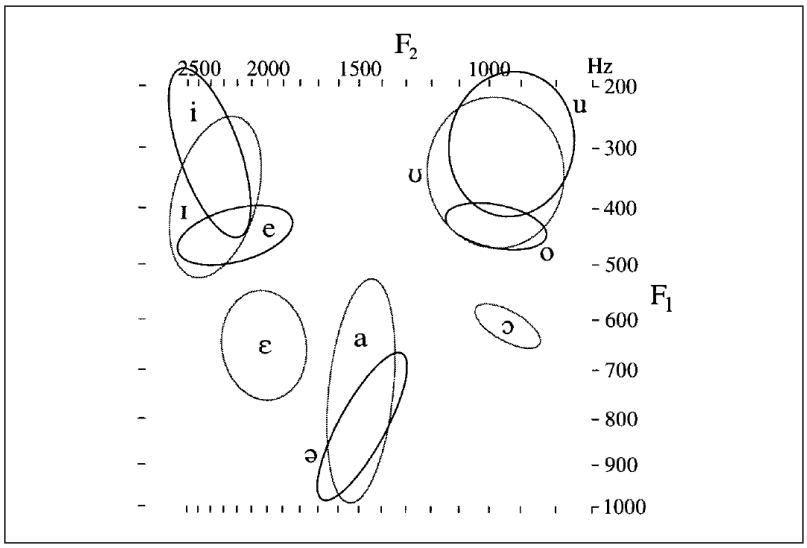
Table 9: Becker-Kristal (2010:426) - average normalized F1 differences in Hz between vowel pairs

		i-ɪ	u-ʊ	e-ɛ	o-ɔ
21U-2EO	Degema (Edoid)	49	107	131	148
Niger-Congo	Konni (Gur)	50	30	180	140
2IU-2EO	Maa (Nilotic)	86	85	121	100
Nilo-Saharan	Mangbetu	40	64	83	151
	Baale (Surmic)	40	34	119	95

As with Starwalt's study, the F1 differences are smaller between high vowels than between mid vowels. However, these acoustic differences may not translate to perceptual difficulty.

There is a paucity of perceptual work on ATR contrasts in African languages. Fulop et al (1998) report a perception study on Degema (Edoid, Nigeria) which has a 10 vowel ATR system. Listeners performed a vowel identification task on synthesized vowels. Results show they could only reliably use F1 to distinguish mid vowel pairs (e - ɛ and o - ɔ), but not high vowel pairs. Figure 2 shows the F1/F2 position of vowels identified by five Degema listeners. There is considerable overlap between the two high vowels as well as the mid [+ATR] vowels.

Figure 2: Formant space of Degema vowels synthesized by five listeners (Fulop et al 1988:96)



The Degema study is suggestive, but uses synthesized tokens and eliminates other cues such as voice quality, which speakers may be relying on to determine ATR vowel differences. Kingston et al (1997) covary both F1 and voice quality in a perception experiment (of English). Their results suggest that F1 differences may be smaller if voice quality distinctions boost perception. In other words, high vowel distinctions may be conveyed through cues other than or in addition to F1, and speakers may rely on these cues as much as F1. This has not yet been tested with speakers of African ATR languages. Keeping these caveats in mind, based on the F1 differences and the phonological behavior of ATR systems, I propose the following principle:

(5) **Activation Principle:** If +high vowels contrast for ATR, [+ATR] is strongly activated and triggers harmony

It is the [+ATR] vowel of the vowel pair, /i u/, that appears to be responsible for harmony activation in both 2IU-2EO and 2IU-1EO systems. 2IU systems show a strong propensity for [+ATR] dominance (Casali 2008, 2016).[3] This activation and the perceptual difficulty that high vowels pose leads to different behavior in 2IU-1EO and 1IU-2EO systems with respect to allophones.

