Phonetics vs. phonology:

Fundamental frequency as a correlate of stop voicing in English and Spanish

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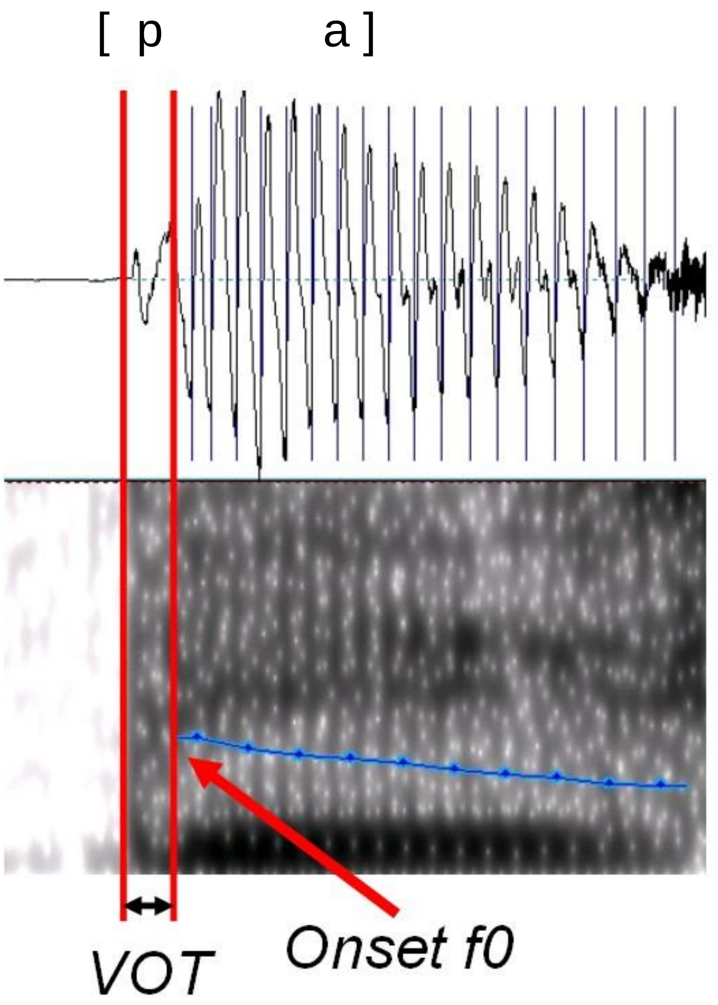
Acknowledgments

- This is a join work with Amanda Shultz, Fernando Llanos, and Alexander Francis at Purdue University.
- English data was collected by Amanda Shultz.
- Spanish data was collected by Fernando Llanos.
- We are grateful to Prof. Juana Gil Fernandez for allowing us the use of lab facilities at CSIC in Madrid.

Onset F0

- Fundamental frequency at the *onset of vocalic voicing* is effected by the voicing qualities of the preceding consonant:
  - Voiced consonants -> lower onset F0
  - Voiceless consonants -> higher onset F0



Tonogenesis

- This tendency is believed to have contributed to *tonogenesis* in some languages, where consonant voicing is accompanied by (1) or substituted by (2) exaggerated systematic F0 perturbations on the following vowel (Kingston 2011):
  1 - Yabem and Korean
  2 - Western Kammu dialects, Eastern Cham or Utsat

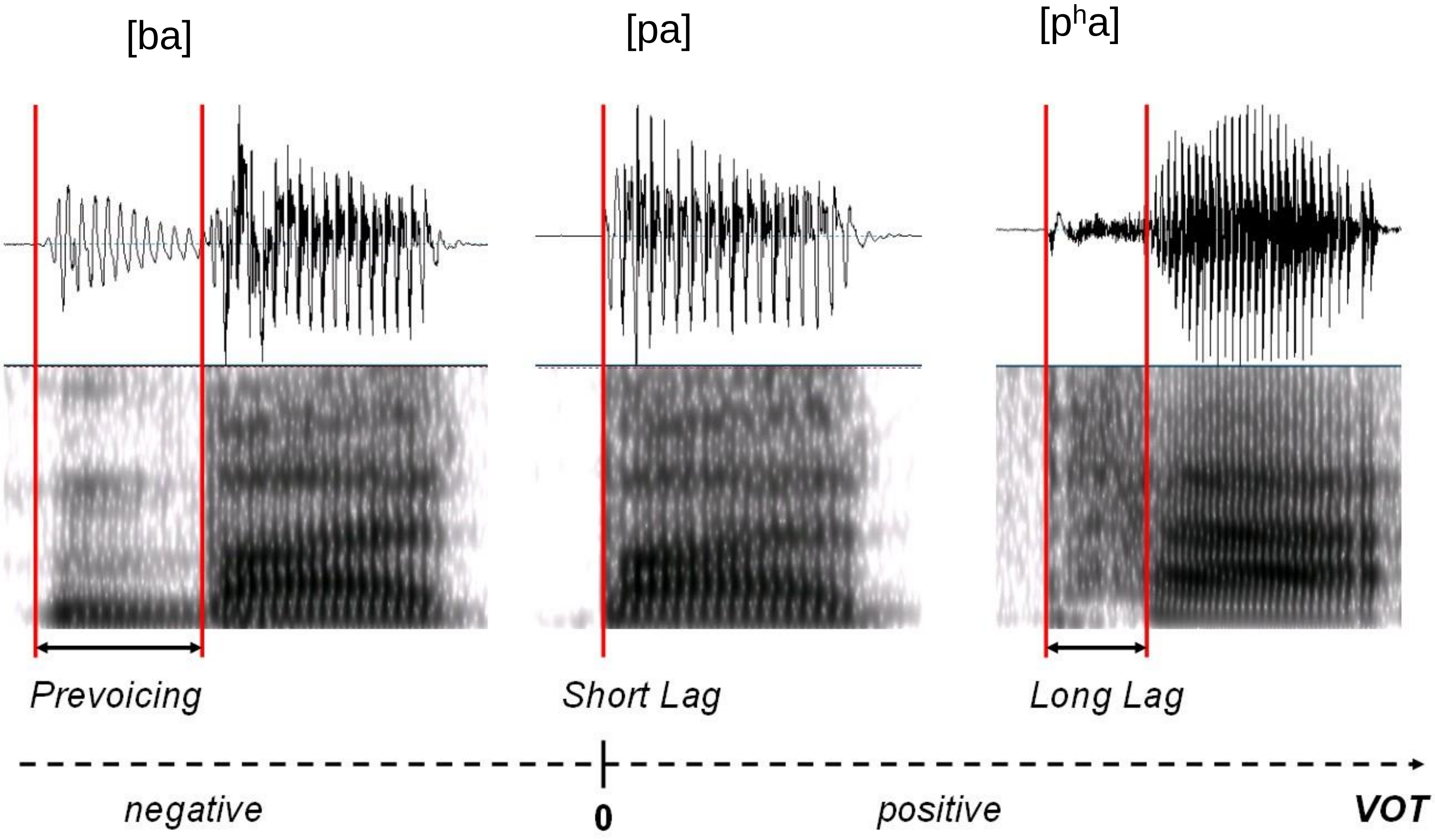
Automatic?

- This covariation appears to be relatively consistent across languages, suggesting that it is an automatic uncontrolled/able consequence of articulation and/or aerodynamics of voicing production.
- What exactly about voicing is causing the covariation?

Types of voicing distinction

- The answer to this question is complicated by the fact that phonological voicing is not phonetically uniform across languages.
  - At least two types of voicing contrasts are common:
    - prevoiced vs. voiceless unaspirated
    - voiceless unaspirated vs. voiceless aspirated.
  - In terms of *Voice Onset Time* (VOT) parameter these three types are referred to as:
    - negative or lead VOT (for prevoiced)
    - 0 or short lag VOT (for voiceless unaspirated)
    - positive or long lag VOT (for voiceless aspirated)

VOT continuum



Voicing and F0 perturbation

- The two types of VOT distinctions sometimes are lumped together as a [+/- voice] distinction.
  - Despite the fact that both articulatorily and acoustically they are very different:
    - Presence or absence of vocal fold vibration vs.
    - Presence of absence of aspiration.
- Most F0 perturbation accounts focus on prevoiced - 0 VOT distinction (although some use English as example).
- Thus, we are looking for the causes of F0 perturbation in mechanism involved in promotion OR suppression of vocal fold vibration during obstruent production.

Phonetic causes of F0 perturbations

- Larynx lowering to facilitate airflow through glottis for voiced consonants.
  - Results in vocal folds slackening, through tilting of the cricoid cartilage forward relative to the thyroid cartilage (Hombert et al. 1979; Kingston 2011).
  - Which results in *lower* onset F0.
- Suppression of VF vibration in voiceless consonants is achieved through greater longitudinal tension.
  - Evidenced by higher cricothyroid muscle activity in voiceless consonants (Löfqvist et al. 1988)
  - Resulting in *higher* onset F0.

Expectations

- Based on this explanation, we predict *lower* onset F0 after actively *voiced* obstruents, and *higher* onset F0 after *voiceless* ones.
- No phonetic reason to expect a difference in onset F0 between *voiceless aspirated* and *unaspirated*?
- Unless… Higher airflow rate after aspirated stops may condition higher onset F0 (Ladefoged 1967; Ohala 1973)
- There is, also a phonological reason – to emphasize the acoustic difference between the contrasting sounds (Keating 1984).
- What does the research show?

