Contrast enhancement and cue trading in Irish consonant articulations

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Modern Irish

Irish (or *Gaeilge*) is the ‘first official language’ of the Republic of Ireland.

But: an endangered minority language!

- Language of daily use for 2-3% of the population (about 100,000 speakers) (2011 census data).
Official *Gaeltacht* (Irish-speaking) areas
Secondary articulations in Connemara Irish

<table>
<thead>
<tr>
<th></th>
<th>LABIAL</th>
<th>CORONAL</th>
<th>DORSAL</th>
<th>GLOTTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STOP</strong></td>
<td>p p̟</td>
<td>t t̟</td>
<td>k k̟</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b b̟</td>
<td>d d̟</td>
<td>g g̟</td>
<td></td>
</tr>
<tr>
<td><strong>FRICATIVE</strong></td>
<td>f f̟</td>
<td>s s̟</td>
<td>x x̟</td>
<td>h (h̟)</td>
</tr>
<tr>
<td></td>
<td>v v̟</td>
<td></td>
<td>(ɣ) (ɣ̟)</td>
<td></td>
</tr>
<tr>
<td><strong>NASAL</strong></td>
<td>m m̟</td>
<td>n n̟</td>
<td>η η̟</td>
<td></td>
</tr>
<tr>
<td><strong>LIQUID</strong></td>
<td></td>
<td>l l̟</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>r r̟</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

By convention: [C] = [C̟]
Secondary articulations in Connemara Irish

<table>
<thead>
<tr>
<th><strong>PALATALIZED /Cʲ/</strong></th>
<th><strong>VELARIZED /Cˠ/</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><em>beann</em> /bʲɔːn/ 'peak'</td>
<td><em>bán</em> /bɔːn/ 'white'</td>
</tr>
<tr>
<td><em>cait</em> /katʲ/ 'cat (PL)'</td>
<td><em>cat</em> /kat/ 'cat (SG)'</td>
</tr>
</tbody>
</table>
Dialect descriptions: Secondary articulations

Palatalization $[C^j]$

• Front of tongue raised towards hard palate.
• Dorsal position resembles high front $[i \ j]$  

Velarization $[C^ɣ]$

• Back of tongue raised towards soft palate.
• Dorsal position resembles high back $[u \ \emptyset]$  

(de Bhaldraithe 1945:24, Breatnach 1947:26, Mhac an Fhailligh 1968:24, etc.)
Secondary articulations in Connemara Irish

Acoustic correlates of $[C^j]$ (Ní Chiosáin & Padgett 2012):

• Raised F2 on adjacent vowels
• Stop releases (esp. coronals):
  – Louder and longer
  – Higher spectral COG
  – Some degree of affrication

• Not much data on fricatives and sonorants.
Secondary articulations in Connemara Irish

Secondary palatalization and velarization reportedly reinforced by labial gestures.

- /Cɣ/: lips actively rounded
- /Cj/: lips actively spread

Lip rounding and dorsum backing both lower F2

(e.g. Stevens 1998).

(e.g. Ó Cuív 1944:31-51, Ó Siadhail 1991)
Contrast enhancement or trading relations?

Research question 1:

• Are rounding/retraction combined to enhance the acoustic salience of /CV CJ/ contrasts? (Stevens & Keyser 1989)
  • Rounding achieves maximal acoustic dispersion.

• Or do speakers trade-off between rounding and tongue body gestures to achieve acoustic stability?
  • E.g. lip rounding can compensate for weak velarization, as a strategy to achieve consistent (low) F2.
Reinforcement and phonological targets

Continuous reinforcement: reinforcement occurs to achieve numerically-defined acoustic targets.

- Phonological targets are specified in a continuous space (e.g. F2 values).
- Reinforcement is a low-level process – can gradiently compensate for changes in gestural magnitude.
- Predicts token-by-token, inverse correlation between degree of backing and degree of lip rounding.

(e.g. Perkell et al. 2000, Flemming 2001, Keyser & Stevens 2006, Kingston 2007, Stevens & Keyser 2010, Niziolek et al. 2013a,b and references there)
Reinforcement and phonological targets

**Discrete reinforcement**: reinforcement occurs at an abstract, categorical level of encoding.

- Phonological targets are specified in a discrete space (e.g. labial constriction).
- Gestures are either present or absent – there is no phonological modulation of gestural magnitude.
- Predicts little/no correlation in magnitude of lip rounding and dorsal gestures.

(e.g. Stevens et al. 1986, Browman & Goldstein 1989 *et seq.*, Padgett 2001, 2003, and references there)
Secondary articulations: coronals

Coronal /Cɣ/: raising and backing of tongue body less extreme?

