How /b, d, g/ differ from /p, t, k/ in Spanish:
A dynamic account

LabPhon 12

Benjamin Parrell
Department of Linguistics
University of Southern California

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Realization of Spanish stops: 
The traditional description

Voiceless stops (/p, t, k/):
  always realized as voiceless, unaspirated stops

Voiced stops (/b, d, g/):
  voiced, unaspirated stops when they occur:
    • in phrase initial position
    • after a nasal
    • after /l/ (for /d/ only)

  voiced spirants/approximants [β, ð, γ] elsewhere
BUT, alternation between stops and approximants is gradient, not categorical

Production affected by:

- speaking rate
  (Soler & Romero, 1999)
- lexical stress
  (Cole et al., 1999; Ortega-Llebaria, 2004)
- flanking vowel height
  (Cole et al., 1999; Hualde et al., 2010)
- adjacent segments
  (Carrasco & Hualde, 2009; Eddington, 2009; Hualde et al., 2010; cf. Kingston, 2008)
Production of voiceless stops also varies

/p, t, k/ are often realized with partial or full voicing

(Torreblanca, 1976; Machuca, 1997; Lewis, 2001; Hualde et al., 2010)

/p, t, k/ are sometimes produced as approximants, either voiced or voiceless

(Torreblanca, 1976; Machuca, 1997; Lewis, 2001)
The outstanding phonological issue

How are Spanish /b, d, g/ and /p, t, k/ distinguished at the level of phonological representation, given their highly variable and overlapping productions?

[- tense] vs. [+tense]? (e.g. Martínez Celdrán, 2008)

short vs. long? (Hualde, 2005)

spirants vs. stops? (Lavoie, 2001)
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proposal

experiment design

results

modeling the results
Could duration differences underlie constriction degree differences?

/p/

duration /p/

target

/b/

duration /b/

undershoot
Dynamic approach obviates overtly controlled allophony

Fortition is a dynamic consequence of duration increased duration at a phase boundary leads to a closer approximation/achievement of target (e.g. Byrd & Saltzman, 2003)

Simple explanation for post-nasal stops full stops are produced as duration of total nasal + stop sequence is long enough for full closure

Possible unified explanation for traditional allophony and “sub-allophonic” variation?
Goals for current study

Verify whether voiced and voiceless stops differ in duration and constriction degree at the articulatory level

previous studies have all relied on acoustics

Test the hypothesis that duration differences can explain constriction degree differences between /b, d, g/ and /p, t, k/
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Stimuli & subjects

EMA used to collect articulatory data

Labial stops (/p/ and /b/) in /aCa/ context

Three prosodic boundaries:
  phrase boundary, word boundary, and word-internal conditions

8-12 repetitions per condition collected from 2 speakers of Peninsular Spanish
Three measures of duration were used

Three measures of duration were used.
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/b/ is shorter than /p/, except phrase initially

subject A

subject B
Difference in total duration is due to constriction duration differences

subject A

subject B
Movement duration is equal for /p/ and /b/
/b/ is less constricted than /p/, except phrase initially

subject A

subject B
Testing the duration hypothesis

The relationship between constriction duration and constriction degree was examined using a linear regression between the two variables.

Tested across word-boundary and word-internal conditions (no differences in duration or CD)
Tokens of /b/ with longer durations are more constricted

Subject A
/b/ $R^2$: 0.26
/b/ $p < .02$

Subject B
/b/ $R^2$: 0.32
/b/ $p < .03$
Duration alone cannot explain constriction differences

Duration does influence constriction degree

**BUT** /b/ and /p/ overlap in duration, but not constriction degree
One alternative to target differences: Stiffness

**Stiffness**: The speed of articulator movement can vary independently of changes in magnitude or duration.

(Beckman & Edwards, 1992; Byrd & Saltzman, 1998; Edwards et al., 1991; Roon et al., 2007)

A gesture with lower stiffness will take longer to reach its target position than the same gesture with a higher stiffness
One alternative to target differences: Stiffness

Stiffness = [±tense]? (cf. Martínez Celdrán 2008)
Two methods for calculating stiffness

1) peak velocity (cm/sec)  
   maximum displacement (cm)  
   (Edwards et al., 1991; Roon et al., 2007)

2) time from gesture onset to peak velocity  
   (Byrd & Saltzman, 1998)
/b/ and /p/ do not differ in stiffness
Discussion:
Duration and constriction

/b/ and /p/ must differ in their constriction target

Is /b/ then an approximant? Not necessarily:
If voiced stops have more-open-but-still stop-like constriction targets, we might see the same degree of undershoot in voiced and voiceless stops. In the former case undershoot may lead to incomplete closure while in the latter it would not.
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Input to articulatory model

• /p/ and /b/ synthesised in a /ka_a/ context in TaDA articulatory synthesizer (Nam et al. ,2004)
• Constriction targets:
  – /p/-2: -2 mm (standard for English stops)
  – /b/-0.5: -0.5 mm
  – /b/0: 0 mm
• Durations of LA closure gesture:
  – 80 ms (word internal/word boundary)
  – 200 ms (phrase boundary)
Equal undershoot for all gestures, but different results

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complete closure  mixed results  incomplete closure
Model acoustics mirror articulation

/p/-2

/b/-0.5

/b/0

burst

frication
Conclusions

Spanish /b, d, g/ and /p, t, k/ differ in duration and target constriction degree, as well as in voicing

No difference in stiffness

/b, d, g/ in Spanish are stops, even though their target is different from that of /p, t, k/

“Fortition” of /b, d, g/ a at phrase boundary is the dynamic consequence of well-attested phrasal lengthening effects

(e.g. Fougeron & Keating, 1997; Byrd et al., 2006)
Can undershoot explain variation in /p, t, k/ as well?

Spirantization of voiceless stops might be attributable to further undershoot of the lips due to reduced duration.

Voicing of voiceless stops may be the consequence of the same processes on the glottal spreading gesture.

Laryngoscopic evidence for small magnitude glottal spreading gesture (Martínez Celdrán & Planas, 2007)