Experimental evidence

Language	Study	Higher onset F0	Methods
English	Onde 1984	t (non-sign.?)	5S, 5 tokens
Korean	Han 1967 Kim K. 1968 Kagaya 1974	t^h t^h t (8%, 1 S)	2S 1S? 2S, 12 tokens
Hindi	Kagaya&Hirose 1975	t (5%)	1S, 12 tokens
Danish	Fischer-Jørgensen 1968 Jeel 1975 Reinholt Petersen 1983	No effect t^h (smwht) t^h (smwht)	 Speaker variability Speaker variability
Thai (Standard, Bangkok)	Ewan 1979 Gandour 1974 Erickson 1975	t^h (5%) t (8%) t^h - 7S	1S, 90 tokens 1S, 90 tokens 11S, 8 tokens
Cantonese	Francis et al. 2006	t	16S, 10 tokens
Taiwanese	Lai et al. 2009	t^h	10S, 30 tokens
Mandarin	Xu&Xu 2003	t	
Wu dialect (Wufang)	Ballard 1975	Hist. tone lowering after t^h	

Experimental evidence

- Six out of 14 randomly selected studies report F0 raising after *unaspirated* stops
- Seven report F0 raising after *aspirated* stops
- One reports no effect
- Note, however, small number of subjects in earlier studies.
- Conclusions? Onset F0 differences seem to be maintained but not in a consistent direction.
- Supports the phonological view:
  - Not an automatic consequence of aspiration/VOT differences but a controlled emphasis of phonological distinctions.

Phonetics vs. Phonology

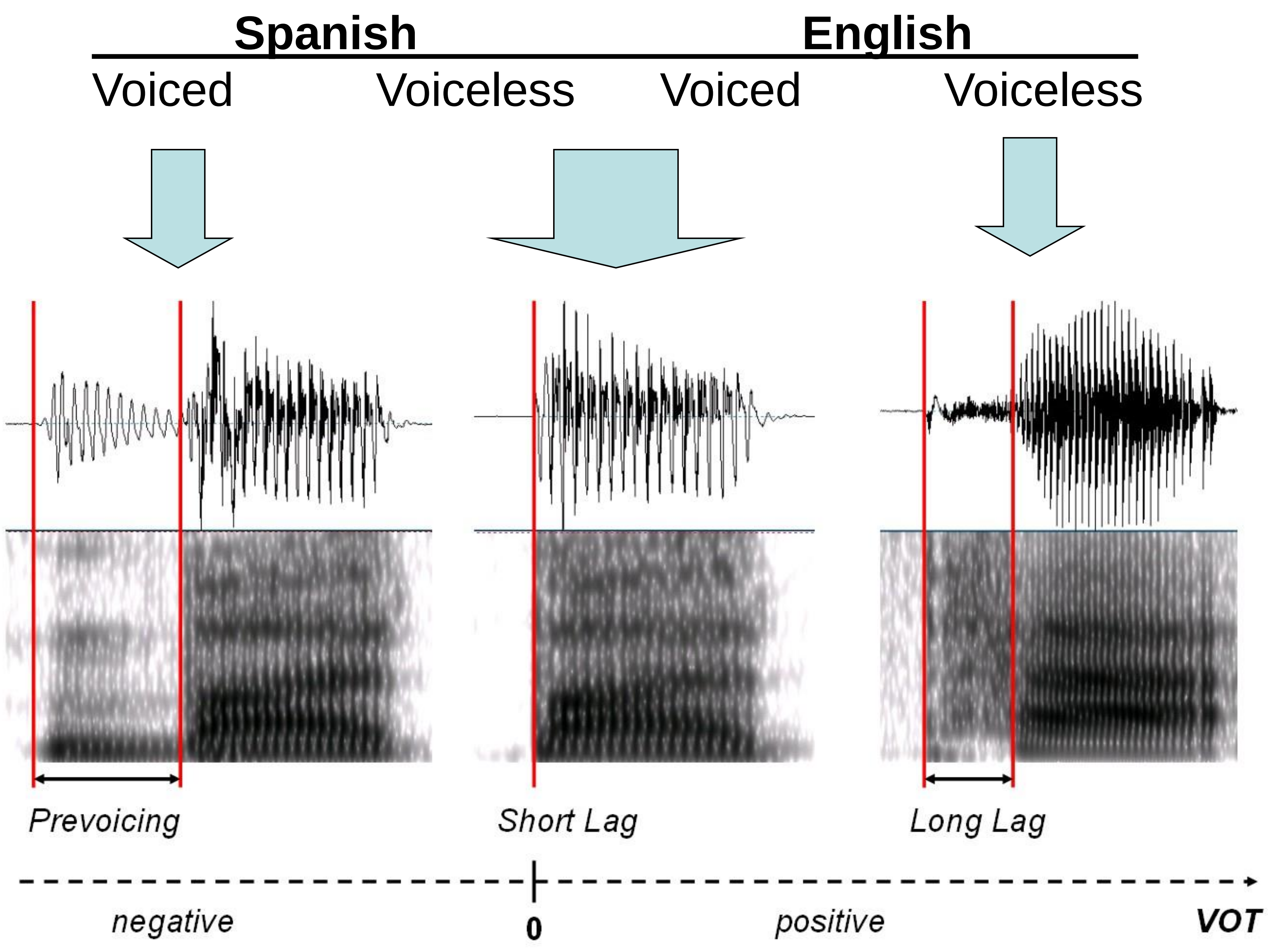
- Why is the difference so consistent between voiced and voiceless?
  - Kingston and Diehl (1994, 1995) and Kingston *et al.* (2008) argue that lower onset F0 after prevoiced stops integrates perceptually with voicing during closure and emphasizes the sensation of low-frequency energy, increasing the perceptual difference between voiced and voiceless stops.
  - There is no such reason to implement onset F0 differences in a particular direction between aspirated and unaspirated stops.

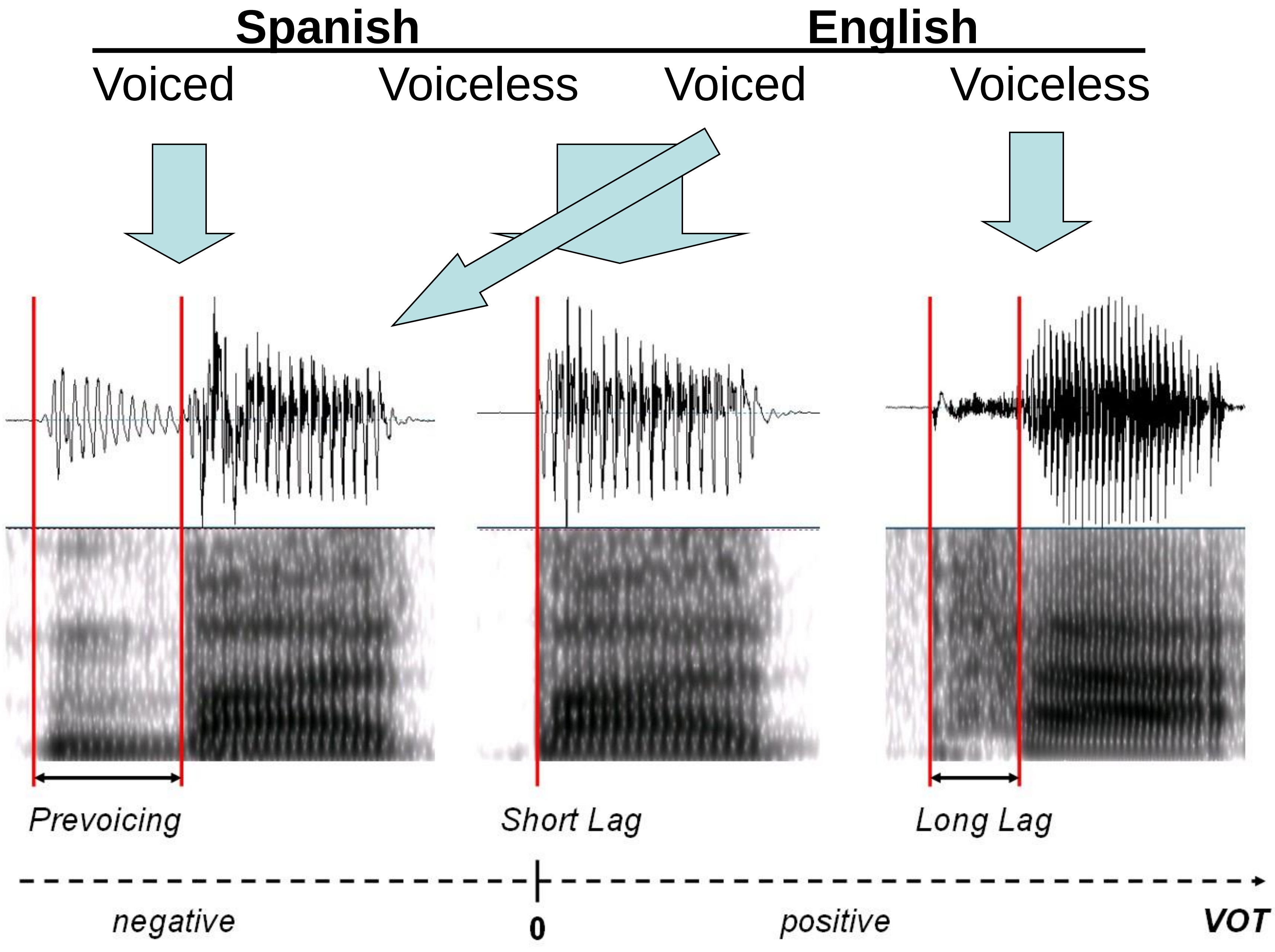
The present study

- GOAL:
  - To investigate the onset F0 distribution with respect to phonetic categories of prevoiced, unaspirated, and aspirated initial stops
  - in a comparable experimental setting
  - across two languages where these phonetic categories are used differently to implement the phonological [+/- voice] distinction.

