An acoustic investigation of the [ATR] feature effect on vowel-to-vowel coarticulation

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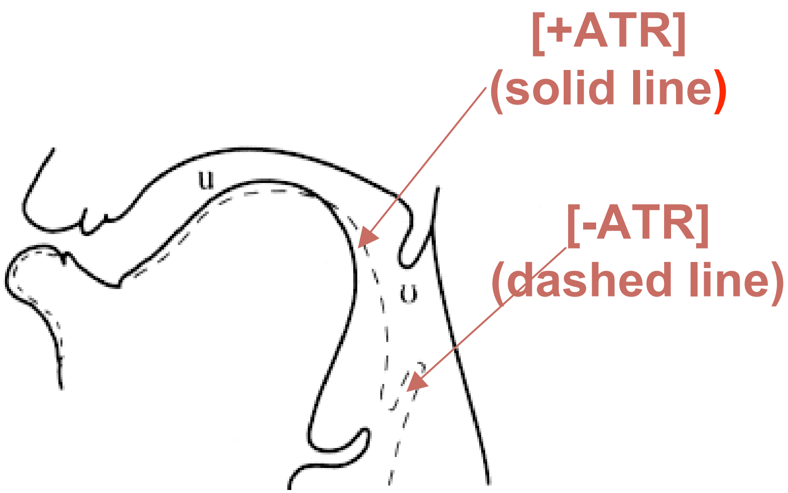
Introduction

- Phonological theory holds that words are constructed of **features**.
- Features presumably have an observable role in speech production and perception.
- We test this connection by searching for consistent **articulatory** and **coarticulatory** effects of those features.

The [ATR] feature

- The Advanced Tongue Root (ATR) feature contrasts tense (+) and lax (-) vowels.
- Its existence as a phonological feature in English has been challenged by Harshman and Goldstein, 1977.
- ***If [ATR] is a valid feature it should have a straightforward association with certain acoustic changes.***



Note that this figure is from Ladefoged's tracings of a cinefluorographic movie of an Igbo speaker so it is only used here as a reference.

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Coarticulation and phonological features

- Henke's theory of "feature spreading": features are either specified or not; their effects spread out across unspecified regions.
- Feature spreading terminates when a feature is specified.
- ***If [ATR] is a feature there should be no phonological effects on the far side of a vowel that specifies it.***

Phonetic coarticulation models typically describe speech in terms of articulatory gestures or targets. Coarticulation is then described in terms of overlap of two gestures as a result of inertial or mechanical limitations ot the articulators or a planning process to reach phonologically specified soft targets.

Aims of this work

- We investigated the local and coarticulatory acoustic correlates of the [ATR] feature.
- We conducted a systematic survey of the strength of [ATR]-driven vowel-to-vowel co-articulation for two cases:

  - Adjacent vowels: V - V
  - Across an intervening vowel: V - V - @
- Any observed effect can be attributed only to the [ATR] difference. *All other phonemes were kept the same*
- *If [ATR] is a feature its coarticulatory effect on neighboring vowels should be consistent.*

If an articulatory target is related to the [ATR] feature the corresponding acoustic properties should display relatively little variability.

Experimental methods

- 27 subjects (15 M and 12 F), native speakers of Southern British English, 19-34 years old, students/staff of OU.
- Subjects read out an average of 456 phrases each, randomly taken from a pool of 408 with 4% of sentences read 4 times.
- This paper analyses the replicated ones.

Speech Material

- Text consisted of (CV)$CV^tCV^rCV^dC$(VC)

  tri- and tetra-syllabic utterances.
- V^r (the *resistor* vowel) was chosen from a set of 11 vowels, V^d (the *detector* vowel) was always a schwa and V^t (the *transmitter* vowel) consisted of 4 [±ATR] pairs /i/ vs /ii/, /u/ vs /uu/, /uh/ vs /aa/ and /o/ vs /oo/.
- Each sentence was paired with another sentence which was identical except from the [±ATR] pair.

Speech Material

- Example phrases:

  “b<u>ea</u>ch hunter” vs “b<u>i</u>tch hunter’’

  “it h<u>u</u>ms operas’’ vs “it h<u>a</u>rms operas”

  “they st<u>o</u>ck lemurs” vs “they st<u>a</u>lk lemurs”

  “p<u>u</u>ll to the thing” vs “p<u>oo</u>l to the thing”

- The combinations of phonemes before and after the transmitter define the different ***contexts*** of the phoneme pairs under investigation.