4.2 *Missing vowels and harmony patterns* If vowels are missing in a system, which vowels are they and what are the properties of the harmony? In the 2IU-1EO systems in the database, it is the [e o] vowels that are missing. Furthermore, these vowels are consistently created as allophones via ATR harmony. Consider the following table that shows how 26 of these languages have [e o] as allophones of /ɛ ɔ/, while in three others /ɛ ɔ/ alternate with higher +ATR vowels, causing neutralization. There are three languages in which /ɛ ɔ/ are reported not to alternate. In Gwama and Opo (Otero, personal communication), +ATR harmony occurs only between high vowels. In Che (Wilson 2002) the mid vowels /ɛ ɔ/ do not occur in suffixes. There are three other languages for which no information on allophones is available.

[3] There are some +ATR dominant languages that also exhibit [-ATR] harmony. Komo [xom], a Koman language spoken in Ethiopia has a 2IU-1EO system wherein +ATR harmony produces +ATR allophones of /ɛ a ɔ/ in the regressive direction (Otero 2015). Yet, it has progressive [-ATR] harmony between high vowels - the lower vowels never trigger -ATR harmony. This suggests that [-ATR] can be activated through contrast, but is constrained to operate within the same height category.

Table 10: Allophones of [-ATR] vowels in 2IU-1EO systems

	[e o]	**[i u]**	**[i ɐ]**	**none**
Nilo-Saharan	15	1 (Fur)	0	2 (Gwama, Opo)
Niger-Congo	11	1 (Laru)	1 (Palor)	1 (Che)
Total	**26**	**2**	**1**	**3**

This propensity to produce +ATR allophones of the mid vowels is characteristic of systems that exhibit +ATR dominance, as identified by Casali (2003, 2008, 2016). Other properties that he identified include suffixes that trigger +ATR harmony, no co-occurrence of [+ATR] [i u] and [–ATR] [ɛ ɔ], vowel coalescence resulting in [+ATR] vowels, and neutralization to [-ATR] vowels. In contrast to 2IU-1EO languages, -ATR dominance is observed more often in 1IU-2EO systems. One interpretation of this pattern is that allophones forming strong perceptual pairs ([e] vs. [ɛ] and [o] vs. [ɔ]) are favored or not blocked as outputs of harmony. As discussed above, the mid [+ATR] and [-ATR] vowels are acoustically separated with large F1 differences even in 2IU-1EO languages (Starwalt 2008).

In contrast to the behavior of 2IU-1EO systems, 1IU-2EO languages do not consistently correlate with strict harmony. It appears that mid vowels only weakly activate [ATR]. This weak activation could result in harmony, or it could result in inertia or no harmony. There is no strong perceptual reason for mid vowels to trigger harmony. Unlike 2IU-1EO languages, the missing [ɪ ʊ] vowels are not commonly created via harmony. Of the 82 1IU-2EO languages with vowel harmony in the database (strict or trace), only three are reported to have [ɪ ʊ] as allophones: Avikam (Dumestre 1971, Herault 1983) Okpamheri (Elugbe 1989) and the Ijesa, Ikiti, Ifaki and Akure dialects of Yoruba (Oyelaran 1973, Przezdziecki 2005). We interpret this pattern to indicate that allophones that form weak perceptual pairs (high [-ATR] and [+ATR]) are disfavored as outputs. In other words, if high vowels contrast, harmony will extend and strengthen the perceptual contrast. But if they do not contrast, harmony will tend not to produce additional vowels that would create difficult perceptual pairings.

In strict harmony languages, if [-ATR] is activated, harmony can create allophones of the [+ATR] vowels. However, activation of [+ATR] with [e o] allophones of /ɛ ɔ/ triggered by high vowels as well as mid vowels, has not been observed. For trace languages, /i u/ behave as neutral vowels and cooccur with [-ATR] /ɛ ɔ a/. Both -ATR and +ATR harmony is reported, but only among mid vowels.