Phonetics of voicing

- English prevocalic stops:
  - Voiced
    - Typically short lag voiceless unaspirated
    - Occasionally lead VOT prevoiced
  - Voiceless
    - Long lag aspirated
- Spanish prevocalic stops:
  - Voiced
    - Lead VOT prevoiced
  - Voiceless
    - Short lag voiceless unaspirated


Spanish
English
Voiced
Voiceless
Voiced
Voiceless
Prevoicing
Short Lag
Long Lag
negative
0
positive
VOT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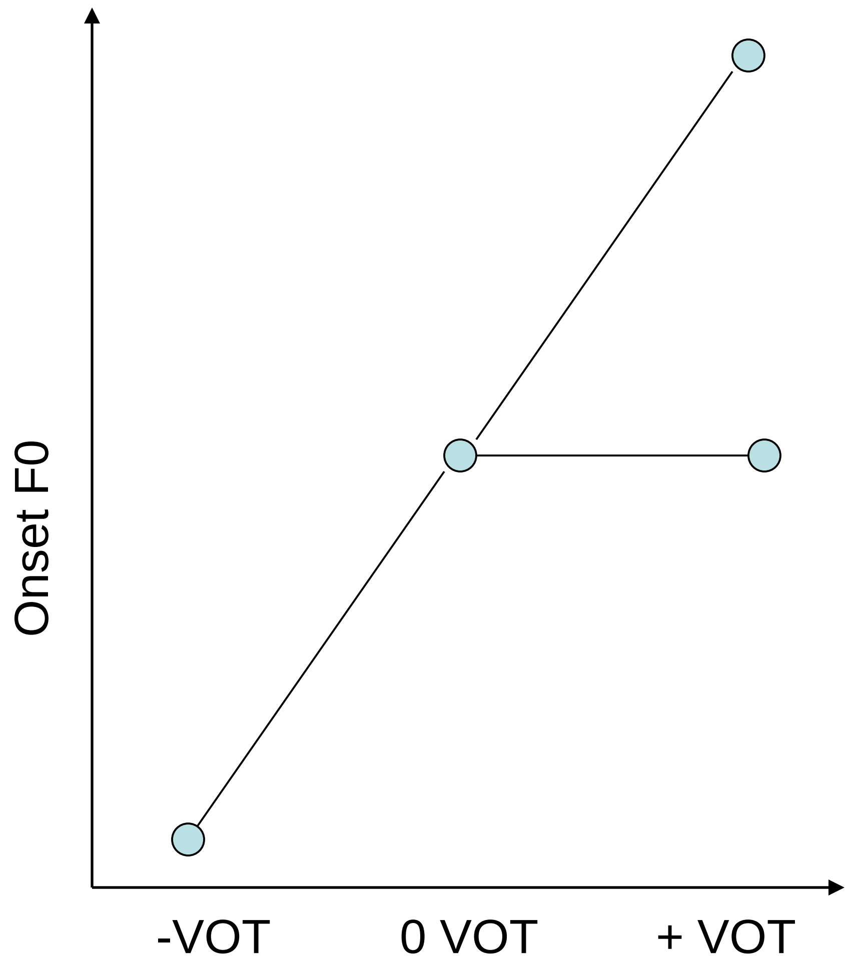
VOT

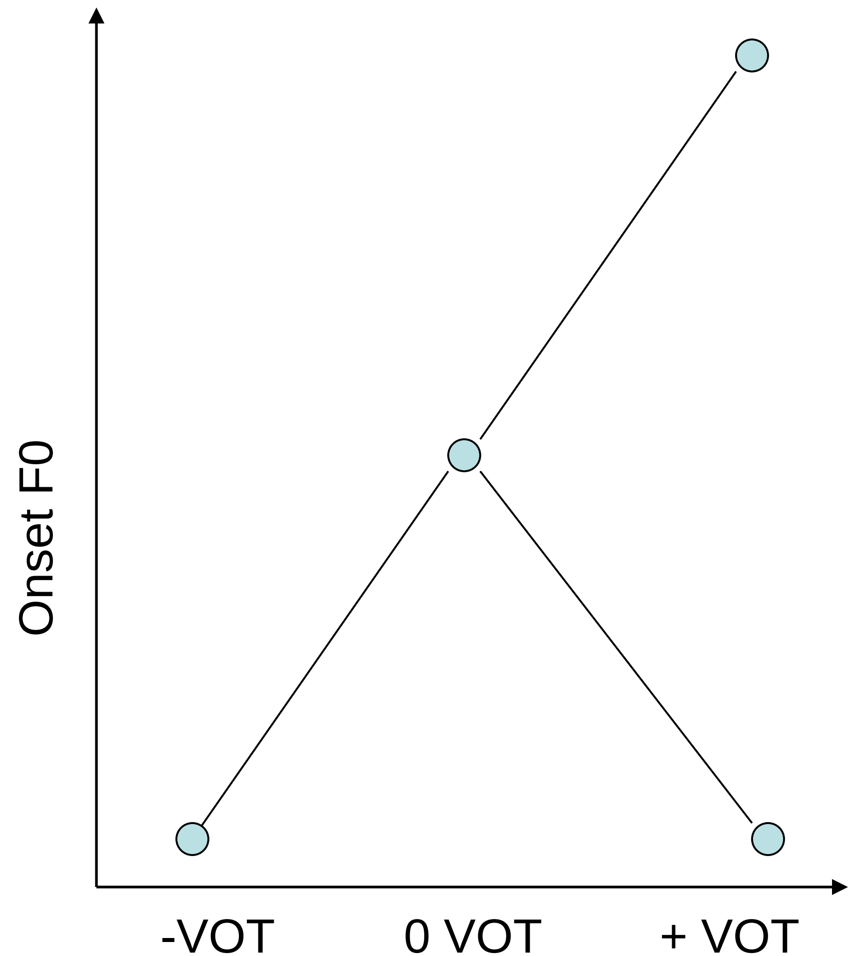
Predictions

- **Phonetic explanation** (automatic):
  - Onset F0 voiceless > voiced: [t], [t^h] > [d] independently of their phonemic status (i.e. in both English and Spanish)
  - Onset F0 [t^h] > [t] (if aerodynamic story is correct), or possibly [t^h] = [t]



Predictions

- **Phonological explanation** (controlled)
  - Difference observed only between those phonetic categories that are also phonologically distinctive
  - Onset F0 voiceless > voiced: [t] > [d]
  - Onset F0 [t^h] > [t] or [t^h] < [t]



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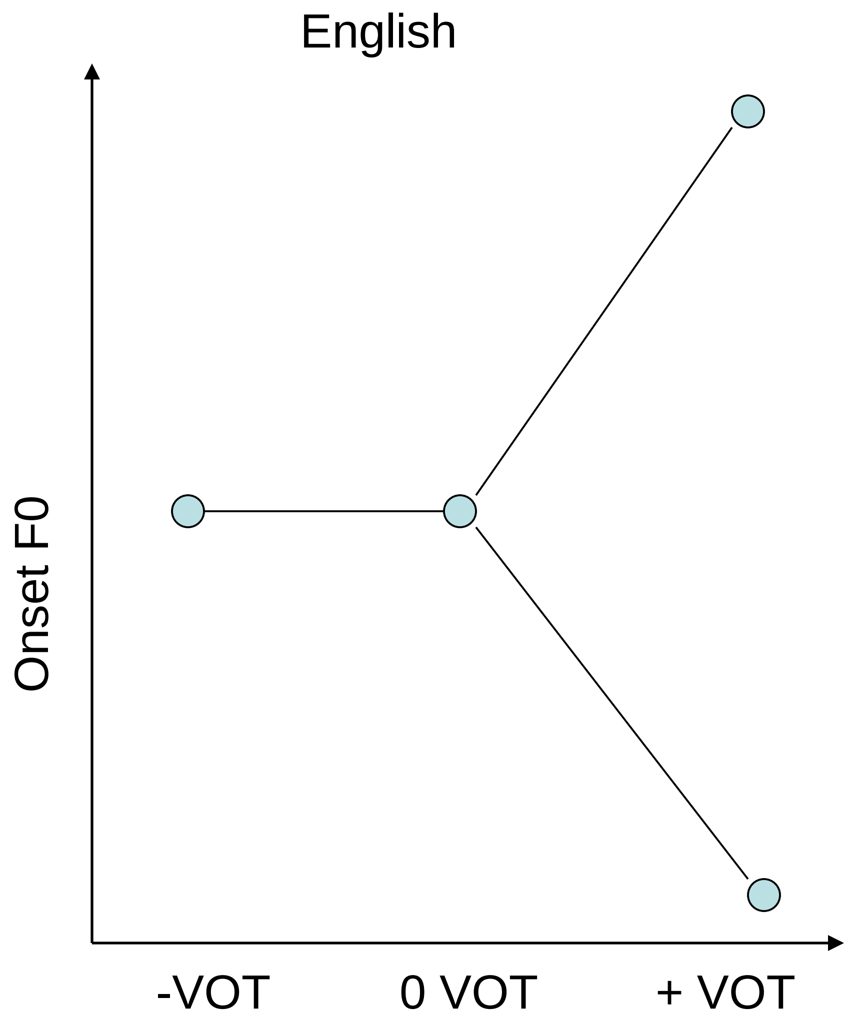

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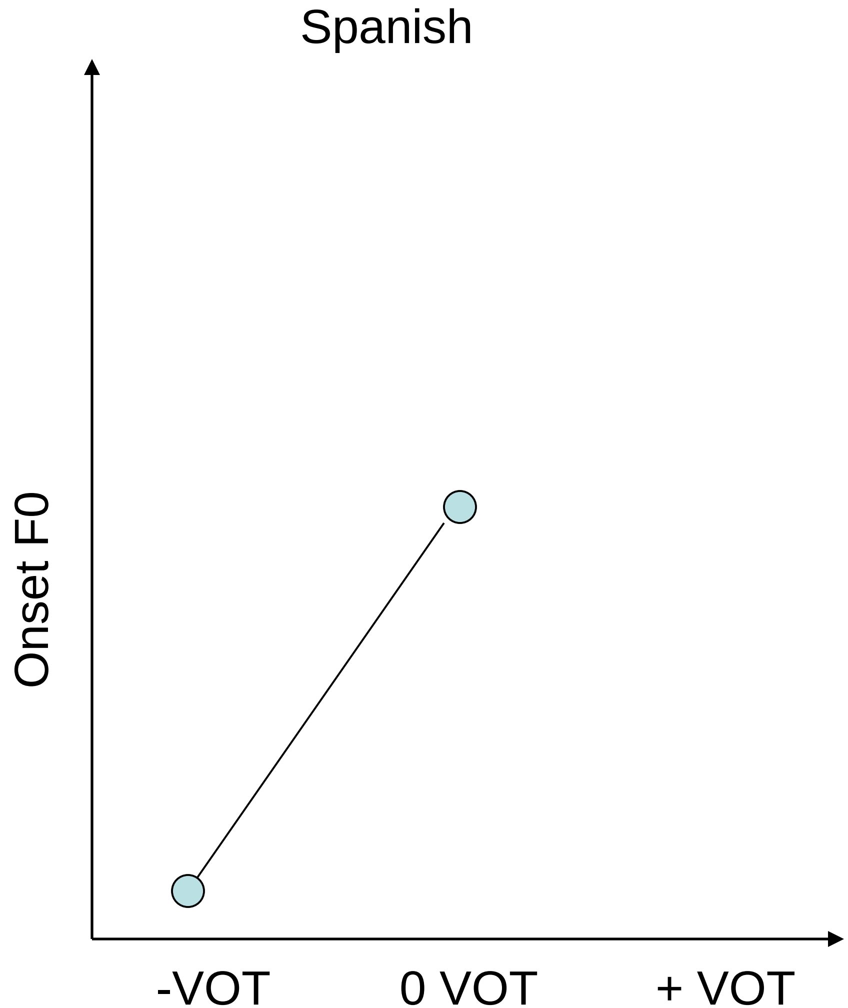


