Using ultrasound articulatory signals to investigate the phonetic motivations of English /æ/ tensing

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uOttawa
/æ/ in North American English (Labov et al., 2006)
A linguistic problem: Raising of /æ/ before /g/ (1)

- Zeller (1997) reported that younger, but not older, speakers from the Milwaukee area merged /æg/ with /ejg/ (e.g., *hag* = *Haig*)

- Labov, Ash, and Boberg (2006) reported the same merger for some speakers in Wisconsin, Minnesota, and central Canada; they also noted that /æ/ tended to be higher before /g/ than before /d/ over a somewhat wider area
A linguistic problem: Raising of /æ/ before /g/ (2)

- Bauer and Parker (2008), Benson et al. (2011): speakers from Eau Claire, Wisconsin, raised /æg/
- Bauer and Parker’s ultrasound data show that tongue body is raised in /æg/ but still distinct from other front vowels.
- Wassink (2015) concluded that /æg/ and /εg/ were raised in Seattle.

A figure from Bauer and Parker (2008) illustrating differences in average trajectories
A linguistic problem: Raising of /æ/ before /g/ (3)

- Purnell (2008), using x-ray data, found that, after /æ/, Wisconsin subjects articulated /g/ more fronted than /k/ and with more forward lip position.
Potential phonetic motivations for pre-velar raising

- Palatal-induced upgliding has occurred other times in the history of English, mostly before voiced stops and fricatives (and mostly not before voiceless stops).
  - Palatal [ç] conditioned upgliding in Middle English, e.g. OE eahta [æoxtə] > *[æçtə] > ME eight [aiçt]
  - /g/=[ɟ], /ŋ/=[ɲ], /ʃ/, and /ʒ/, as in bag, hang, cash, and azure, respectively, condition upglides in various American dialects (see, e.g., Kurath and McDavid 1961; Hartman 1969; Thomas 2001)

- Hyperarticulation before voiceless obstruents?
  - There is some evidence that vowels can show more extreme articulations before voiceless obstruents than elsewhere (e.g., Wolf 1978; Summers 1987; Moreton 2008)
  - For low vowels, this means that F1 values are higher before voiceless obstruents than before voiced obstruents (so that the vowel reaches a lower position before voiceless obstruents).
/æ/ raising in other contexts

- /æ/ raising before nasals is widespread in North American English.
- Apparent phonetic motivation: Nasalization has a strong effect on F1 in low vowels, altering their perceived height (and may also raise F2; Krakow et al. 1988)
- Raising in other contexts (e.g., before anterior voiceless fricatives) attributable to an earlier lengthening event.
Speaker 1: acoustic raising+fronting and tongue raising+fronting

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De Decker and Nycz (2012): /æ/-tensing in New Jersey
Speaker 3: acoustic raising+fronting only

![Graph showing acoustic raising+fronting for Speaker 3](image-url)
Selection of single representative image from target segment
Selection of single representative image from target segment
Tongue surface contour tracing
Purnell (2008): Pellet trajectories from XRMB database (Westbury, 1994)

Tongue Pellet Trajectories for /æg/ and /æk/ for Select Tokens and Speakers

a. PVR-Affected Speaker WID14

Coda Voicing
- -k
- -g

American Speech
Published by Duke University Press
Time-varying signals from PCA of XRMB data (Story, 2007; Story and Bunton, 2013)

Fig. 7 Audio waveforms (upper), time-varying coefficients (middle), and formant contours (bottom) based on the production of four vowels by a male talker. Note the time-varying coefficients are continuous throughout the entire 3.6 s duration; the lines are thickened during the portions of time where sound is present.
EigenTongues decomposition (Hueber et al., 2007)

- Principal component analysis of vocal tract images (Hueber et al. 2007 for ultrasound; Carignan et al. 2013 for MRI)
- Principal Component loadings remapped onto original spatial location
- A video becomes a matrix of PC scores
- http://phon.wordpress.ncsu.edu
Acoustic/articulatory vowel plots
Acoustic/articulatory vowel plots