Table 11: Patterns of harmony in 1IU-2EO systems

	Triggers	**Targets**	**Language**	**Dominant harmonic feature**
Strict	ɛ ɔ a	i u e o → [ɪ ʊ ɛ ɔ]	Ekiti Yoruba	[-ATR]
	i u e o	ɛ ɔ → [e o]	??	[+ATR]
Trace	ɛ ɔ	e o → [ɛ ɔ]	Komo [kmw]	[-ATR]
	e o	ɛ ɔ → [e o]	Tommo So	[+ATR]

In Komo [kmw] (Thomas 2011), [-ATR] is activated on mid vowels and [-ATR] spreads to [+ATR] mid vowels; /i u/ can be considered neutral targets of [-ATR] harmony due to avoidance of creating [ɪ ʊ]. In Tommo So (McPherson 2013), on the other hand [+ATR] is activated on mid vowels only. The high vowels, /i u/, even though they are [+ATR] vowels, can be considered neutral triggers and do not participate in harmony.

In summary, the 1IU-2EO systems exhibit three patterns: 1) no harmony in which ATR is not activated 2) trace harmony in which either value is activated and harmony operates between mid vowels; high vowels are not participants either as triggers or targets and 3) strict harmony in which [-ATR] is activated and all vowels participate.

5. Conclusion

This paper has presented a large-scale typological study of the vowel systems of 524 African languages in order to assess how the presence of ATR vowel harmony correlates with a language's vowel inventory, and what kind of harmonic systems occur in different language phyla and in different geographical areas within the Macro-Sudan belt. Languages with contrasts among high vowels and mid vowels shows a strong propensity to have ATR vowel harmony: 97%. The same rate of harmony is attested in 21U-1EO languages: 97%. Furthermore, in most of the 2IU-1EO languages, mid vowels participate in harmony and have +ATR counterparts generated through harmony. However, if a language has a contrast among mid vowels but not high vowels, the 1IU-2EO pattern, the same rates are not observed. Only 36% of these languages show vowel harmony. In addition, there are restrictions on vowel participation, such that in only 4% of the harmonic languages do the high vowels participate in harmony and have -ATR counterparts generated through harmony. The other languages show harmony only between mid vowels, or have static cooccurrence restrictions. I have suggested that these patterns are rooted in perception. High vowel pairs are difficult to distinguish in terms of the main acoustic correlate of ATR, F1, and this favors harmony, whereas mid vowels show greater F1 differences. In terms of genetic and areal patterns, Nilo-Saharan languages show a very strong division: 2IU-1EO languages have ATR harmony and 1IU-2EO languages do not. In addition, languages spoken in the same general area as Nilo-Saharan also show similar tendencies. These include Kordofanian languages of the Nuba Mountains, Ubangi languages of Sudan and Bantu languages spoken in the eastern Democratic Republic of the Congo. It is not clear why there are these differences in ATR systems in different phyla and geographic areas. Future research could address if the two areal patterns of ATR harmony also show acoustic and articulatory differences.

References

Allen, Blake, Pulleyblank, Douglas, & Ajíbóyè, Ọládiípọ̀. (2013). Articulatory mapping of Yoruba vowels: An ultrasound study. *Phonology* 30, 183-210.

Archangeli, Diane & Douglas Pulleyblank. 1994. *Grounded Phonology*. Cambridge, MA: MIT Press.

Andersen, Torben. 1999. Vowel quality alternation in Mabaan and its Western Nilotic history. *Journal of African Languages and Linguistcs* 20:97-120.

Anonby, Erik. 2007. Review of Grammaire du beria, by Angelika Jakobi and Joachim Crass. *Journal of African languages and linguistics* 28:2, 217-20

Bakovic, Eric. 2000. *Harmony, dominance and control*. PhD dissertation. New Brunswick, NJ: Rutgers University.

Bamgbose, Ayo 1967. Vowel Harmony in Yorùbá. *Journal of African Languages* 6, 1-8.

Becker-Kristal, Roy. 2010. *Acoustic Typology of Vowel Inventories and Dispersion Theory: Insights from a Large Cross-Linguistic Corpus. PhD Dissertation*, UCLA.

Cahill, Michael. 2007. *Aspects of the Morphology and Phonology of Konni*. Dallas: SIL International.

