Some observations on the phonetics of [ATR] contrasts

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1. Overview

Aim of the lecture: To summarize some of what is known about the articulatory, acoustic and auditory / perceptual properties of [ATR] and identify some of the controversies and unsolved problems that exist.

Claim: The state of our knowledge of the phonetic properties of [ATR] presents something of a "good news - bad news" scenario.

On the one hand:

- The phonetic basis of [ATR] contrasts in a few languages (e.g., Akan) has been extensively studied and much has been learned.
- It is likely that the same phonetic properties occur in many other languages with similar ATR harmony systems.
- The number of ATR harmony languages for which some instrumental work has been done is growing.
- The number of ATR harmony languages for which thorough *non-instrumental* descriptive studies exist is also growing.

On the other hand:

- For the vast majority of ATR harmony languages, no instrumental studies exist.
- Most ATR harmony languages lack adequate phonological and impressionistic phonetic studies.
- Certain very basic typological questions about how [ATR]-like vowel contrasts are implemented in different languages remain unanswered (and in some cases have not been seriously addressed).
- For various reasons, direct instrumental observation of the articulatory gestures underlying [ATR] contrasts cannot easily be undertaken in many research contexts.
- Acoustic investigation of [ATR] contrasts is hampered by the fact that the acoustic correlates of [ATR] are partly but not fully understood.
- Perceptual studies, which arguably constitute the most promising approach to addressing certain unanswered questions, are at present almost non-existent.

Much more phonetic research into the behavior of [ATR] is needed!

2. Articulatory properties of [ATR]

Impressionistic (Pike 1967, Stewart 1967) and instrumental (Ladefoged 1964, Painter 1973, Lindau 1987, Lindau et. al. 1972) studies beginning in the late 1960's clearly established that the vowels /ieou/ in Akan and some other languages are generally made with the tongue root in a more advanced position, while the vowels /ɪɛaɔʊ/ are made with the tongue root in a more retracted position.

Other studies showed that tongue root position is not the *only* articulatory correlate of the [ATR] vowel contrast in languages such as Akan.

Additional gestures:

- The larynx is lower for [+ATR] vowels (Lindau 1976).
- For [+ATR] vowels, the walls of the pharyngeal cavity are expanded in the transverse as well as the front-back dimension (Tiede 1996).

These two additional gestures lead to a larger pharyngeal cavity (pharynx) with [+ATR] vowels. Advancing the tongue root has the same effect.

This means that expansion (with [+ATR] vowels) or contraction (with [-ATR] vowels) of the pharyngeal cavity is a better measure of the [ATR] contrast than tongue root position alone, at least in languages like Akan (Lindau 1979).

Other phonetic (articulatory) realizations of [ATR]

The way in which [ATR] contrasts are articulated varies considerably from language to language (Jacobson 1980, Lindau et. al. 1972, Lindau & Ladefoged (1986)).

- In Dho-Luo (some speakers), [ATR] involves mainly tongue root advancement / retraction.
- In Ateso, [ATR] involves mainly tongue body raising rather than tongue root position.
- In Igbo, both tongue root advancement and tongue body raising are involved in production of [ATR] contrasts.

(It is not known whether larynx raising is also involved in Igbo and Dho-Luo.)

Each of these languages is a nine-vowel language with productive ATR harmony of the sort found in many other African languages. (Thus there is phonological evidence that a feature [ATR] is involved.)

It has also been suggested that [ATR] distinctions in some languages are realized at least in part by differences in the mode of vibration of the vocal folds. ([+ATR] vowels involve a breathier phonation, [-ATR] vowels a creakier phonation.)

Inter-speaker variation

Different speakers of the same language sometimes differ in the gestures they employ to implement an [ATR] contrast.

[ATR] contrasts in Dho-Luo may be implemented using either tongue height adjustment or tongue root movement, with or without vertical larynx displacement, depending on the speaker (Lindau & Ladefoged 1986:470)/

Conclusion: It is probably not possible to give a single invariant articulatory definition of [ATR] that applies to all ATR harmony languages.

It is important to realize however that there are very few ATR harmony languages whose articulatory mechanisms have so far been subjected to direct instrumental investigation.