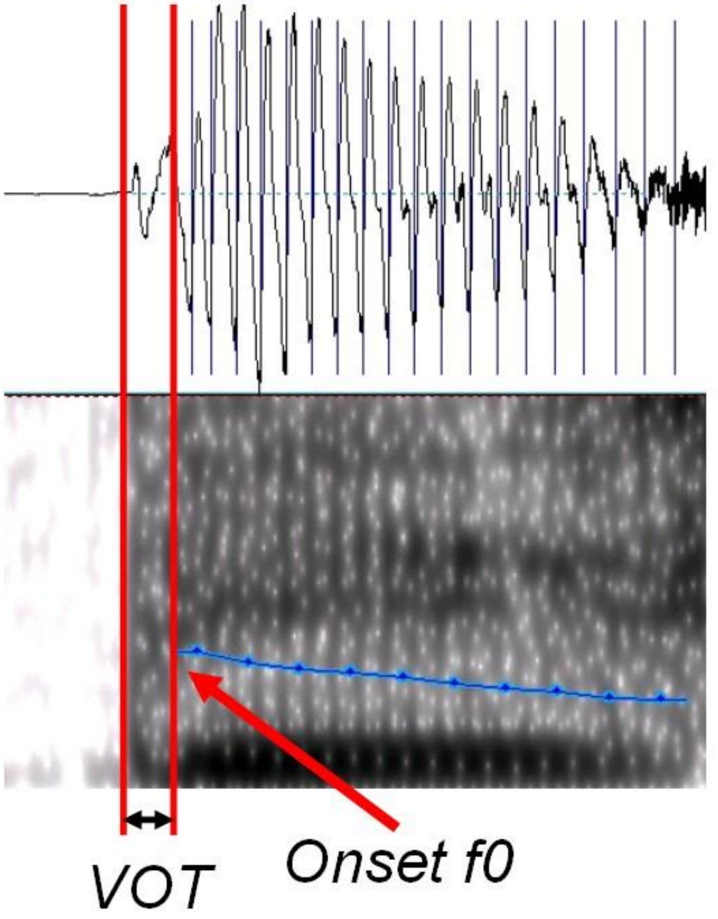
Experiment

- 30 NS Am. English (W. Lafayette, IN), 24 NS Spanish (Madrid, Spain)
- English: 4 b - p min. pairs
  - BAT/PAT + 8 filler pairs
- Spanish: 4 b - p min. pairs
  - BATA/PATA + 8 filler pairs
- Words randomized on screen, 5 blocks, 2 sec + ISI 0.5 sec

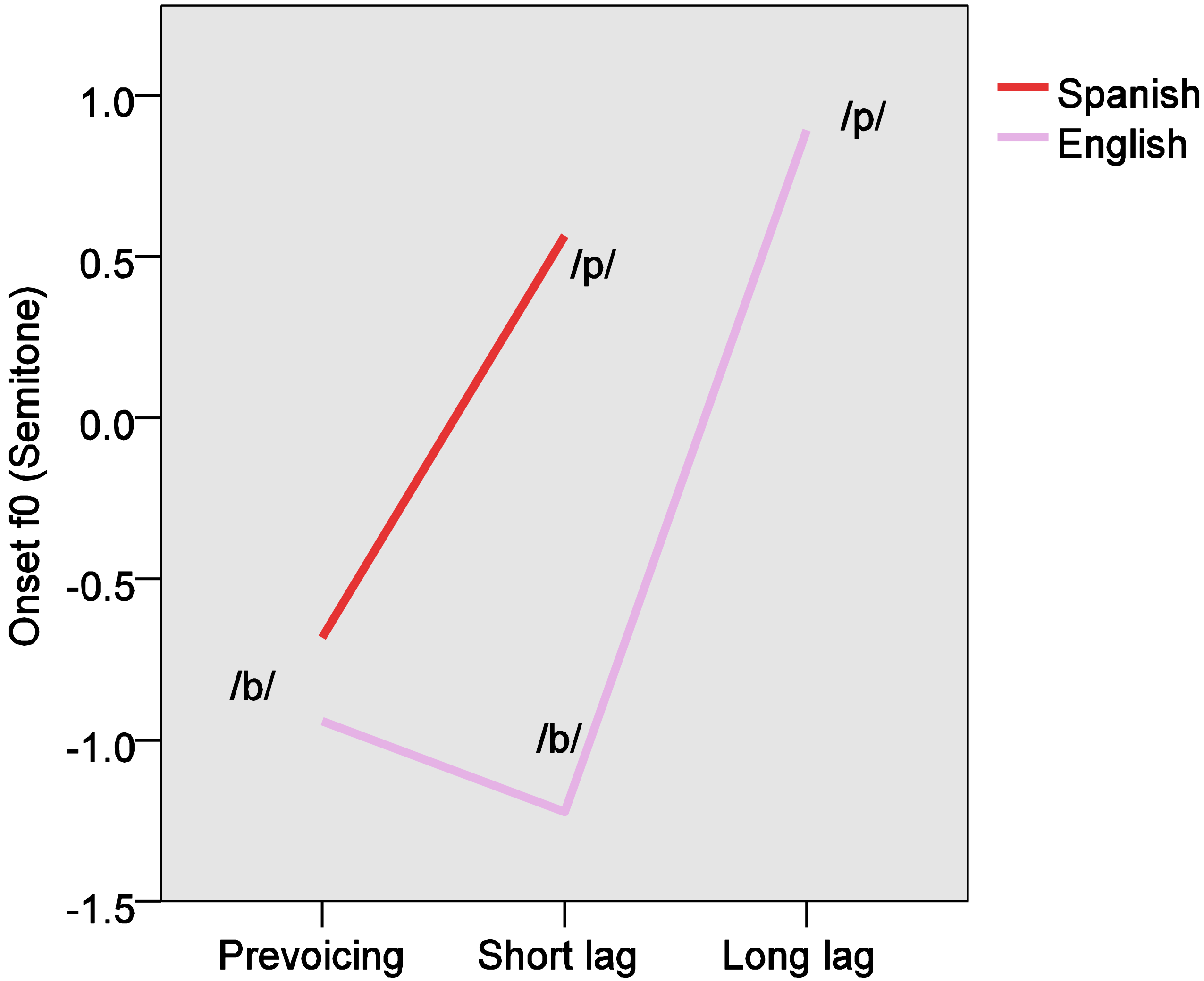
Experiment

- **VOT:**
  – Beginning of the burst to the onset of voicing.
- **Onset f0:**
  – First post-VOT interval at which Praat algorithm detected periodicity.
  – **Onset f0 normalization:**
    - Converted to semitones relative to the mean onset f0 of each speaker:

      12 ln(x / individual mean onset f0) / ln2.



