Vowel variability and the characterization of /æ/
Hypotheses

• CL is qualitative in vowels (Wood).
  • CL displays discrete dynamics in speech (“pivoting”, Iskarous)

• CD is quantitative (Iskarous).
  • CD displays continuous dynamics in speech
  • Prediction: more variability along CD than CL
  • Prediction: CD and CL engage different types of sound changes (“regular” vs. “lexical diffusion”)
**XRMB study**

- 57 speakers of AE, students at U. Wisconsin in 1988-1993, most from WI or nearby (IL, MN)
- 118 tasks per speaker including connected speech (read passages or sentences), prosodified number sequences, citation word lists etc.
- Head-movement corrected articulator trajectories from beam-tracked pellets, normalized to occlusal plane reference

- Forced alignment segmentation of the audio (Tiede and Yuan) for passages, sentences, and prosodified number strings (34 tasks)
- 45 speakers
- Temporal midpoints for /i/ /e/ /ɪ/ /ɛ/ /æ/ /u/, vowels for whom CD and CL can be approximated.
- 50-100 vowels per subject
XRMB study

- CD estimated by distance of T3 from closest point on palate trace.
- CL estimated by horizontal distance of T3 from upper teeth.
- Values normalized to the range of exhibited by each speaker for these measures over the entire corpus.
Sample Result

- Range-normalized values for CD and CL for front vowels and /u/.
- For /i/, /ɛ/, /æ/, there is greater variation for CD than for CL.
- For /i/ and /e/, the opposite seems true.
CD vs CL variation

- Vowels with no contact between tongue and palate and/or teeth show greater variability of CD, as predicted.
- Barrier of teeth or palate could limit the CD variability of /i/, /u/, /e/.
- BUT examination of the distribution of CD values for these three vowels, pooled over all speakers, reveals highly skewed distributions.
CD vs CL variation

Histograms of CD values over all subjects

/i/ skew = 1.5250
/e/ skew = 0.7947
/u/ skew = 1.2907
/I/ skew = 0.4005
/ɛ/ skew = -0.1891
/æ/ skew = 0.0629

More Constricted  Less Constricted
Normal and LogNormal Distributions for CD and CL

- For the CD distributions of /i/, /u/, /e/, normal and log-normal models were fit.
- The log-normal models for CD of /i/ and /u/ are much better (had higher log-likelihood scores) than for the normal models.
- The variability parameter value ($\sigma$) of the log-normal models for CD is higher than the $\sigma$ of CL (modeled with either normal or log-normal fits).
- Thus, the effective variation (with reference to a model) is higher for CD than for CL, even for /i/ and /u/, and possibly /e/.
Normal and LogNormal Distributions for CD and CL

CD

\[ \sigma = 0.62 \]
\[ \sigma = 0.092 \]

CL

\[ \sigma = 0.10 \]

\[ /i/ \]
\[ /e/ \]
\[ /u/ \]
Variability and Sound Change

• Results are also consistent with hypothesis that regular sound changes in vowels (e.g. vowel shifts) occur along CD dimension.

• But variability of /ae/ is consistent with it being a palatal vowel. And it shows regular raising patterns in the front.
While Wood (1979) represents /æ/ as a \textit{pharyngeal} vowel, for an unconstricted vowel (e.g. for /æ/ or /ɛ/ or /a/), very similar area functions would be produced by \textit{controlling} the constriction in the pharyngeal or palatal locations.

Example of /æ/ from USC MRI-TIMIT corpus:
How is /æ/ controlled?

- Catford’s 1977 polar representation of vowel constrictions makes this point:

- Qualitative shift from controlling CD for CL=pharyngeal to CL=palatal would not produce much change in average shape for a wide constriction like æ.

- However, pattern of variability would change, and would now pattern with the other front vowels.
Quantitative and Qualitative aspects of /a/-->/æ/

- Fronting and backing of individual vowels:
  - Fronting of /a/ (e.g., Labov, 1994)
  - Variability in the CD of a pharyngeal constriction could produce an unconstricted /æ/ vocal tract shape
Quantitative and Qualitative aspects of /a/ --> /æ/

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![](image)

But reanalysis is qualitative!
Wood (1982) proposed that tense palatal vowels have more displacement of the tongue from the mandible towards the palatal CL than do lax vowels.

This is consistent with Perkell’s (1971) observation of advanced tongue root in tense vowels. The action of the posterior genioglossus muscle pulls the tongue root forward, causing the front of the dorsum to bulge toward the palate.

We expect that if /æ/ is tense and /ɛ/ is lax, then /æ/ is expected to more constricted than /ɛ/ for a given jaw height.
All 45 speakers in the corpus have a more narrow mean CD for /æ/ than for /ɛ/.
But All 45 speakers in the corpus also have a lower jaw height for /æ/ than for /ɛ/ (sample speaker shown here).
A discrete change: Tensing and raising of /æ/

Discrete change in Jaw-Tongue synergy

More Constricted

FRONT

CL

CD

HIGH

JAW HEIGHT

FRONT

CL

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Discreteness and Continuity in Language Design and Sound Change

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Production of /æ/ vs. /ɛ/ requires different coordination regimes for how the tongue and jaw work together.

Thus, change from a lax vowel like /ɛ/ to a tense vowel like /æ/ would require a change in coordination regime.

This is a structural change, or change in type, not a change along a continuous dimension, as Labov (1994) has also argued.

If the lower jaw of /æ/ results in a higher F1, and the narrower constriction results in a higher F2, then this would produce the “peripheral” position of /æ/ (Labov, 1994) in a formant-based height-backness space.
Palatal Vowels in English

<table>
<thead>
<tr>
<th></th>
<th>Jaw</th>
<th>Tongue</th>
</tr>
</thead>
<tbody>
<tr>
<td>/i/</td>
<td>Hi</td>
<td>Tense</td>
</tr>
<tr>
<td>/ɪ/</td>
<td>Hi</td>
<td>Lax</td>
</tr>
<tr>
<td>/eɪ/</td>
<td>Mid</td>
<td>Tense</td>
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