Some reasons:

- The main technology used early on--x-ray cinematography--can no longer be used, for health reasons.
- Alternatives such as MRI cannot be used except in medical facilities.

- A relatively new technology, portable ultrasound devices (Glick et. al. 2006), overcomes these limitations but remains very expensive.

Does this mean that it is not possible to make any meaningful inferences about the articulatory gestures involved in [ATR] contrasts in other Ghanaian languages?

3. Acoustic phonetics of [ATR]

Acoustic investigation of [ATR] offers some key advantages over other approaches.

At the same time, acoustic investigations of [ATR] also face some serious challenges.

The "good news":

- It is comparatively inexpensive.
- With training, it is not overly difficult to carry out.

There are however important considerations (e.g., the quality of recordings used) that need to be carefully attended to.

- Results yield *quantitative measures*.
- The primary acoustic correlate of [ATR] distinctions is easily measured in principle and is the same in all known ATR harmony languages: first formant frequency (F_1).

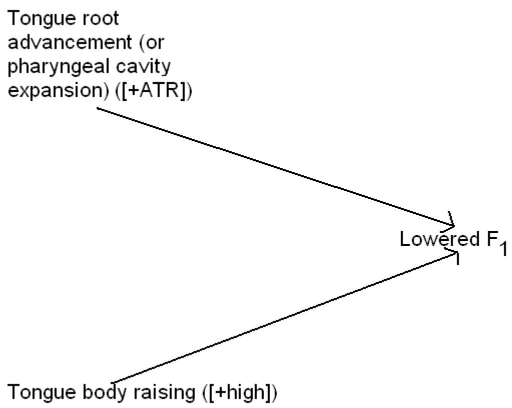
Consistently, a [+ATR] vowel will have a lower F_1 than its [-ATR] counterpart.

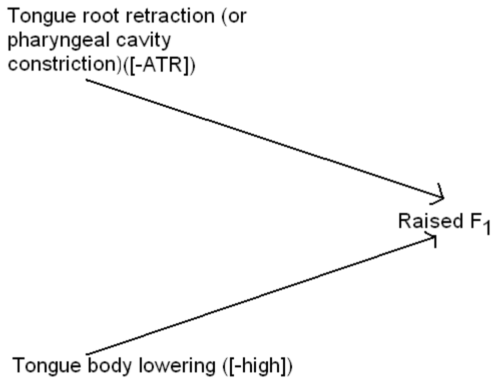
- [i] has a lower F1 than [ɪ].
- [e] has a lower F1 than [ɛ].

etc.

The "bad news":

- The primary acoustic correlate of [ATR] is also the primary acoustic correlate of tongue body raising (i.e., of [+high]).





This poses potentially serious challenges for acoustic investigation of languages that are known or suspected to have [ATR] contrasts.

A general problem:

Suppose that a language has two phonetically similar vowels (either both front or both back) and that one vowel (vowel 1) consistently has a lower F_1 than the other vowel (vowel 2).

Either (or both) of the following possibilities can be concluded from this finding:

- The difference is one of tongue height: vowel 1 is [+high], vowel 2 is [-high].
- The difference is one of ATR (tongue root advancement and/or pharyngeal cavity expansion): vowel 1 is [+ATR], vowel 2 is [-ATR].

In the absence of evidence from other sources, it is not possible to tell which of these hypotheses is correct.

A specific example

Consider a language with a seven-vowel system, e.g., Ewe (some dialects).

It has generally been assumed that the seven vowels in Ghanaian languages such as Ewe are as shown below.

(1) Seven-vowel system assumed in Ghanaian languages

	Front	Central	Back
High +ATR	i		u
Mid +ATR	e		o
Mid -ATR	ɛ		ɔ
Low -ATR		a	

Suppose however that someone were to claim that this analysis is wrong and that the height 2 vowels are actually high [-ATR] vowels [ɪ], [ʊ]:

(2) Alternative seven-vowel analysis

	Front	Central	Back
High +ATR	i		u
Mid +ATR	ɪ		ʊ
Mid -ATR	ɛ		ɔ
Low -ATR		a	

Discussion:

Can acoustic measurements of F_1 determine which analysis is correct?

