Phrase-final creak:
Articulation, acoustics, and distribution

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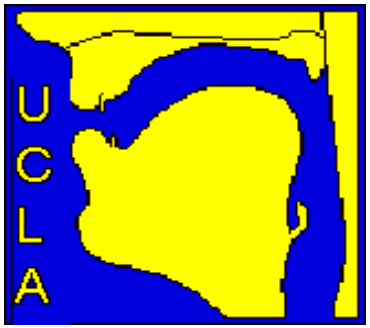


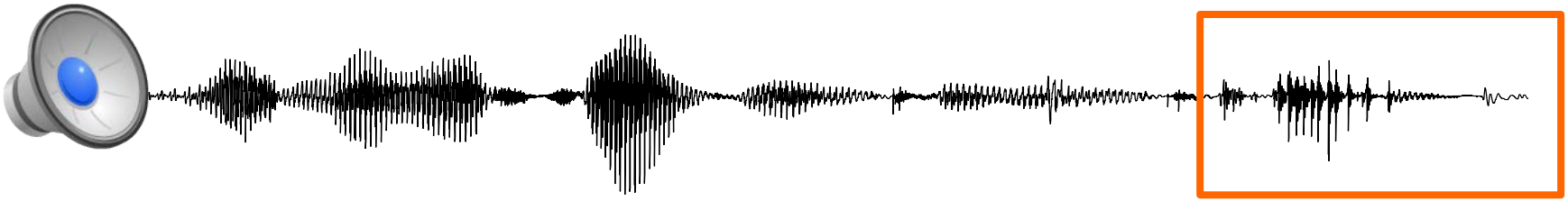
Prototypical creaky voice

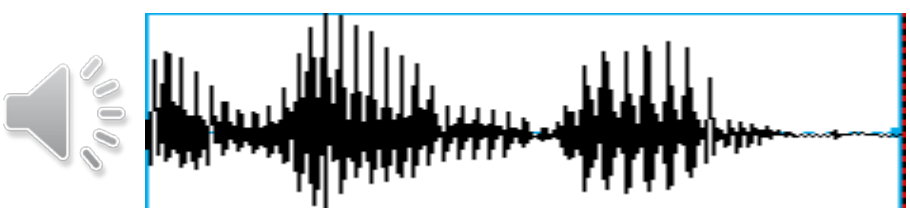
- Low fundamental frequency (F0)
- Irregular F0
- Vocal folds are mostly closed: glottis is constricted
- Low airflow through the glottis
- More energy in higher-frequency harmonics

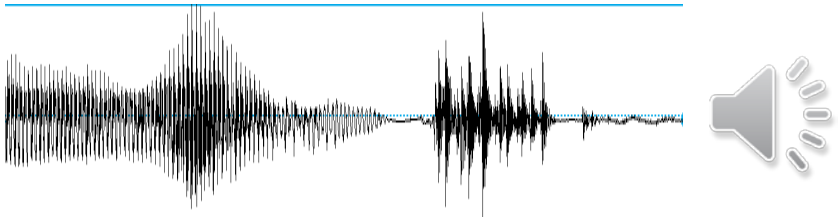
- Creaky voice is common in phrase-final position

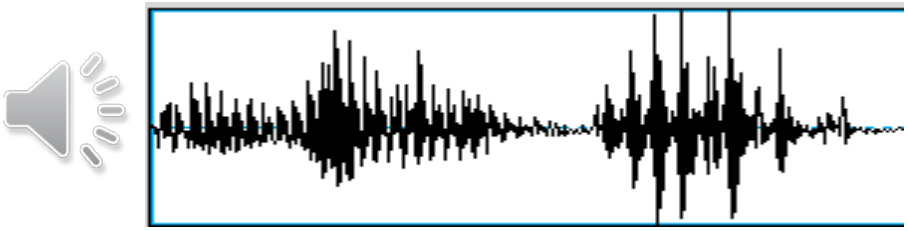
Catford 1966, Laver 1980, Kreiman 1982, Klatt & Klatt 1990, Gordon & Ladefoged 2001

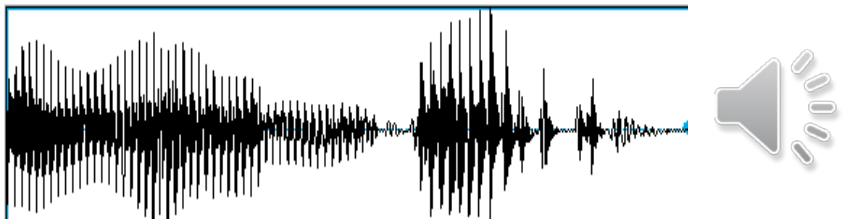
Phrase-final creak

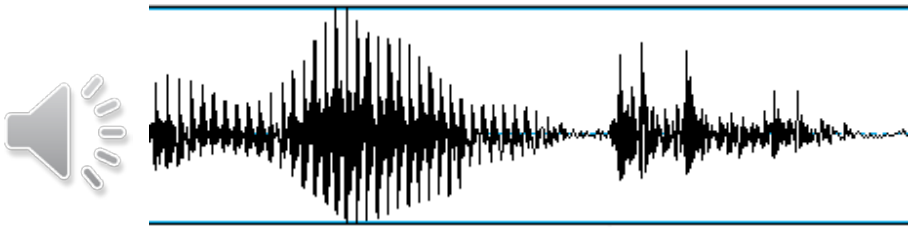


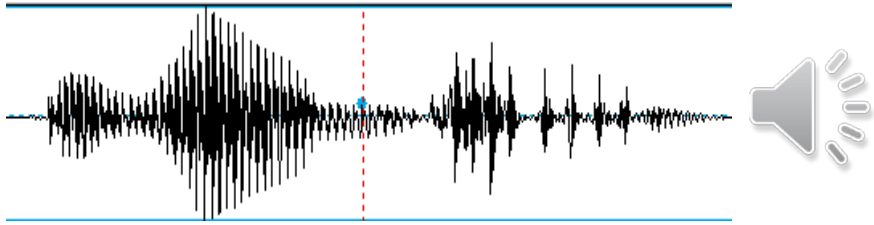












Goals of this study

1. Which phonological/phonetic factors favor the occurrence of phrase-final creak?
2. On what acoustic measures do phrase-final vowels with creaky voice differ from phrase-final vowels without?
3. On what acoustic measures do phrase-final vowels with creaky voice differ from initial vowels with creaky voice?