“But the dentals d, n, t have neutral ə-quality rather than u-quality, yet they are sufficiently distinct in their point of articulation from the corresponding palatals... similarly s is more neutral than velar in quality”

(Mhac an Fhailigh 1968:24)
Secondary articulations in Connemara Irish

Does reduced velarization on coronals threaten the perceptual salience of /Cɣ Cj/ contrasts?

• Weak velarization = weak F2 separation = confusion?

• Not necessarily: *noise components* may still be perceptually distinct.
  – COG, duration, etc.

• **Hypothesis:** weak velarization on coronal /Cɣ/ should be tolerated when the coronal /Cj Cɣ/ contrast is robustly signaled by cues *other* than F2.
Secondary articulations in Connemara Irish

**Research question 2**: for individual speakers, do we find a correlation between:

- Weakness of velarization on coronal /Cγ/.  
- Robustness of noise cues to the /Cγ Cj/ contrast on palatalized vs. velarized coronals.
Ultrasound study

Documenting the articulatory phonetics of secondary dorsal contrasts using ultrasound.

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Máire Ní Chiosáín (UCD)
Ultrasound study

All three major dialect groups (5 speakers each):

• Donegal (Northern)
• **Connemara (Western)**
• Kerry (Southern)
Microphone

Ultrasound probe
# Ultrasound study: sample words

<table>
<thead>
<tr>
<th>Palatalized /C̃/</th>
<th>Velarized /C̃/</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>tí</strong> /t̃iː/</td>
<td><strong>tuí</strong> /t̃iː/</td>
</tr>
<tr>
<td>‘house (gen.sg.)’</td>
<td>‘straw’</td>
</tr>
<tr>
<td><strong>tiús</strong> /t̃uːs/</td>
<td><strong>tús</strong> /t̃us/</td>
</tr>
<tr>
<td>‘thickness’</td>
<td>‘beginning’</td>
</tr>
<tr>
<td><strong>síos</strong> /s̃iːs/</td>
<td><strong>suí</strong> /s̃iː/</td>
</tr>
<tr>
<td>‘down’</td>
<td>‘sitting’</td>
</tr>
<tr>
<td><strong>siúl</strong> /s̃uːl/</td>
<td><strong>sú</strong> /s̃uː/</td>
</tr>
<tr>
<td>‘walking’</td>
<td>‘juice’</td>
</tr>
</tbody>
</table>
Ultrasound study: wordlist

Target consonants:
• PoA: coronal, labial, dorsal
• Secondary articulations: /Cγ Cj/
• Manner: stops and fricatives
• Voiceless consonants only.
  – Exception: lexical gaps forced us to use /bjuː/ and /biː/.

Environment:
• Word-initial [#CV...]
• Vowel contexts: [#Cuː...], [#Ciː...]
Ultrasound study: procedure

• Speakers recruited from *Raidió na Gaeltachta*.
  – 5 speakers
  – Recording took place at *RnaG* studios.

• 24 target words (3 places x 2 manners x 2 vowels x 2 sec. artics.)
  – 6-8 repetitions of each target word per speaker.
  – Wordlist pseudo-randomized
Analysis
Tracing in EdgeTrak
(Li et al. 2005)

C onset for $b’\text{fiú}$ [$b^j$u:] ‘it is worth’
(Speaker 3, rep. 3)
Tracing in EdgeTrak
(Li et al. 2005)

C onset for *b’fhiú* [buː] ‘it is worth’
(Speaker 3, rep. 3)
Raw tracings

bj_u / onset

Y (mm)

X (mm)

20 40 60 80 100 120

-20 -40 -60 -80 -100

BACK
(TONGUE ROOT)

FRONT
(TONGUE TIP)

Rep.1
Rep.2
Rep.3
Rep.4
Rep.5
Rep.6
Rep.7
Rep.8
Statistical methods

Quantitative analysis:

- Principal component analysis (PCA).
- A technique for dimensionality reduction.
- Used in many fields to explore structured covariation (clustering) in large data sets (Jolliffe 2002).
- See Johnson (2008:95-102) for an overview of our method.
Principal components

Overall mean shape for data set

Change in shape/position as PC1 varies (±5`.)

Overall mean shape for data set
Analysis of ultrasound data

Focus primarily on C offset:

- \( C^y C^j \) distinction is perceptually strongest at C-V transition. (e.g. Ladefoged & Maddieson 1996:333-6, Kochetov 2006)

- C-offset =
  - Fricatives: offset of fricative noise
  - Stops: onset of release burst
Results: labial backness
Results: dorsal backness

PC1 (backness) values for C offset

Consonant quality: [fy] [fj] [p\text{\textbar}] [p\text{j}] [s\text{\textbar}] [s\text{j}] [t\text{\textbar}] [t\text{j}] [x\text{\textbar}] [x\text{j}] [k\text{\textbar}] [k\text{j}]

n=61 n=58 n=63 n=59
n=61 n=62 n=62 n=61
n=62 n=61 n=61 n=62
Results: coronal backness
Research question: lip rounding
Does lip rounding co-vary with /C^y C^j/ contrasts?
Lip rounding: side contact

(Goldstein 1991, Kavitskaya and Barnes 2003)
Results: lip rounding in dorsals
Results: lip rounding in coronals

Lip rounding (side contact) values for C offset
Results: lip rounding in labials

Lip rounding (side contact) values for C offset
Results: lip rounding

Linear-mixed effects modeling used to analyze factors which condition side contact (lip rounding).