What other evidence might establish which analysis is correct for a language like Ewe?

A further example (nine-vowel languages)

The fact that a change in F1 can be produced either by a change in tongue height or a change in tongue root position also poses difficulties for acoustic investigation of nine-vowel languages.

The problem:

High [-ATR] and mid [+ATR] vowels may not be distinguishable in terms of their F_1 (or F_2) values.

Why is this?

Suppose that for a speaker of a nine-vowel language, the vowel /ɛ/ has a particular F_1 value, say 550 Hz.

What F1 values might we expect for /ɪ/ and /e/, given the plausible assumptions below?

- Assumption 1: Both /ɪ/ and /ɛ/ are articulated with retracted tongue root and constricted pharynx, while /e/ is articulated with advance tongue root and expanded pharynx.
- Assumption 2: Both /e/ and /ɛ/ have similar non-high tongue body positions, while /ɪ/ has a higher tongue body position.

Since /ɪ/ is a high vowel, it will have a lower F_1 than /ɛ/.

(3) $F_1(\text{ɪ}) = F_1(\text{ɛ}) - \Delta F_1(\text{height})$

That is, the F_1 value of /ɪ/ should equal the F_1 value of /ɛ/ minus whatever change in F_1 (ΔF_1(height)) is produced by raising the tongue body to the position of a high vowel.

Since /e/ has an advanced tongue root and expanded pharynx, it will also have a lower F_1 than /ɛ/:

(4) $F_1(\text{e}) = F_1(\text{ɛ}) - \Delta F_1(\text{ATR})$

That is, the F_1 value of /e/ should equal the F_1 value of /ɛ/ minus whatever change in F_1 (ΔF_1(ATR)) is produced by advancing the tongue root to the position of a [+ATR] vowel.

How will the measured F_1 for /ɪ/ compare with that of /e/?

This will depend on how the *degree* of F_1 change produced by tongue body raising compares with the *degree* of F_1 change associated with tongue root advancement.

The degree of F_1 change in both cases will in turn depend on the magnitude of the articulatory change.

This can vary both across languages and even for different speakers of the same language!

Possible cases:

- Case 1: $\Delta F_1(\text{height}) > \Delta F_1(\text{ATR})$

In this case the vowel /ɪ/ will have a lower F_1 than /e/ (hence /ɪ/ will be acoustically and auditorily higher).

- Case 2: $\Delta F_1(\text{ATR}) > \Delta F_1(\text{height})$

In this case the vowel /e/ will have a lower F_1 than /ɪ/ (hence /e/ will be acoustically and auditorily higher).

- Case 3: $\Delta F_1(\text{height}) = \Delta F_1(\text{ATR})$

In this case, where the changes in F_1 due to both tongue body raising and tongue root advancement are approximately equal, /ɪ/ and /e/ will tend to have virtually identical F_1 values.

Case 3 seems to occur quite commonly.

(5) Case 3 illustrated with hypothetical but typical values:

- Typical F_1 for /ɛ/ (male speaker) = 550 Hz
- Change in F_1 due to tongue root advancement = 125 Hz
- Change in F_1 due to tongue body raising = 125 Hz
- $F_1(\text{ɪ}) = F_1(\text{ɛ}) - \Delta F_1(\text{ATR}) = 550 - 125 = 425$ Hz.
- $F_1(\text{e}) = F_1(\text{ɛ}) - \Delta F_1(\text{height}) = 550 - 125 = 425$ Hz.

Conclusion: F_1 measurements may not be able to distinguish /ɪ/ from /e/ (or, by similar reasoning, /ʊ/ from /o/) in some languages, even if these vowels are in fact phonetically different.

Does this mean that there are no acoustic measures that can distinguish high [-ATR] and mid [+ATR] vowels in languages like Akan?

4. Auditory / perceptual correlates of [ATR]

Some opinions:

- The high [-ATR] vowels /ɪ/, /ʊ/ and mid [+ATR] vowels /e/, /o/ are typically *not* auditorily identical in languages in which their F_1 values are similar or identical (i.e., case 3 of the preceding section).
- Auditorily, they can be distinguished not based on how high they sound, but by means of some other qualitative difference.

This difference has often been described by the term *voice quality*.