There were 224 contexts for the /i/ vs /ii/ case, 53 for the /aa/ vs /uh/, 48 for the /o/ vs /oo/ case and 33 for the /u/ vs /uu/ case.

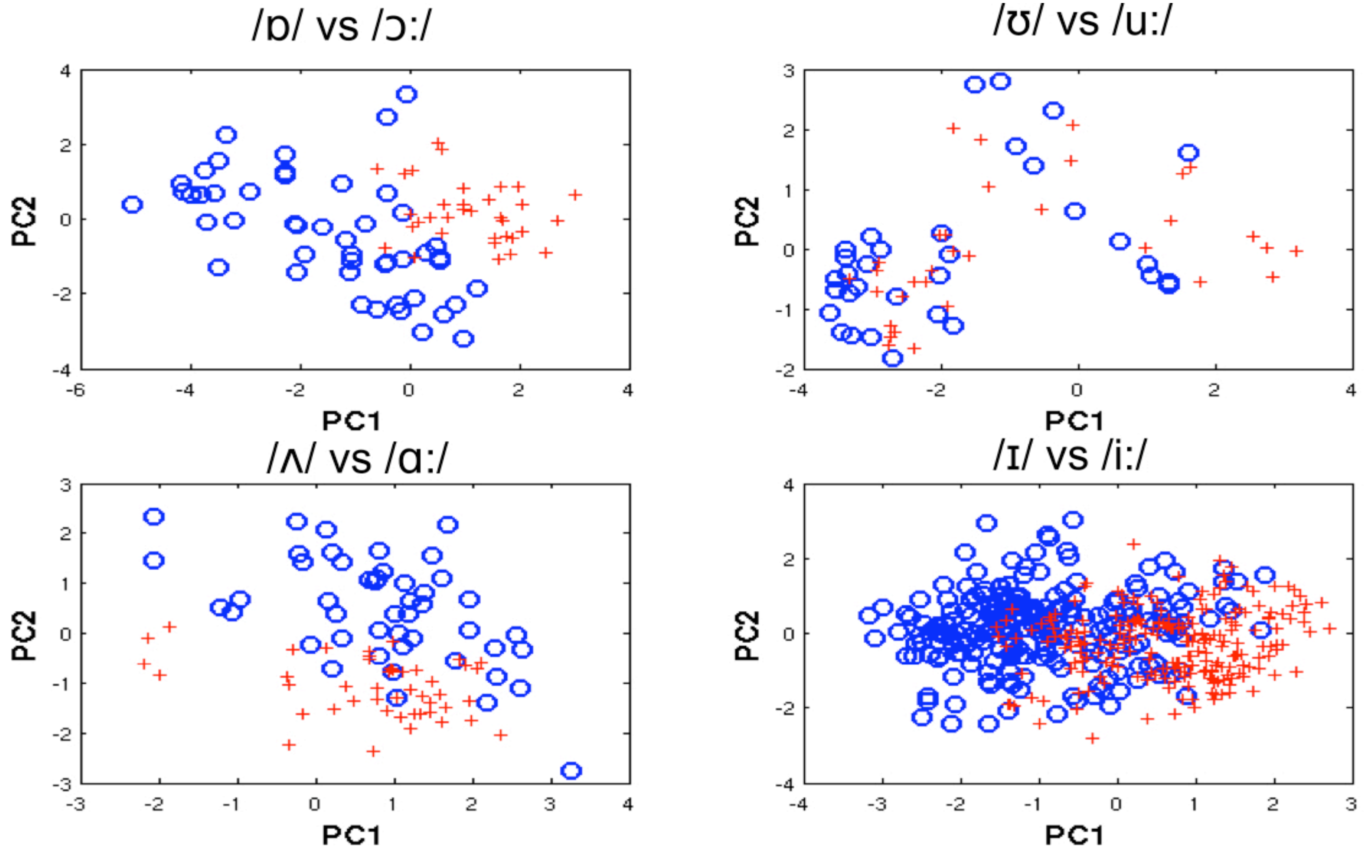
Acoustic Description Vector

- We compute the vector from a *“perceptual spectrum”* which is a power spectrum, collected in 0.7 erb-wide bins, raised to the 1/3 power to approximate the perceived loudness. *We calculate this within 45 ms of the vowel’s midpoint.*
- The vector contains these *specific loudnesses* averaged over a 60ms window, *edge detectors* showing changes in spectral power on a 45ms time scale, a *spectral entropy* measure, a measure of *dissonance* as well as a *voicing* estimator.