Factors favoring occurrence

- Incidence of phrase-final creak varies with the kind of phrase: the larger the phrase-type, the more final creak
- We compare 3 levels of phrasing:
  - Utterance (Break Index (BI) “5”)
  - Full Intonational Phrase (BI “4”)
  - Intermediate Intonational Phrase (BI “3”)
- Requires a prosodically-rich corpus

Price et al. 1991, Redi & Shattuck-Hufnagel 2001

Study 1: BU Radio News Corpus

- Four English speakers (2F, 2M)
- Last vowels in phrase-final words (>100 ms of voicing) were extracted: 2086 tokens
- Break indices (3,4,5) were extracted
- Vowels were binary-coded for presence/absence of creaky voice
  - 'Creaky' = percept of creak + presence of F0 irregularity and/or complete damping of pulses

Ostendorf et al. 1995

News Corpus: Factors tested

- Break index
- Presence of pause (and pause length in ms)
- Distance of target phrase from end of Utterance (in number of syllables, phrases)
- Number of words in target phrase
- Duration of phrase (ms)
- Duration from end of phrase to following pitch accent
- Presence of final coda stop
- Fundamental frequency (F0, in Hz) (mean over vowel)

News Corpus: Analysis

- Logistic mixed-effects regression modeling presence of creak as a function of coded factors

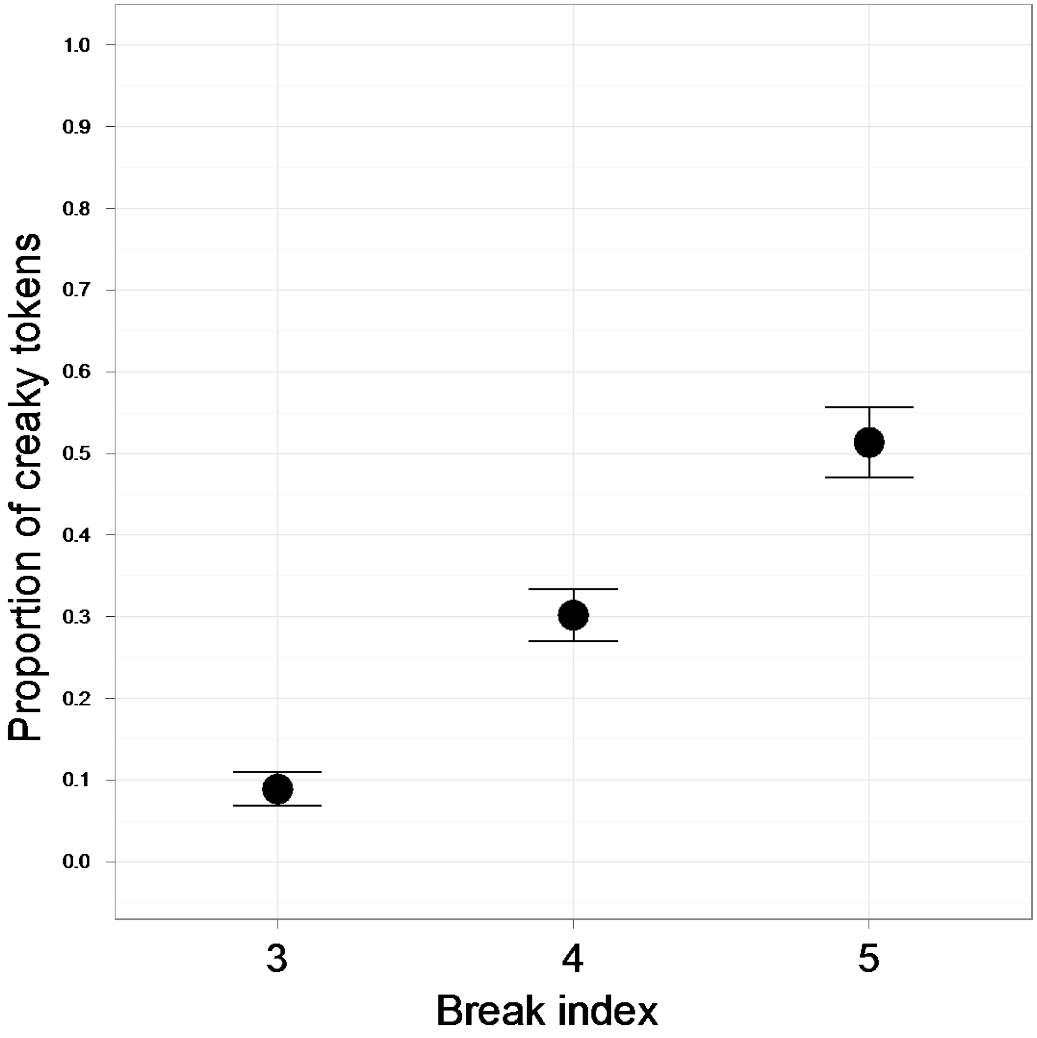
BU Corpus: Results

Only 2 factors make creak more likely:

- Lower F0 (before BI 3, 4)
- Before a bigger phrase break (an effect beyond that of F0)

- No other significant predictors
- Consistent across all 4 speakers

Break Index effect



Higher BI → more likely to have phrase-final creak

Over half of **Utterance-final** tokens have phrase-final creak

Acoustic properties of phrase-final creak

- What acoustic measures distinguish vowels coded as “creaky” vs. “non-creaky”?
- News Corpus speakers all creak ~50% of time Utterance-finally (BI = 5)