PCA Data collection Articulatory signals

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13/31
PC loadings heatmaps (first nine PCs for one speaker)

PC1
PC2
PC3
PC4
PC5
PC6
PC7
PC8
PC9
Ultrasound image acquisition (at NCSU and uOttawa)

- Terason t3000
- 8MC3 microconvex array
- Ultraspeech software (Hueber et al., 2007)
- Articulate Instruments probe stabilization headset
- 120 monosyllabic words, randomized and repeated 3 times
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- 120 monosyllabic words, randomized and repeated 3 times
Pilot: 21 speakers (overlaid on ANAE /æ/ map; Labov et al. 2006)
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Quantified images $\rightarrow$ articulatory signal with sampling rate $=$ system frame rate

- Deriving time-series data from measured tongue contour tracings (Falahati, 2013)
- PCs and rotated PCs over time
- Linear Discriminant Analysis of PC scores over time (Pouplier and Hoole, 2013)
- Acoustically-inspired linear combinations of PCs over time...
Acoustic diagonal (Z2-Z1)

Standardized F2 — standardized F1 (Z2-Z1) = designed to match the front diagonal of the acoustic vowel space (Labov et al., 2013)
Articulatory diagonal (art.Z2Z1)

- Audio segmented using P2FA (Yuan and Liberman, 2008) and vowel/approximant formants measured at 7ms intervals
- Linear regression for each speaker’s front diagonal vowels [a æ e ej ɪ i]: (Z2-Z1 ~ PC1 + . . . + PC20)
- 20 coefficients used to make a linear weighted combination of the PCs that approximates Z2-Z1
- Second set of linear regressions using only F1 (to examine relationship between tongue position, nasalization, and F1)

Speaker: nov03
(Broadway, NC; 1992, M)
Articulatory diagonal (art.Z2Z1): heatmaps

Speaker: nov01
(Vancouver, WA; 1976, M)

Speaker: nov03
(Broadway, NC; 1992, M)

Speaker: nov04
(Olympia, WA; 1982, M)

Speaker: nov07
(Arlington, TX; 1992, M)

Speaker: nov11
(Wilmington, NC; 1986, M)

Speaker: nov12
(Fargo, ND; 1981, M)
Alveolar signal (LDA with \[t\ d\ n\ s\ z\]): “sag”
Velar signal (LDA with [k ɡ ɳ]): “sag”
Front diagonal (art.Z2Z1) articulatory signal: “ban”
/æ/ tensing before nasals

- pre-nasal tensing for all speakers except UK and Newfoundland (Wilmington, NC example)
- widespread pre-/m n/ tensing involves peak aligned ≈ with vowel nucleus
- pre-/ŋ/ tensing involves tongue raising aligned to end of vowel (anticipating following velar)
- 16/20 North Americans: pre-/ŋ/ tenser than pre-/ŋ/, both acoustically and articulatorily (cf. Baker et al. 2008)
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F1 vs. Lingual F1 in vowels before /m/ and /b/

nov14: Hickory, NC ("South")
nov05: Burnsville, MN ("North")

F1 frequency

Lingual F1

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Ultrasound articulatory signals and /æ/ tensing
F1 vs. Lingual F1 in vowels before /m/ and /b/
Change in F1 and Lingual F1 in pre-nasal position: /a/
Change in F1 and Lingual F1 in pre-nasal position: /æ/
Change in F1 and Lingual F1 in pre-nasal position: /ɛ/

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Ultrasound articulatory signals and /æ/ tensing
Change in F1 and Lingual F1 in pre-nasal position: /ej/

![Graph showing change in F1 and Lingual F1 in pre-nasal position: /ej/](image)

- **F1 frequency**
- **Lingual F1**

Legend:
- **Canada**
- **North**
- **South**
- **Mid-Atlantic**
- **UK**

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*Ultrasound articulatory signals and /æ/ tensing*
/æ/ tensing: /g/ > /d/