Casali, Roderic. 1995. On the reduction of vowel systems in Volta-Congo. *African Languages and Cultures* 8.109–21.

Casali, Roderic 2002. Nawuri ATR harmony in typological perspective. *Journal of West African Languages* 29(1).3–43.

Casali, Roderic 2003. [ATR] value asymmetries and underlying vowel inventory structure in Niger-Congo and Nilo-Saharan. *Linguistic Typology* 7.307–82.

Casali, Roderic. 2008. ATR harmony in African languages. *Language and Linguistics Compass* 2/3: 496–549.

Casali, Roderic. 2016. Some inventory-related asymmetries in the patterning of tongue root harmony systems. *Studies in African Linguistics* 45:95-140.

Clements, G. Nick & Annie Rialland. 2008. Africa as a Phonological Area. In Bernd Heine & Derek Nurse (eds.) *A linguistic geography of Africa*. Cambridge: Cambridge University Press.

Demolin, Didier. 1989. Production et perception des voyelles en Mangbetu. *Pholia* 4:45-71.

Dumestre, Gérard. 1971. *Atlas linguistique de Côte-d'Ivoire: les langues de la région lagunaire*. Abidjan: Institut de Linguistique Appliquée (ILA). 323pp.

Elugbe, Ben. 1989. *Comparative Edoid: Phonology and Lexicon*. Delta Series No. 6. Port Harcourt: University of Port Harcourt Press.

Fulop, Sean, Ethelbert Kari & Peter Ladefoged. 1998. An acoustic study of tongue root contrast in Degema vowels. *Phonetica* 55:80-98.1988.

Gallagher, Gillian. 2010. *The perceptual basis of long-distance laryngeal restrictions*. MIT Dissertation

Guion, Susan, Mark Post, & Doris Payne. 2004. Phonetic correlates of tongue root vowel contrasts in Maa. *Journal of Phonetics* 32:517-542

Güldemann, Tom. 2010. Sprachraum and geography: linguistic macro-areas in Africa. In Lameli, Alfred, Roland Kehrein and Stefan Rabanus (eds.), *Language and Space: an International Handbook of Linguistic Variation*, volume 2: language mapping. Handbooks of Linguistics and Communication Science 30,2. Berlin: Mouton de Gruyter, 561-585, Maps 2901-2914.

Hansson, Gunnar Ólafur. 2010. *Consonant Harmony: Long-Distance Interaction in Phonology*. (University of California Publications in Linguistics, 145.) Berkeley, CA: University of California Press.

Hérault, Georges. 1983. L'Avikam. In Hérault, Georges (ed.), *Atlas des langues kwa de Cote d'Ivoire*, 254-276. Abidjan & Paris: Institut de Linguistique Appliquée (ILA); Agence de Coopération Culturelle et Technique (ACCT).

Hudu, Fusheini. 2014. [ATR] feature involves a distinct tongue root articulation: Evidence from ultrasound imaging. *Lingua*. 143 (2): 36–51.

Hyman, Larry M. 1999. The historical interpretation of vowel harmony in Bantu, in Jean-Marie Hombert & Larry M.Hyman (eds), *Bantu historical linguistics*. Stanford: CSLI Publications. 235-295.

Jakobi, Angelika Joachim Crass. 2004 *Grammaire du beria (langue saharienne)*. Cologne: Rüdiger Köppe.

Jacobson, Leon. 1980. Voice-quality harmony in Western Nilotic languages. In Robert Vago (ed.), *Issues in Vowel Harmony* 6. Amsterdam: John Benjamins, pp.183– 200.

Kaun, Abigail. 2004. The typology of rounding harmony. In *Phonetically based phonology*, eds. Bruce Hayes, Robert Kirchner, and Donca Steriade, 87-116. Cambridge University Press.

Kaun, Abigail. 1995. *The typology of rounding harmony: An Optimality Theoretic approach*. PhD Dissertation, UCLA.

Keegan, John. 2012. *The Western Sara Languages*. The Sara Language Project. CreateSpace Independent Publishing Platform.