• Two backness-related predictors:
  
  • **Secondary articulation**: /Cʲ/ vs. /Cɣ/  (CATEGORICAL)
    
    • Predicted to be significant under **discrete reinforcement**.
  
  • **Principle component 1**  (CONTINUOUS)
    
    • Can potentially capture *within-category* correlations between backness and rounding.
    
    • Our index of *trading relations* within /Cɣ Cʲ/.
    
    • Predicted to be significant under **continuous reinforcement**.
Results: lip rounding

• **Secondary articulation:** /Cɣ/ > /Cʲ/
  
  – Strongest for dorsals (DOR x /Cʲ/: less rounded)
  
  – Nearly non-existent for coronals (COR x /Cʲ/: more rounded)

• **Degree of tongue-body backing:**
  
  – PC1 does *not* predict lip rounding beyond the categorical /Cɣ Cʲ/ contrast (p > .39 for all predictors involving PC1).

• Other factors affecting lip rounding: vowel context, place, manner, various interactions
Results: lip rounding

Interim conclusions:

• The **categorical** distinction between /Cɣ Cʲ/ strongly conditions lip rounding.

• Finer, within-category distinctions in *strength* of dorsal backing/fronting do not systematically correlate with degree of lip rounding.

• More clearly consistent with *discrete reinforcement* (*enhancement*/*dispersion*) than continuous reinforcement (*trading relations*/*stability*).
Secondary articulations: coronals

Two observations regarding coronals:
• Weaker secondary velarization.
• Little/no reinforcement of /CV Cʃ/ contrast with lip-rounding.

(e.g. Ó Cuív 1944:31-51, Mhac an Fhailligh 1968:24)
Research question: coronals
Are noise cues on coronals sufficiently robust to compensate for weak backing of *velarized* coronals?
[tʃiː]

[tʃɪː]
[s̃iː]

[sviː]

Sound pressure level (dB/Hz)

Frequency (Hz)

2.205 \times 10^4
Secondary articulations: coronals

For each speaker, we correlate:

- **PC1** for coronal /s^v/ and /t^v/ (strength of velarization)
- **Difference** in mean COG for /s^v s^j/ and /t^v t^j/ (distinctiveness of noise components)
Correlation between ΔCOG and PC1
All coronals [Tɣ Tɨ] at C offset

POINT = SPEAKER by MANNER (/s/ or /t/)

$r = -0.57^*$
Coronals: Conclusions

Weak velarization is tolerated on coronal /C^{\gamma}/ when noise cues sufficiently distinguish coronal /C^{\gamma}/~/C^{j}/.
Conclusions

Results:

• Categorical enhancement of /Cy Cj/ contrast with reinforcing lip-rounding, but no trading relations.
• Consistent with view that reinforcement occurs at a relatively abstract level.
  – E.g. [low/high F2], but not [F2=2400Hz]
  – Or: perceptually-driven addition of categorical gestures

(Stevens 1989 et seq., Kingston et al. 2008, etc.)
Conclusions

Results:

• Some support for quantitative trading between:
  – Degree of velarization on coronal /C^v/
  – Acoustic separation of noise cues to coronal /C^v/~/C^j/ contrasts.

• Contrast preservation appears to hold at level of **individual speakers**.
  – Not clear from our (sparse) data whether individual-level trading relations are categorical or gradient.
Issues and further work

• Individual variation.

• Is lip rounding more robust/systematic for productions with *peripheral/ambiguous PC1 values*?
  – Economy of effort: enhancement as a ‘last resort’
  – Preliminary investigation fails to support this prediction ($-0.75 < PC1 < 0.75$).

  (Perkell et al. 2000, Stevens 2004)
Issues and further work

• No evidence of lip-rounding differences for /p\text{Y} p^j/  
  – Contrary to traditional descriptions!

• However: side contact may not be the best measure of lip rounding for labials.
  – Labial closure (esp. for stops /p b/) could induce a ceiling effect for side contact.
  – Better measures:
    • Protrusion
    • Side contact at end of release noise – differences emerge for labials, but still no token-wise trading relations.
Secondary articulations across Irish: labial and coronal variation

(Hickey 2011)
Acknowledgments

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• The staff at Raidió na Gaeltachta
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• Our research assistants:
  – **Yale**: Tom McCoy, Bettina Cheung, Connor McCabe
Thank you!

Go raibh maith agaibh!