- /g/ > /d/ by end of vowel for all speakers (velar pinch) (Arlington, TX example)
- from 2nd half of vowel for most Mid-Atlantic and Southern speakers (Harrisburg, NC example)
- from 1st half of vowel for most Northern speakers (Olympia, WA example)
- entire vowel for all Ontario speakers (Barrie example)
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/æ/ before velars /k g η/: North

nov08: Altoona, WI ("North")

nov12: Fargo, ND ("North")

nov15: Batavia, NY ("North")

nov16: Buffalo, NY ("North")
/æ/ before velars /k g η/: North (including Northwest)

nov01: Vancouver, WA ("North")

nov04: Olympia, WA ("North")

nov05: Burnsville, MN ("North")
/æ/ before velars /k g η/: Canada

nov18: Casselman, ON ("Canada")

nov19: Ottawa, ON ("Canada")

nov20: Barrie, ON ("Canada")

nov21: Lewisporte, NL ("Canada")

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Ultrasound articulatory signals and /æ/ tensing
/æ/ before velars /k g η/: North Carolina

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Ultrasound articulatory signals and /æ/ tensing
/æ/ before velars /k g η/: Misc. South

nov09: Woodbridge, VA ("South")

nov02: Cobbs Creek, VA ("South")

nov07: Arlington, TX ("South")
\( /æ/ \) before velars \( /k\ g\ \eta/ \): Mid-Atlantic and UK

**nov10: Havertown, PA ("Mid-Atlantic")**

**nov13: Prees, Shropshire, UK ("UK")**

**nov17: Philadelphia, PA ("Mid-Atlantic")**

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/æ/ tensing: Philadelphia

- some /d/ > /g/ for one of the Philadelphia speakers
- ‘bad’ > ‘sad’: tongue gesture similar to /æ/ before /n/ (like two of De Decker and Nycz’s (2012) four New Jersey speakers)
- Anterior voiceless fricatives involve gesture similar to ‘bad’ and almost all of the pre-/m n/ raising we have seen so far.
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Summary: /æ/ raising

- Pre-nasal and Philadelphia tensing: large tongue raising gesture at the vowel nucleus.
- F1 lowering in pre-nasal /æ/ is accounted for by tongue raising.
- Pre-velar /æ/ raising is a matter of timing (because pre-velar vowels end with velar contact).
- The dorsal target appears to more anterior for /g/ than for /k/ for many speakers, but conspicuously not for some, including the one UK speaker and the one Texas speaker.
  - Many of our Upper Midwest and Ontario speakers have pre-/g/ raising and articulatorily distinct /g/ and /k/.
  - Our Northwestern speakers have pre-/g/ raising but articulatorily similar /g/ and /k/.
  - Our North Carolina speakers have distinct /g/ and /k/ but no pre-/g/ raising.
Ultrasound is a relatively easy and practical way to collect articulatory data on the scale necessary for variation studies. By reducing the labor involved in ultrasound data analysis, articulatory signals make ultrasound data analysis much more flexible and make studying the dynamics of speech production more practical.

Signals derived from PCs using acoustic data can be used to track linguistically relevant tongue movements (e.g. articulatory movement along the front edge of the vowel space).

Acoustically-derived signals can also be used to distinguish effects of tongue movement from effects of lips, nasalization, etc.
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Articulatory signals Matlab scripts and polar SSANOVA R script: http://phon.wordpress.ncsu.edu or google “NCSU phonology”


Anteriority of closure: Velar palatalization

\[ \{g,k\}a \quad \{g,k\}æ \quad \{g,k\}i \]

-3 -2 -1 0 1 2
word group

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Ultrasound articulatory signals and /æ/ tension
Anteriority of closure: Velars after /æ/
Anteriority of closure: Velars before /i ej e a/

- **Mid-Atlantic**
- **South**
- **North**
- **Canada**

Box plots showing ultrasound articulatory signals and /æ/ tensing.
Anteriority of closure: Velars after /i ej e a/

**Mid-Atlantic**

**South**

**North**

**Canada**

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Ultrasound articulatory signals and /æ/ tensing