Voice quality

In some ATR harmony languages, [+ATR] and [-ATR] vowels have been described as having different overall qualities.

These have been given a variety of subjective labels.

- Some labels used to describe the quality of [+ATR] vowels: "breathy," "deep," "muffled," "hollow"
- Some labels used to describe the quality of [-ATR] vowels: "bright," "choked," "brassy," "creaky"

These voice quality differences have been reported mainly in Nilo-Saharan languages of East Africa. They have not been widely reported in West African languages.

Some further opinions:

- Voice quality differences do in fact exist in many if not most languages of Ghana.
- It is these differences, and not any differences in auditory height, that allow hearers to distinguish /ɪ/ from /e/ and /ʊ/ from /o/ auditorily even in languages in which the high [-ATR] and mid [+ATR] vowels are not clearly distinguished by F_1.
- These differences are almost certainly produced by expansion of the pharyngeal cavity in the case of [+ATR] vowels and/or constriction of the pharyngeal cavity in the case of the [-ATR] vowels.

In some African language communities, native speakers have devised their own terms to describe the quality difference between [+ATR] and [-ATR] vowels. In some Nilo-Saharan languages, for example, native speakers describe the [+ATR] vowels as "heavy" and the [-ATR] vowels as "light" (Dick Watson, personal communication).

If voice quality differences are real, they should be correlated with some acoustic difference.

Efforts to find such an acoustic correlate (e.g., Hess 1992, Fulop et. al. 1995, Guion et. al. 2004), which might serve as a supplement to F_1 measurements, have proved partly successful. There is more to be learned about the acoustic properties of [ATR]!

Perhaps the most successful measure investigated so far is something called F_1 bandwidth, which works reasonably well in distinguishing Akan /ɪ/ and /e/ (Hess 1992) for at least some speakers..

At present, the most reliable means of establishing whether high [-ATR] and mid [+ATR] vowels are really different auditorily is some form of perceptual test.

Basically this involves recording real or artificial minimal pairs for the two vowels to be compared (e.g., /e/ and /ɪ/) and playing them back for native speakers of the language to see whether they can tell which vowel is which, apart from any cues from context. (It is also of interst to establish whether trained linguists can hear the difference as well.)

References

Fulop, Sean, Ethelbert Kari, and Peter Ladefoged. 1998. An acoustic study of the tongue root contrast in Degema vowels. Phonetica 55:80-98.

Glick, Bryan, Douglas Pulleyblank, Fiona Campbell, and Ngessimo Mutaka. 2006. Low vowels and transparency in Kinande vowel harmony. Phonology 23.1-20.

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

Hess, Susan. 1992. Assimilatory effects in a vowel harmony system: an acoustic analysis of advanced tongue root in Akan. Journal of Phonetics 20:475-492.

Jacobson, Leon C. 1980. Voice-quality harmony in Western Nilotic languages. Issues in Vowel Harmony, ed. by Robert M. Vago, 183-200. Amsterdam: John Benjamins.

Ladefoged, Peter. 1964. A phonetic study of West African languages. (West African language monographs, 1.) Cambridge: Cambridge University Press.

Lindau, Mona. 1976. Larynx height in Kwa. UCLA Working Papers in Phonetics 31:53-61.

Lindau, Mona. 1979. The feature expanded. Journal of Phonetics 7:163-176.

Lindau, Mona. 1987. Tongue mechanisms in Akan and Luo. UCLA Working Papers in Phonetics 68:46-57.

Lindau, M.E., and P. Ladefoged. 1986. Variability of feature specifications. In J.S. Perkell and D.H. Klatt (eds), Invariance and variability in speech processes, 464-479. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Lindau, Mona, Leon Jacobson, and Peter Ladefoged. 1972. The feature Advanced Tongue Root. UCLA Working Papers in Phonetics 22:76-94.

Pike, Kenneth L. 1967. Tongue-root position in practical phonetics. Phonetica 17:129-140.

Painter, Colin. 1973. Cineradiographic data on the feature 'covered' in Twi vowel harmony. Phonetica 28:97-120.

Stewart, John M. 1967. Tongue root position in Akan vowel harmony. Phonetica 16:185-204.

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