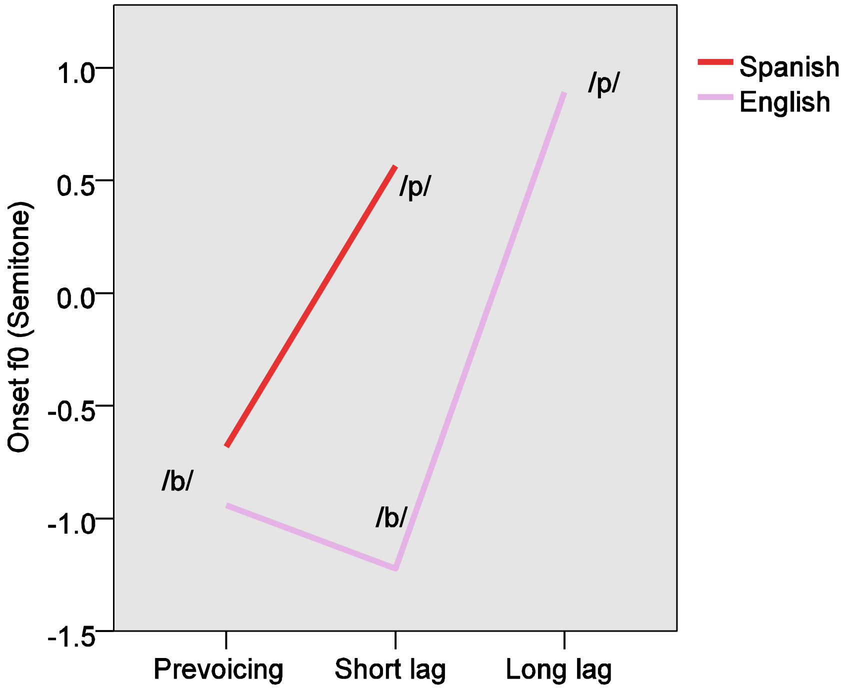
Results

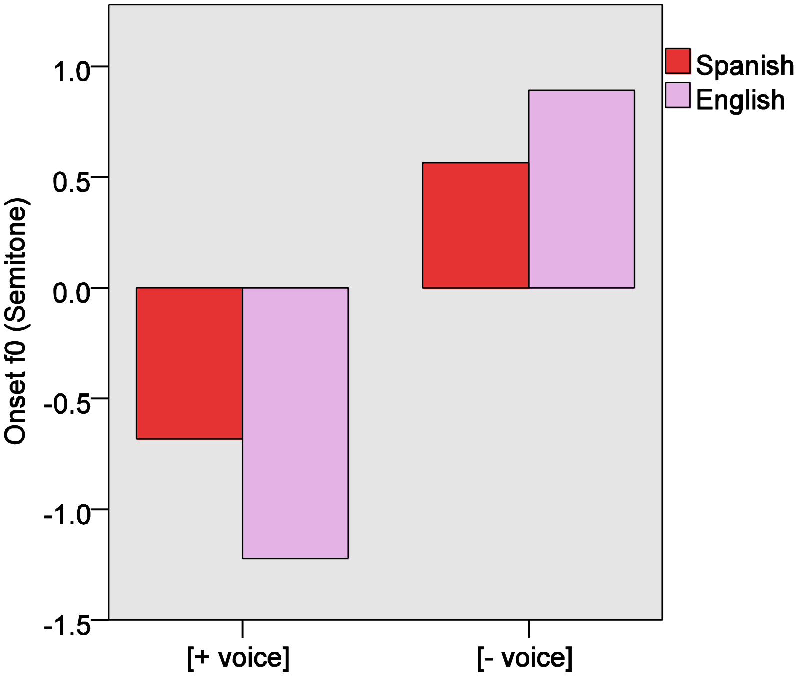


Onset f0 (Semitone)
1.0
0.5
0.0
-0.5
-1.0
-1.5
Prevoicing
Short lag
Long lag
Spanish
English
/p/
/p/
/b/
/b/

Results: by phonological category

- Effect of *Phonological Category* within each language:
  - Onset f0 significantly higher after [-voice] than after [+voice] in both languages ($p < 0.001$).





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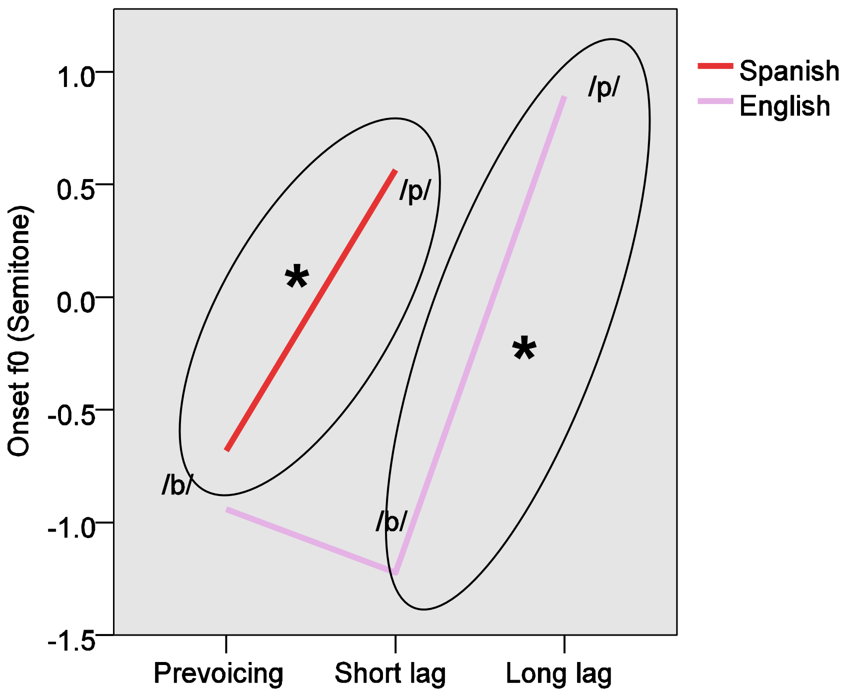
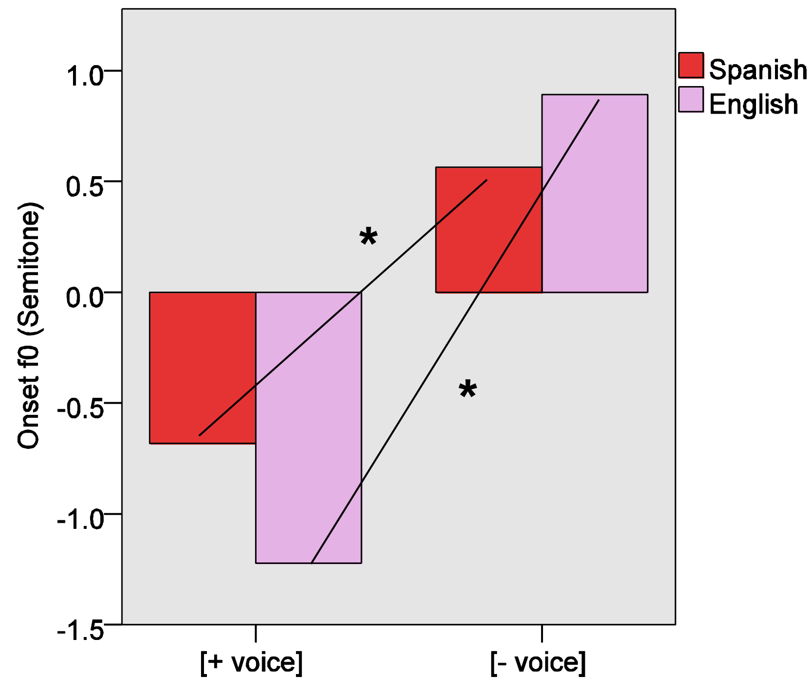


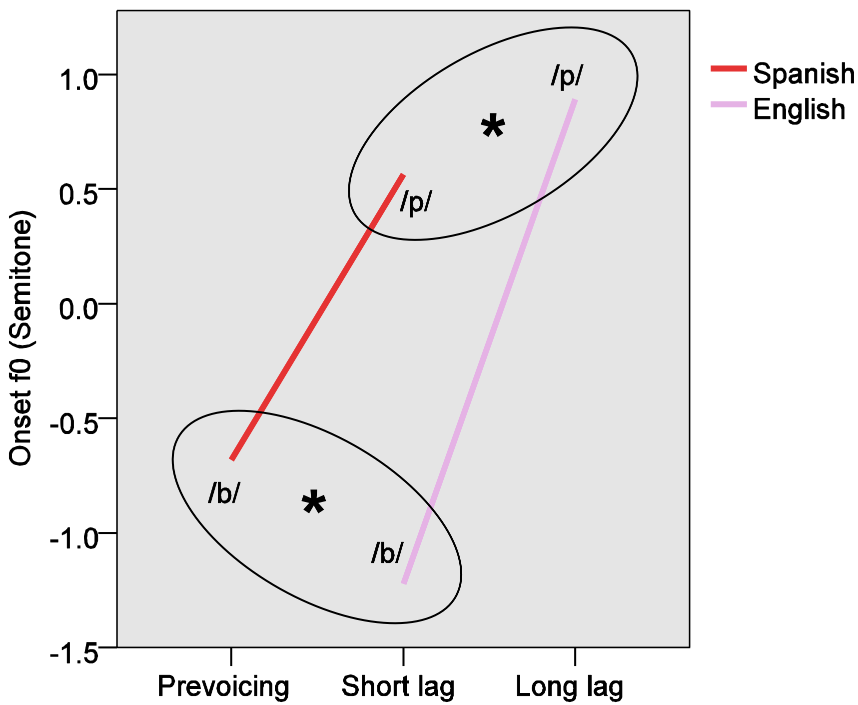


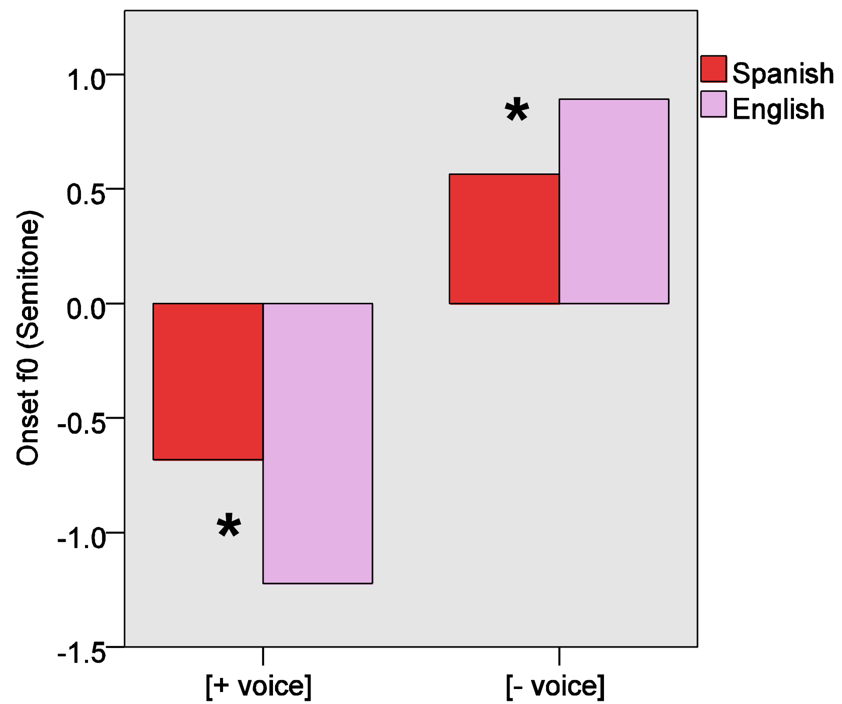
So far…

- **For phonological**: Contrasting phonological categories are well differentiated through onset F0 independently of their phonetic realization.