Acoustic measures of vowels

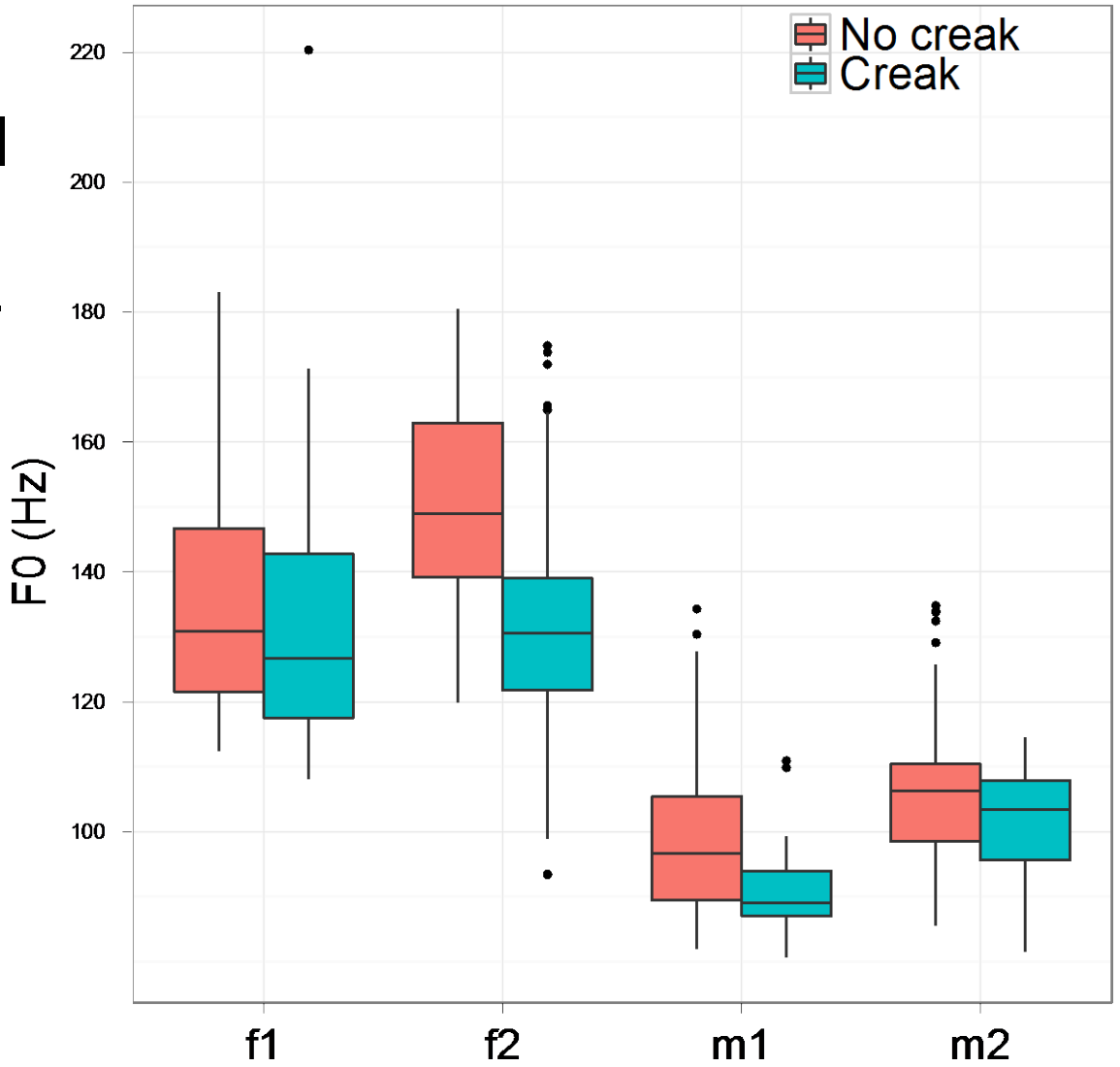
- Fundamental frequency (F0)
- Noise in lowest frequencies (HNR05) – reflects irregularity of voicing, or added noise
- Subharmonics-to-Harmonics ratio (SHR) – reflects additional harmonics added by multiple pulsing
- Relative energy in first 2 harmonics (H1*-H2*) – lower value reflects increased constriction of the glottis

- Assessed using linear mixed-effects regression

Acoustic results: Fundamental Frequency (F0)

Lower for creaky Utt-final vowels than for non-creaky Utt-final vowels for all speakers