Acoustic Description Vector

- The vectors were used to train a classifier which distinguishes between sounds which are phonologically the same vs different (c. 82% correct) *We used a Bayesian classifier trained on pairs of sounds obtained from equivalent (for class 1) and non-equivalent (for class 2) points in the same text.*
- The classifier was then converted into an approximate, acoustically-based measure of phonological distance by mapping the acoustic description vectors into a new coordinate system where the Euclidean distances are a good approximation to phonological distance.
- This way all components are equally important and correlations have been removed.

Acoustic Description Vectors



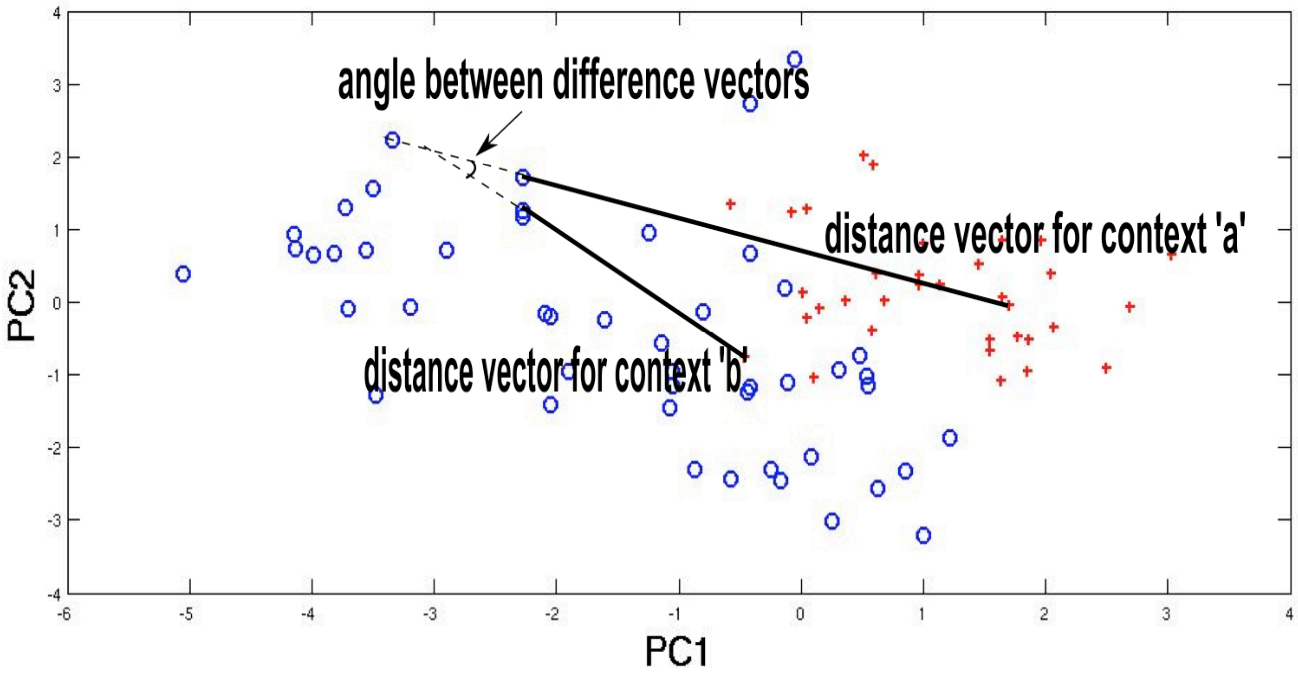
First two principal components of vectors. Each point represents the average of the acoustic description vectors for a single context.

Measuring the effect of [ATR]

- We calculate the effect of [±ATR] by calculating the *difference vectors* between the average acoustic description vectors from identical contexts but with opposite [ATR] values.
- *If an articulatory target exists for [ATR] its effect should be consistent.*

We calculated the difference vectors between the average acoustic description vectors for the transmitter, resistor and detector vowels. The resistor and detector values give a measure of the coarticulatory effect of the [ATR] feature whereas the transmitter angles give an indication of the whether the [ATR] vowel has a consistent articulatory target.

Measuring the effect of [ATR]



The principal components of the acoustic description vectors averaged over the contexts are plotted for the /aa/ vs /uh/ pair. The solid lines show the difference vectors between the [+ATR] and [-ATR] pairs for identical contexts. The angle between the two difference vectors indicates the strength of the (co)-articulatory effect relative to normal utterance-to-utterance variation.