Results: by phonological category

- Effect of *Language* within each phonological category:
  - **[+voice]** Onset f0 significantly higher in Spanish [+voice] than in English ($p < 0.001$): *[p] < [b] → Greater VOT ≠ higher onset f0 !*
  - **[-voice]** Onset f0 significantly higher in English [-voice] than in Spanish ($p < 0.001$): *[pʰ] > [p]*





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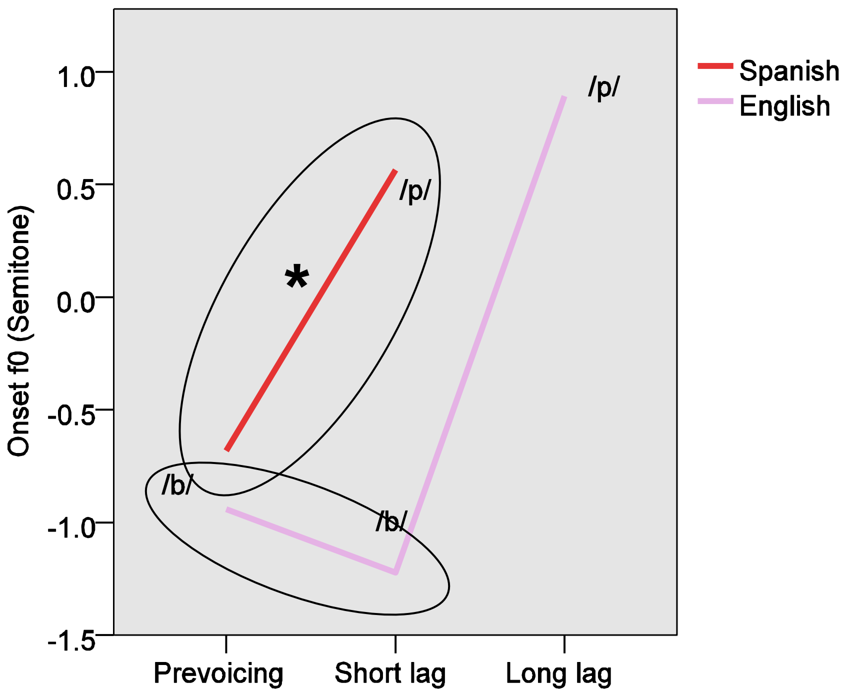
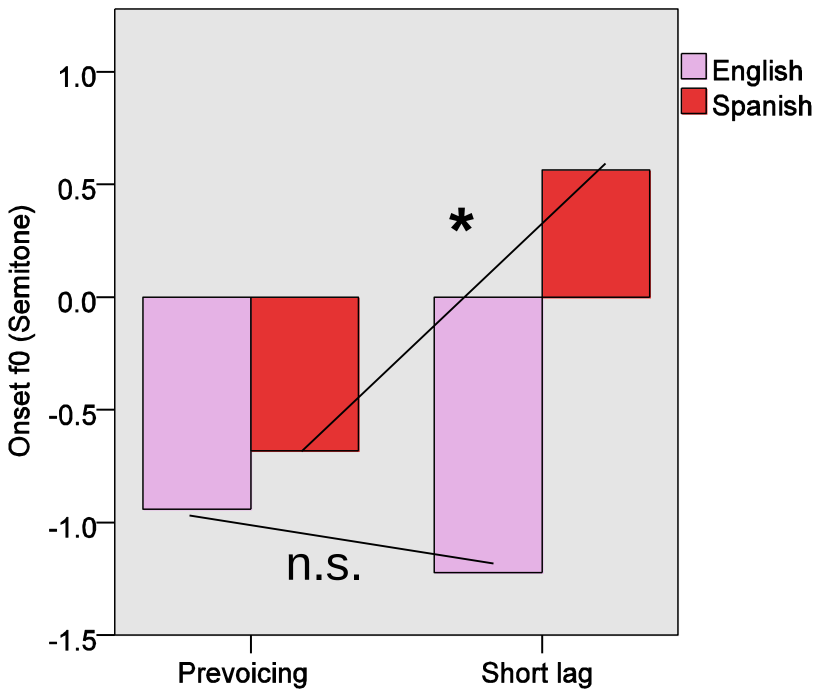
- **Against phonetic**: As much as it is justified to compare these *across* languages, voiced stops are <u>not always</u> lower in onset F0 than voiceless ones.

Results: by phonetic category

- Effect of *Phonetic Category* within each language:
  - **Spanish**: onset F0 significantly higher after voiceless than after voiced ($p < 0.001$): [p] > [b]
  - **English**: non-significant difference in the opposite direction: [p] = [b]





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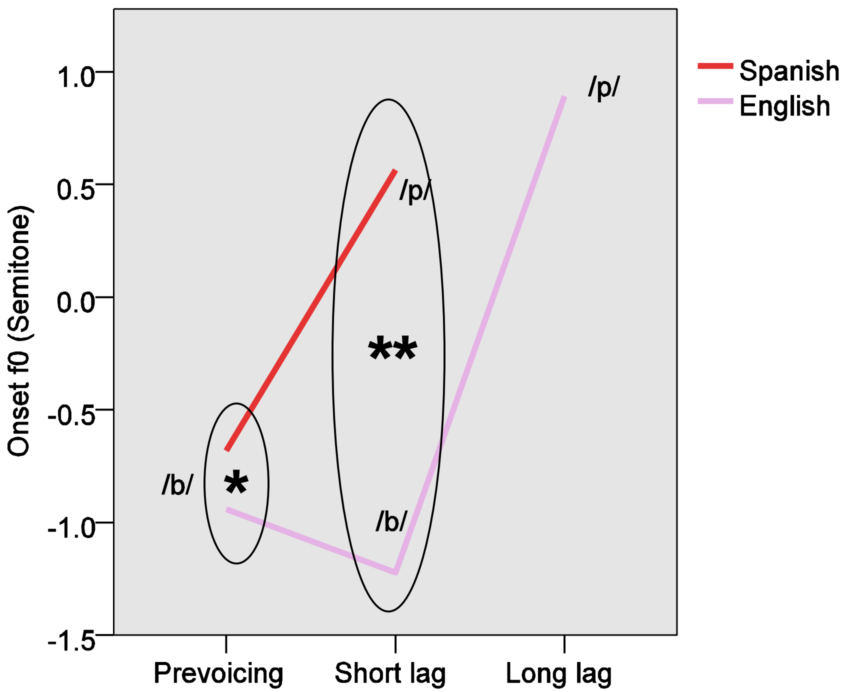
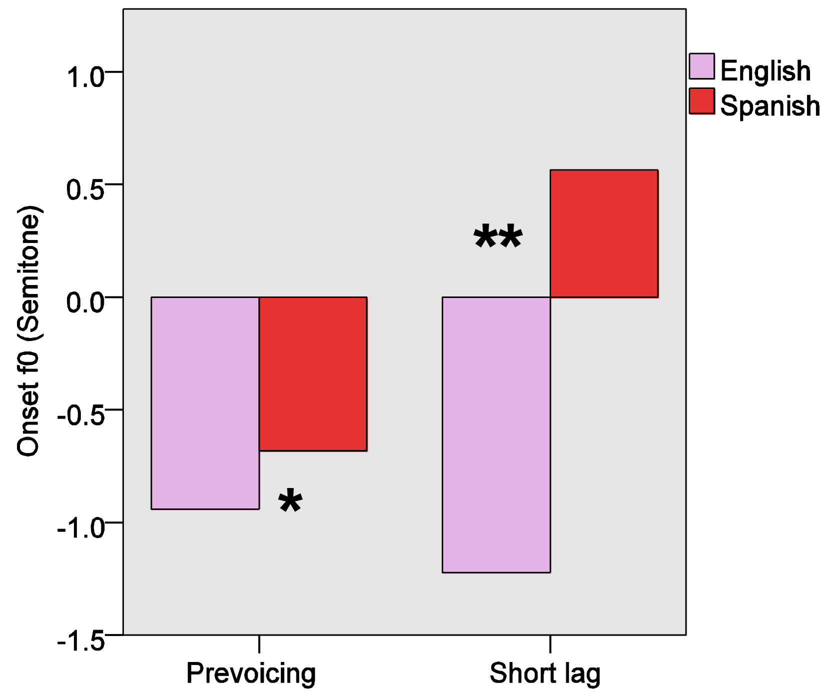
- **Against phonetic**: As much as it is justified to compare these *across* languages, voiced stops are <u>not always</u> lower in onset F0 than voiceless ones.
- **For phonological:** The same phonetic categories are distinguished through onset F0 when contrasting but not when non-contrasting.

Results: by phonetic category

- Effect of *Language* within the shared phonetic categories :
  - **[prevoiced]:** Onset F0 Spanish > English ($p < 0.01$)
  - **[short lag]:** Onset F0 Spanish > English ($p < 0.001$).