Kilpatrick, Eileen. 1985. Bongo phonology. *Occasional Papers in the Study of Sudanese Languages* 4, 1-62.

Kimper, Wendell. 2011. 2011. *Competing Triggers: Transparency and opacity in vowel harmony*. PhD Dissertation, University of Massachusetts Amherst.

Mahanta, Shakuntala. 2008. *Directionality and Locality in Vowel Harmony*. Utrecht: LOT Publications.

McCollum, Adam. 2015. Labial harmonic shift in Kazakh: Mapping the pathways and motivations for change. In *Proceedings of The 41st Annual Meeting of the Berkeley Linguistics Society*, 329-352.

McCollum, Adam. 2016. Vowel dispersion and Kazakh labial harmony. *San Diego Linguistic Papers* 6, 29-65.

McPherson, Laura. 2013. *A Grammar of Tommo So*. Mouton de Gruyter.

Obikudo, Ebikare. 2008. On the reduction of vowel harmony in Nkoroo. Paper presented at the 22nd CLAN, University of Maiduguri.

Oyelaran, Olasope O. 1973. Yoruba vowel co-occurrence restrictions. *Studies in African Linguistics* 4:155-182

Przezdziecki, Marek A. 2005. *Vowel harmony and coarticulation in three dialects of Yoruba:Phonetics determining Phonology*. Ph.D. dissertation, Cornell University, Ithaca, N.Y.

Remijsen, Bert, Otto G. Ayoker & Timothy Mills. 2011. Shilluk. *Journal of the International Phonetic Association* 41, 131-145.

Rolle, Nicholas, Matthew Faytak & Florian Lionnet. 2016. The distribution of ATR and interior vowels in the Macro-Sudan Belt. *47th Annual Conference on African* Linguistics. UC Berkeley: Berkeley, CA.

Rolle, Nicholas, Matthew Faytak & Florian Lionnet. 2017. The distribution of advanced tongue root harmony and interior vowels in the Macro-Sudan Belt. *Proceedings of the Linguistics Society of America* 2, 10: 1-15.

Rose, Sharon & Rachel Walker. 2004. A typology of consonant agreement as correspondence. *Language* 80, 475-531.

Starwalt, Coleen 2008. *The Acoustic correlates of ATR harmony in seven- and nine-vowel African languages: a phonetic inquiry into phonological structure*. PhD Dissertation, University of Texas, Arlington.

Stewart, John M. 1967. Tongue Root Position in Akan Vowel Harmony *Phonetica* 16: 185-204.

Suomi, Kari. 1983. Palatal vowel harmony: a perceptually motivated phenomenon? *Nordic Journal of Linguistics* 6, 1-35.

Tiede, Mark K. 1996. An MRI-based study of pharyngeal volume contrasts in Akan and English. *Journal of Phonetics* 24: 399–421.

Thomas, John Paul. 2011. A morphophonology of Komo: Non-tonal phenomena. *SIL Electronic Working Papers* 2011-006.

Vanderelst, John. 2016. *A Grammar of Dagik – A Kordofanian Language of Sudan*. Köln: Rüdiger Köppe Verlag.

Walker, Rachel. 2000. *Nasalization, Neutral Segments and Opacity Effects*. New York: Garland.

Walker, Rachel. 2011. *Vowel Patterns*. Cambridge University Press.

Walters, Josiah. 2016. *A Grammar of Dazaga*. Leiden: Brill.

Williamson, Kay 1983-4. Vowel merger in harmony languages. *Journal of the Linguistic Association of Nigeria* 2: 61-82.

Williamson, Kay. 2004. Typical vowel systems and processes in West African Niger-Congo languages. *Journal of West African Languages*, 30(2).

Wilson, Janet. 2002. From preposition to plural marker and more: grammaticalization of Kuche banà. *Studies in African linguistics* 31. 155-175.

Yigezu, Moges. 2002. *A comparative study of the phonetics and phonology of Surmic languages*. PhD dissertation, Universite Libre de Bruxelles.