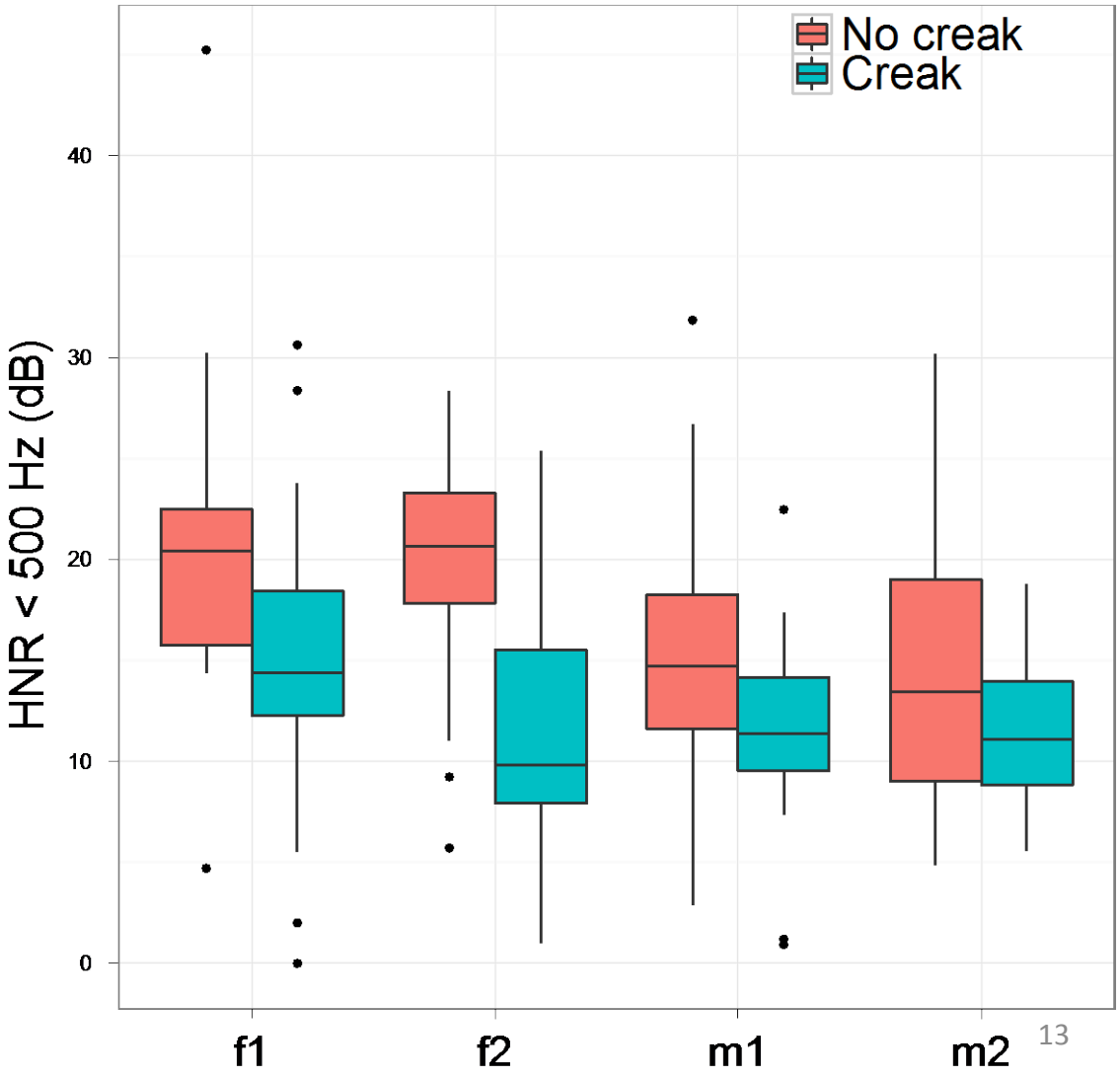
= Lower F0 in creak



Acoustic results: Harmonics-to-noise ratio (HNR)

Lower for creaky Utt-final vowels than for non-creaky Utt-final vowels for all speakers

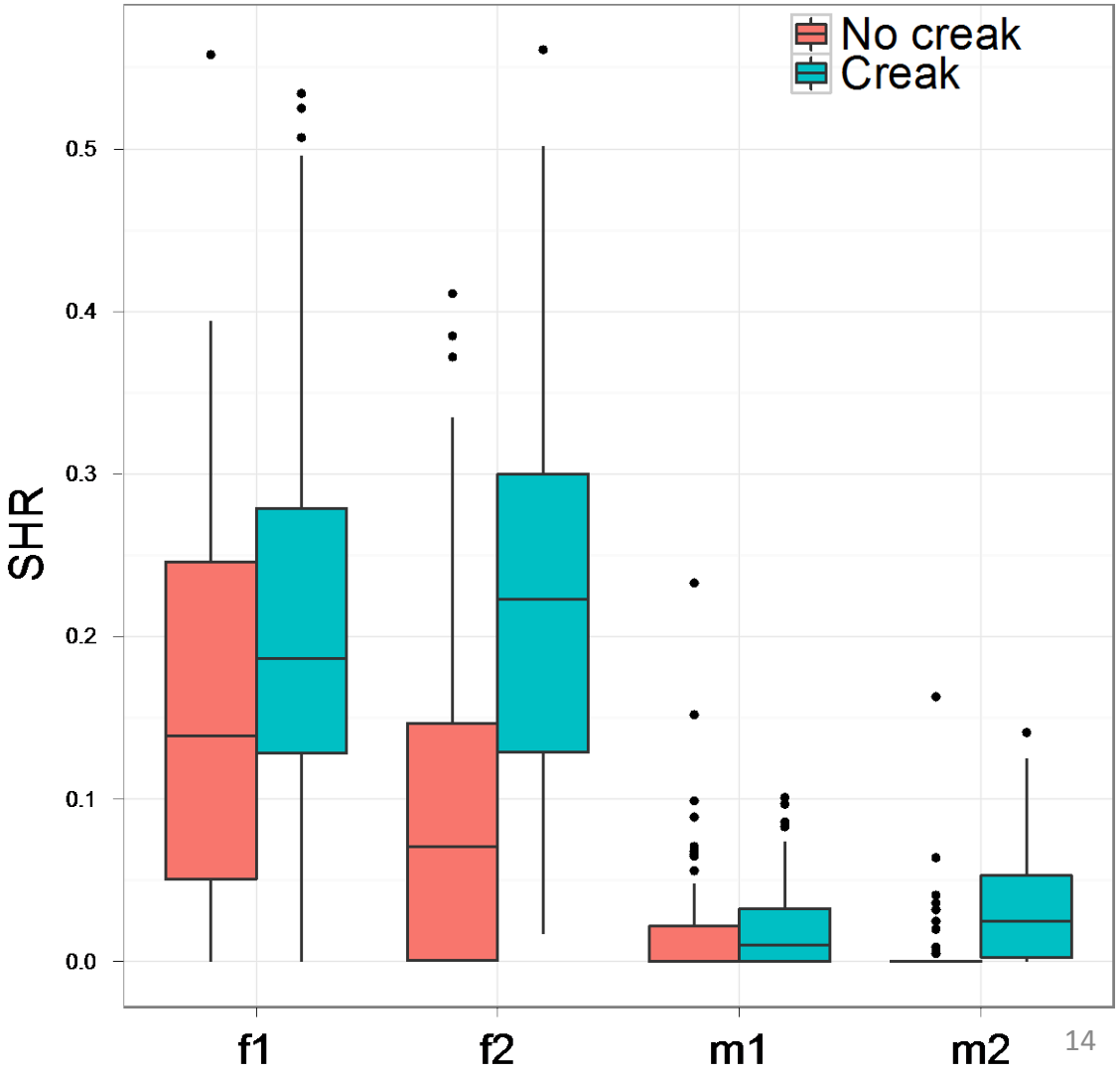
= More **aperiodicity** in creak



Acoustic results: Subharmonics-to-harmonics ratio (SHR)