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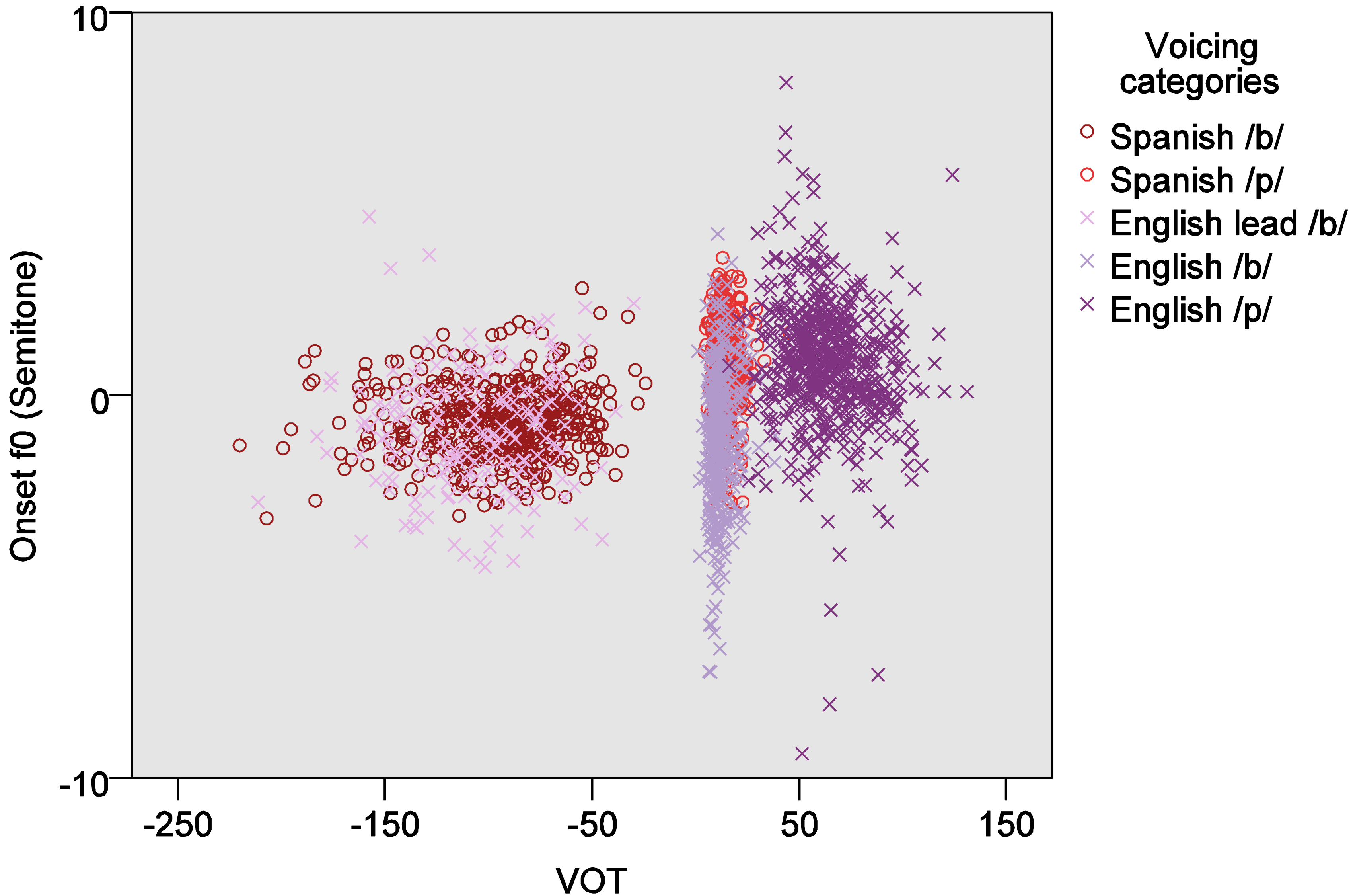
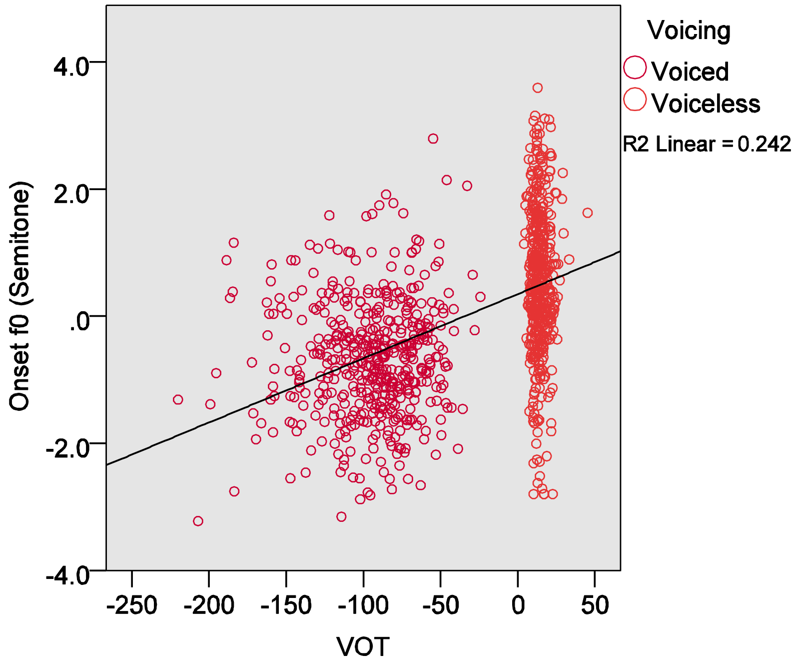
- **Against phonetic**: As much as it is justified to compare these *across* languages, voiced stops are <u>not always</u> lower in onset F0 than voiceless ones.
- **For phonological:** The same phonetic categories are distinguished through onset F0 when contrasting but not when non-contrasting.
- **Against phonetic** (?): The same phonetic categories across languages are not similar in onset F0 values. If language-specific effect why not consistent across categories?

Results: Distribution



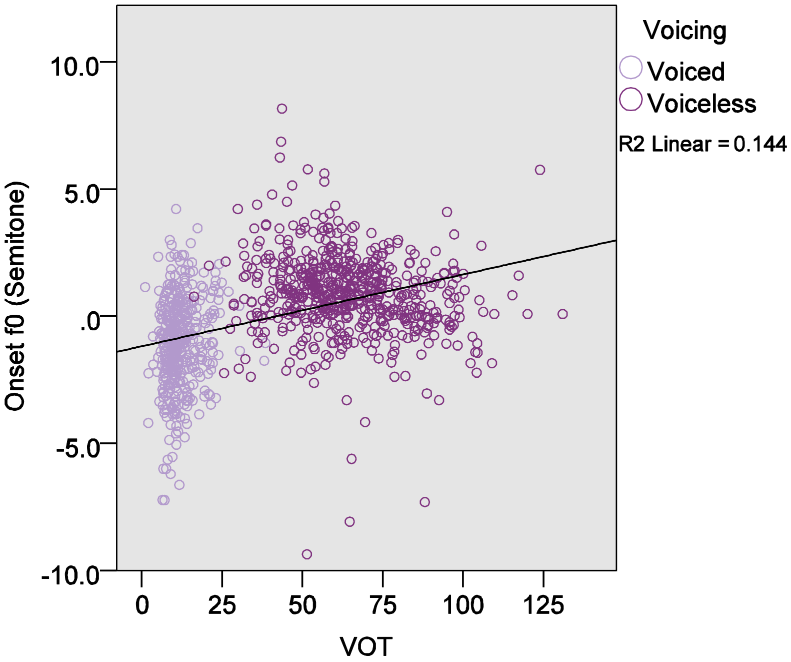
Results: VOT - onset F0 correlation

Spanish



R = 0.49, p < 0.001

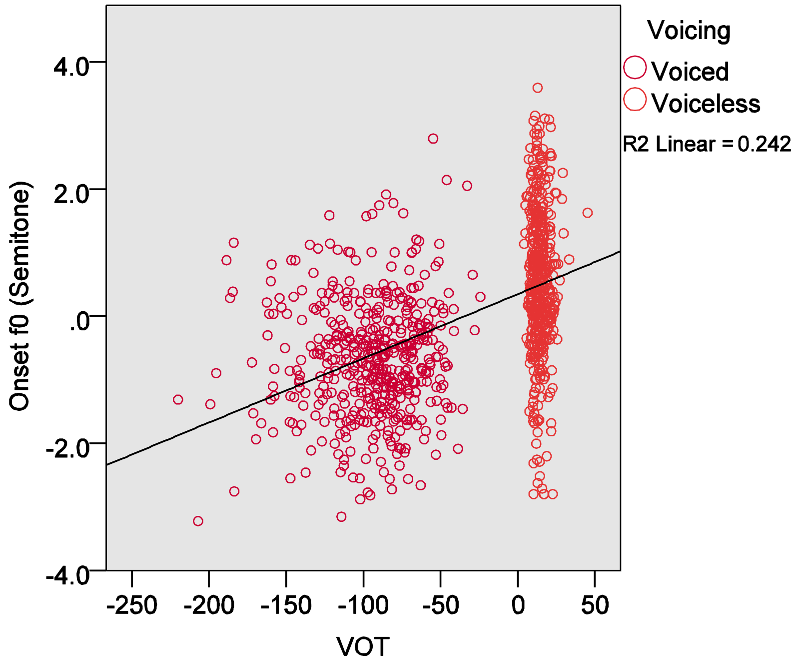
English



R = 0.38, p < 0.001

Results: VOT - onset F0 correlation

Spanish



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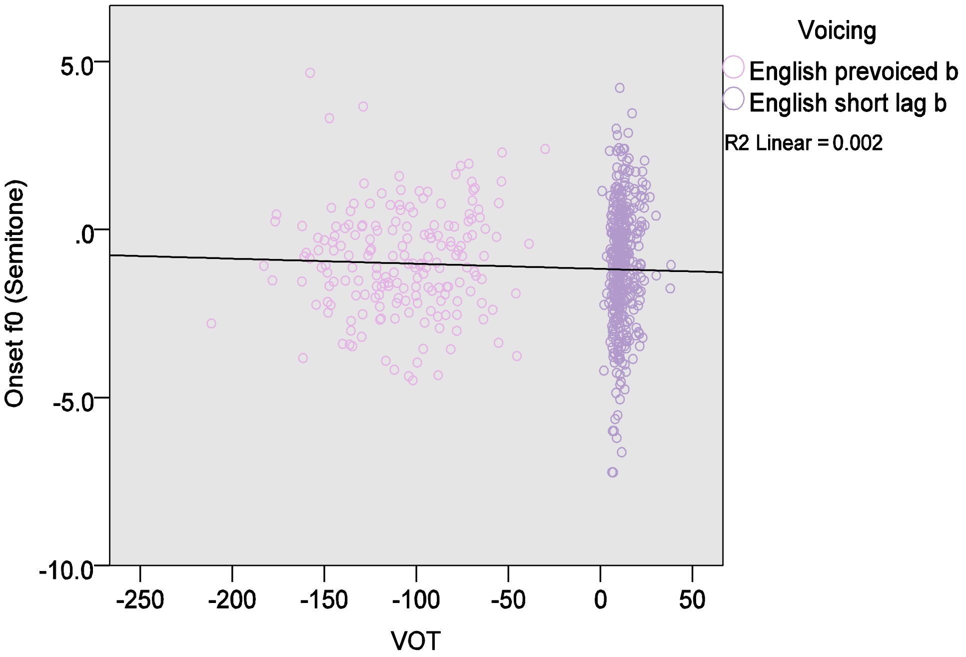
English