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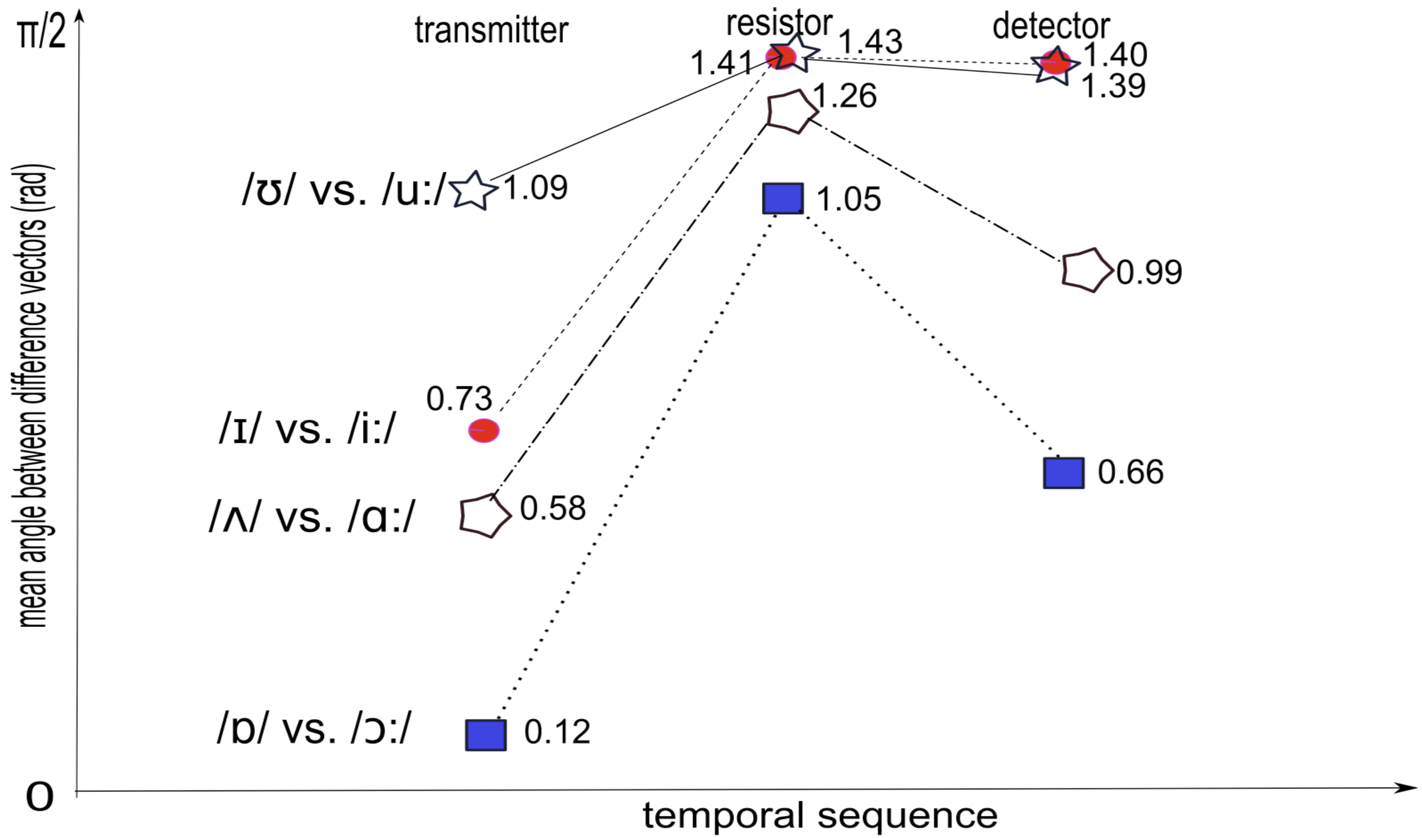
Results:Angles



If the angle is near π/2 radian the co-articulatory effect caused by the [ATR] feature is much smaller than variation; if the angle is small the effect is consistent and much larger than variation.

Conclusion 1

- We investigated the strength of the [ATR] feature on vowel-to-vowel carry-over co-articulation using 27 speakers of Southern British English.
- We found that [ATR] makes strong distinctions in ***low*** vowels (/uh/ vs /aa/ and /o/ vs /oo/) and less reliable ones in ***high*** vowels (/u/ vs /uu/ and /i/ vs /ii/).

Conclusion 2

- Across many different contexts [ATR] will coarticulate *across a vowel* and modify a following schwa.
- Unexpectedly we observed a stronger coarticulatory effect across a resistor vowel onto a schwa than on the resistor vowel itself.