Higher for creaky Utt-final vowels than for non-creaky Utt-final vowels for all speakers

More **subharmonics (multiple pulsing)** in creak

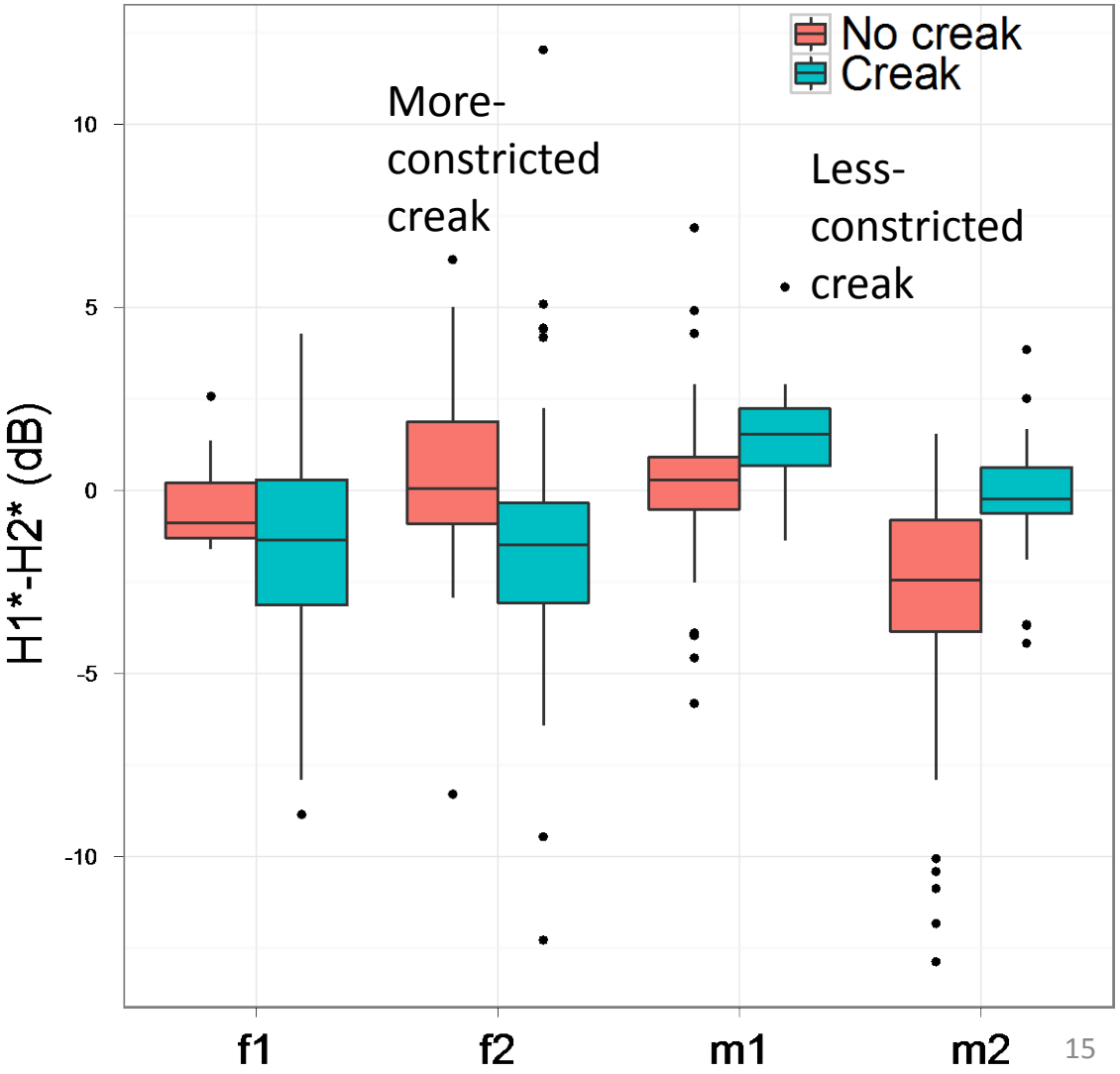


Acoustic results: H1*-H2* (glottal constriction)

Not sig. for f1

Lower for **creaky** than for non-creaky for f2 (**more constricted**)

Higher for **creaky** than for non-creaky for m1, m2 (**less constricted**)



Interim summary

- Utt-final vowels coded as “creaky” are:
  - Lower-pitched
  - Noisier
  - More multiply-pulsed voicing
  - For 1 speaker more constricted, for 2 others less constricted

compared to Utt-final vowels coded as “non-creaky”