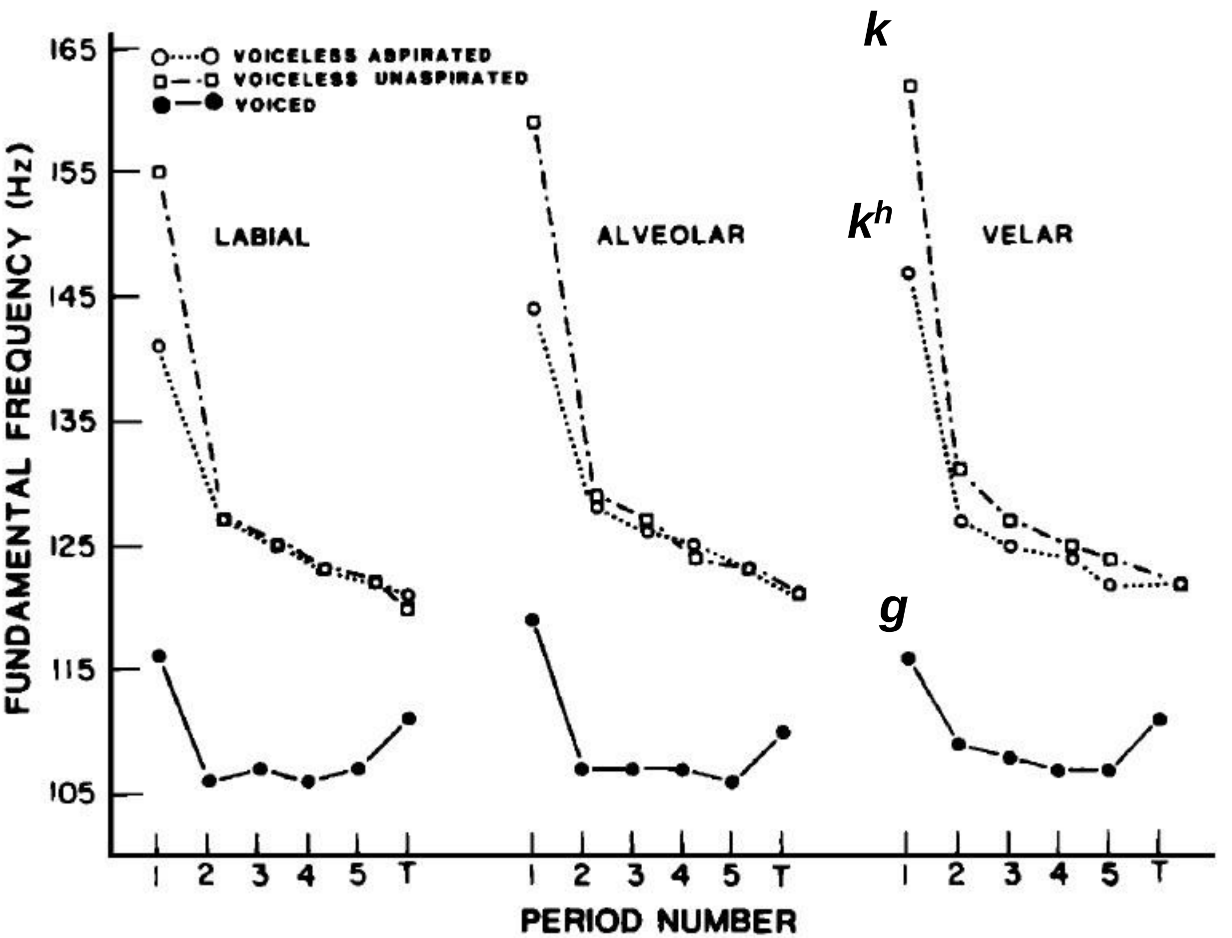
R = - 0.04, n.s.

Conclusions

- Both mean and correlation analyses point towards phonologically-based distribution of onset F0 values:
  - Onset f0 is maximally distinctive between contrasting phonological categories of each language.
  - Equivalent phonetic categories across languages do no agree in onset f0 (short lag [p] and prevoiced [b]).
  - Equivalent phonological categories within language are not distinguished through onset f0 (prevoiced vs. short lag in English).

Ohde 1984

- How do we reconcile these findings with earlier data reported in Onde 1984:



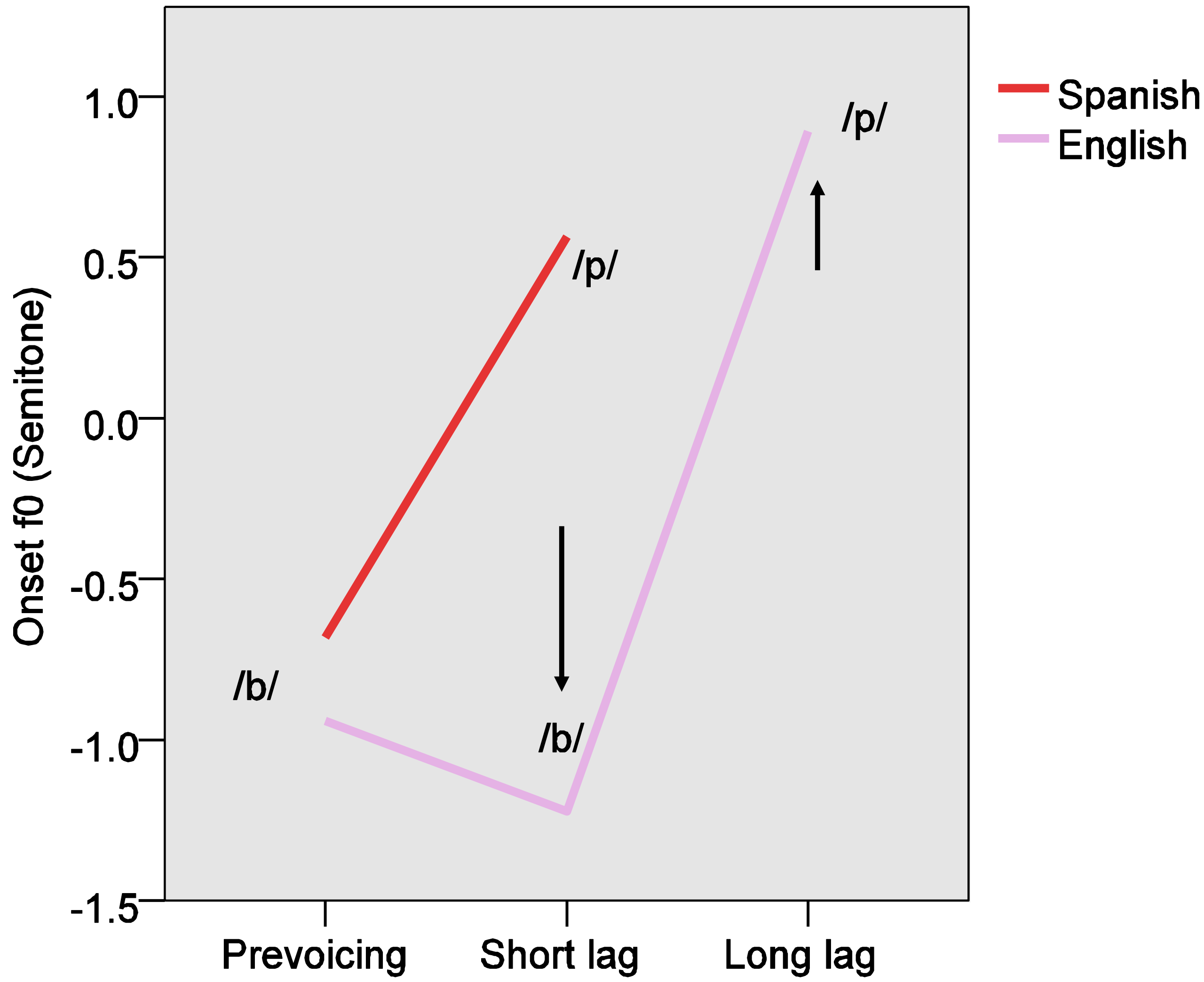
Onde 1984

- Onde 1984: $b < p = p^h$
- Present study: $b = p < p^h$

- Environment matters:
  - Onder 1984: “Say hə CVC again”
  - Where CVC is ***bot***, ***pot*** or ***spot***.
  - In this setting
    - ***[b] in bot*** would be prevoiced and low in onset F0
    - ***[p^h] in pot*** would be aspirated and high in onset F0
    - ***[p] in spot***, is unaspirated and crucially <u>non-contrastive</u> with either [b] or [**p^h**] -> no special care is taken to separate it from either.

Possible interpretation

- The comparison of these two studies suggests that in English syllable-initial stops
  - Onset F0 is actively lowered in voiceless unaspirated in order to provide a better contrast with voiceless aspirated.
  - Possibly, onset F0 is also actively raised in voiceless aspirated.
  - In non-contrastive environments these two are indistinguishable in onset F0.



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Prevoicing
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Spanish
English

Alternative explanations?

- AE are not as familiar with producing prevoiced stops in initial position
  - As a result, their prevoiced stops may not have been always voiced throughout ->
  - A less pronounced effect on onset F0?
- However, AE prevoiced stops are even lower than Spanish in onset F0.
  - It is the voiceless unaspirated where the dramatic difference between two languages is observed.

Phonetics or phonology?

- Probably both:
  - Phonetic tendency, at least, for voiceless consonants to have a higher onset F0 than voiced ones.
  - This difference can be enhanced or suppressed (reversed?) to emphasize phonological contrasts.
  - Evidence for adaptive dispersion theory of contrast (Liljencrants and Lindblom 1972; Lindblom 1986; 1990) in the domain of secondary cues.

Thank you!