Interim summary

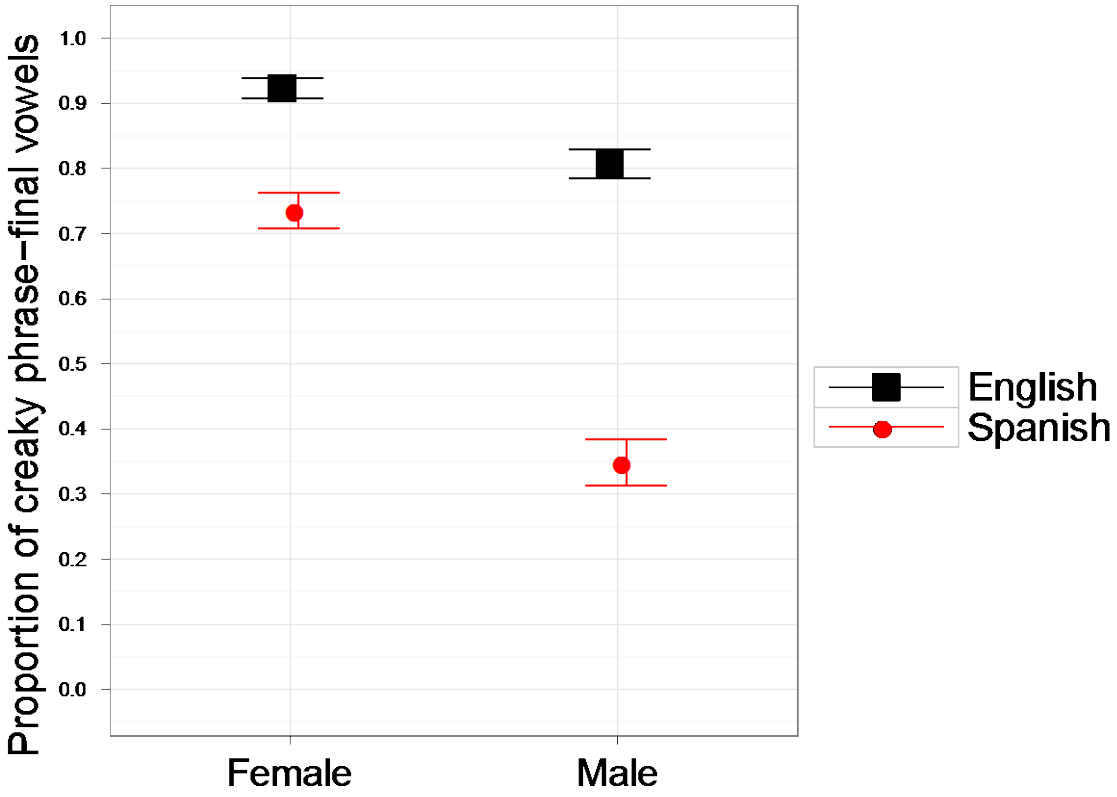
- Cross-speaker differences in H1*-H2* are not unexpected:
  - Prototypical creaky voice is generally more constricted, but:
  - Slifka (2006) found evidence for **less constriction** in Utterance-final creak – the glottis opens, lung pressure drops, and voicing begins to fail, irregular but breathy
  - **How common is less-constricted creaky voice?**
- Next corpus is larger: 12 speakers of English, 12 of Spanish
  - Younger speakers, more phrase-final creak

Study 2: English/Spanish sentence corpus

- Audio recordings from Garellek (2014)
- 12 English (6 F, 6 M) and 12 Spanish speakers (7 F, 5 M)
- Sentence-reading task:
  - English sentences end in ‘today’, ‘day’, ‘slept’, ‘trip’, ‘week’
  - Spanish sentences end in ‘dia’, ‘encontrarla’, ‘ella’, ‘fuimos’
- These words were coded for presence/absence of creak, just as in News Corpus study (here, Utterance-finally)

English/Spanish corpus: Incidence of phrase-final creak

- English speakers creak more
- Women creak more
- Spanish men less
- Overall incidence is higher than in News Corpus



Analysis of 9 speakers

We identified 9 speakers who had good distributions of both creaky and non-creaky phrase-final vowels (> 15%) :

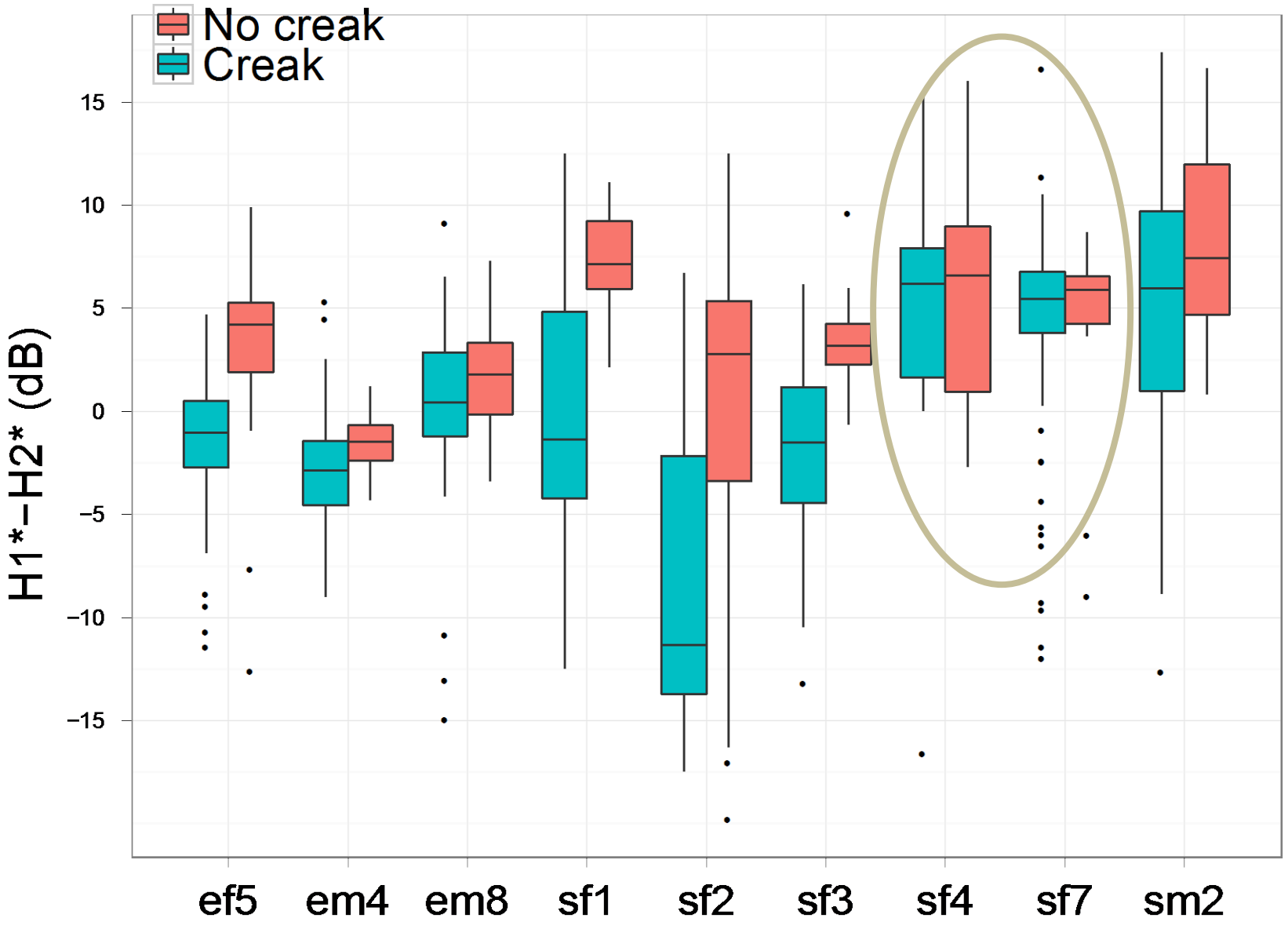
- 6 Spanish speakers (1 M)
- 3 English speakers (2 M)

English/Spanish corpus: Acoustic analysis

- Same acoustic measures as in News Corpus: F0, HNR, SHR, and H1*-H2*
  - Recall, cross-speaker differences in H1*-H2* for creaky vs. non-creaky Utterance-final vowels in News Corpus
- Statistical analysis: linear mixed-effects regression models comparing creaky vs. non-creaky tokens

English/Spanish corpus: Acoustic results

- Like in the News Corpus, Utterance-final creaky voice (compared to non-creaky) is:
  - Lower in F0
  - Noisier/less periodic
  - More period-doubled
- Unlike News Corpus, effect of creaky voice is usually lowering of H1*-H2* (constriction)
  - Except for 2 speakers (sf4, sf7), where no difference is found. No speakers had higher H1*-H2* in creaky voice.


No creak
Creak
H1*–H2* (dB)
15
10
5
0
−5
−10
−15
ef5
em4
em8
sf1
sf2
sf3
sf4
sf7
sm2

Study 3: Initial vs. final creaky voice

- In same corpus, English sentences also had phrase-initial creaky voice
  - ‘glottalization’ of prominent word-initial vowels like *Anna* [ˈ(ʔ)æ̰nə]
- How does Utterance-final creak compare with the phrase-initial creak?

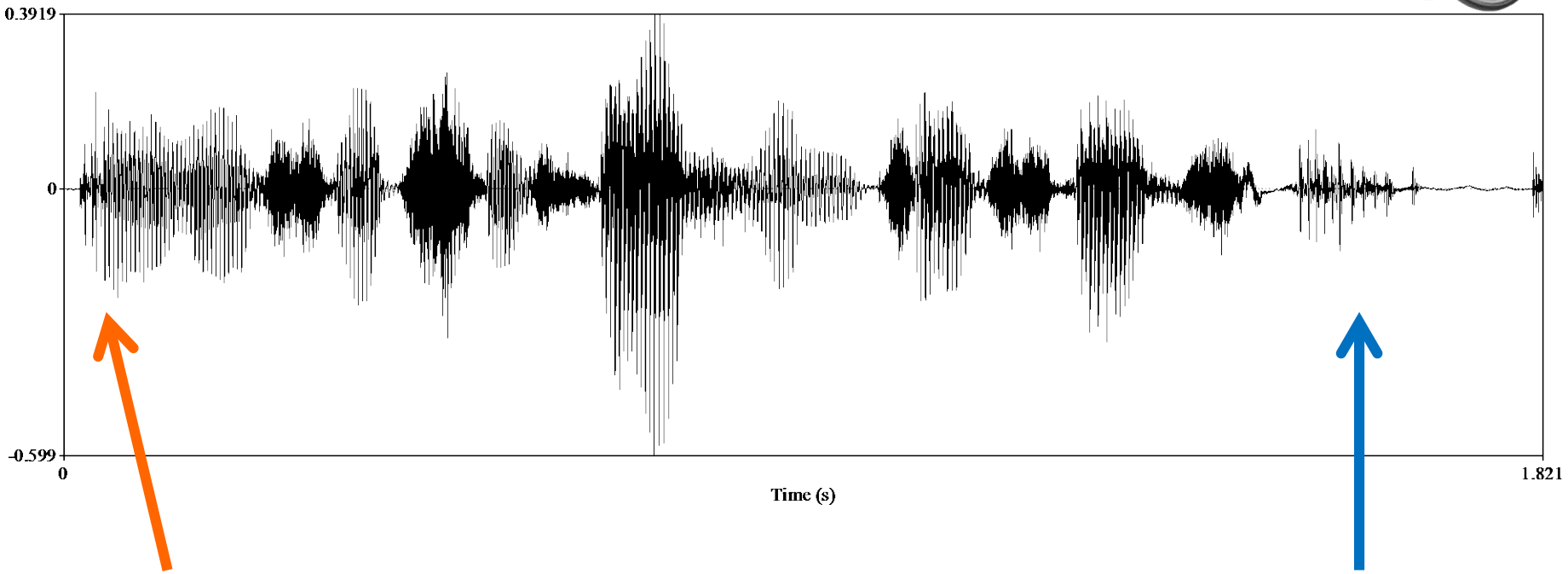
Garellek 2014

Initial vs. final creaky voice

- They depend on different factors:
  - Phrase-final creak is F0 dependent; initial creaky voice is not
  - Phrase-final creak extends over multiple segments/words; initial creaky voice is only on initial vowels
  - Phrase-final creak is not prominence-sensitive; initial creak is
- They might well have different sources, and therefore differ acoustically

Garellek 2014

Initial vs. final creaky voice



‘**Anna** said she saw him just last **week**.’

English sentence corpus

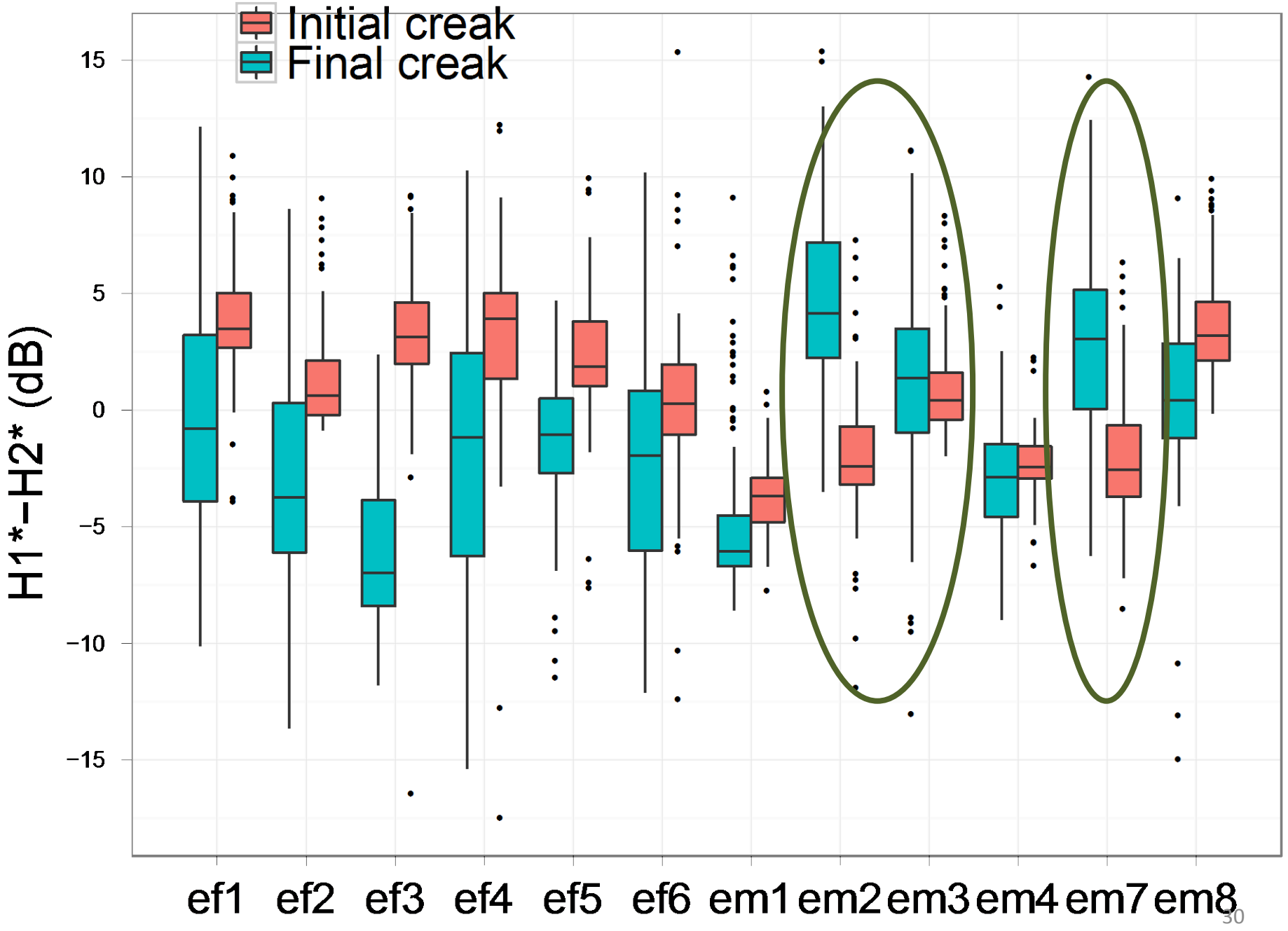
- In English/Spanish sentence corpus, only English speakers creak in both positions
- 12 English speakers' sentences
  - 2079 creaky final vowels
  - 835 creaky initial vowels
- Same acoustic measures as before
- Similar statistical comparisons as before (no language comparison)

English sentence corpus: Acoustic results

- Fundamental frequency (F0)
  - **Lower for creaky Utt-final** vowels than for creaky phrase-initial vowels, for all speakers
- Harmonics-to-noise ratio (HNR05)
  - **Lower for creaky Utt-final** vowels than for creaky phrase-initial vowels, for all speakers
- Sub-harmonics-to-Harmonics ratio (SHR)
  - **Higher for creaky Utt-final** vowels than for creaky phrase-initial vowels, for all but one speaker
- **Utterance-final creak is thus generally creakier than phrase-initial creak**

English sentence corpus: Acoustic results

- Relative energy in first 2 harmonics (H1*-H2*)
  - **Lower H1*-H2* (more constricted)** for creaky Utt-final vowels than for creaky phrase-initial vowels, for all but 3 speakers, for whom final creak has **higher H1*-H2* (less constricted)**
  - These differences are often quite large
- **Utterance-final creak is thus generally, though not always, more constricted than phrase-initial creak**


Initial creak
Final creak
H1*–H2* (dB)
15
10
5
0
−5
−10
−15
ef1
ef2
ef3
ef4
ef5
ef6
em1
em2
em3
em4
em7
em8

Summary

- Study 1: Phrase-final creak is more likely at ends of higher phrases, and with lower F0; no other factors tested mattered
- Study 1+2: Utterance-final creak differs from non-creak by its
  - Lower F0 and periodicity
  - H1*-H2* generally lower (more constriction)
- Study 3: Utterance-final creak differs from phrase-initial creak by its
  - Lower F0 and periodicity
  - H1*-H2* generally lower (more constriction)

Phrase-final creak: Conclusions

- Why do we do it?
  - To reach a low F0 target
  - To signal end of phrase
- How do we do it?
  - Usually by increased glottal constriction
  - Always by less periodic voicing

Thank you!