2pSC23

Shannon entropy predicts the sonority status of natural classes in English

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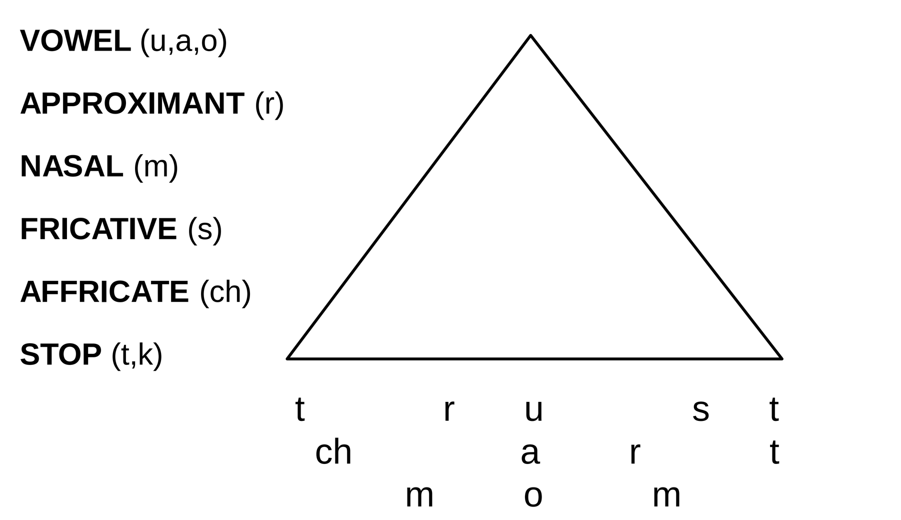
INTRODUCTION

THE SONORITY SEQUENCING PRINCIPLE (SSP)

- Speech sounds tend to occur within the **syllable** according to specific patterns of co-occurrence that are predictable from the following minimal **hierarchy of sonority** classes (Clements, 1990)

Vowel > Approximant > Nasal > Fricative > Affricate > Stop

- According to SSP, sounds near the nuclear position of the syllable tends to rank higher in the sonority hierarchy than peripheral sounds



- The SSP holds for all languages with a few exceptions, like in English, in which pre-nuclear stops can be preceded by fricatives (e.g. spot, string; Kawasaki & Ohala, 1997)
- During the last several decades, linguists have searched for an acoustic correlate of the sonority hierarchy to establish the acoustic basis of the syllable (Clements, 2009)

THE PRESENT STUDY

- In the present study, we introduce a new measure of **spectral complexity**, inspired in Shannon entropy (see *Methods I*), that classifies natural American English classes according to the sonority hierarchy
- The accuracy of spectral complexity in the estimation of sonority was compared with the one of intensity, the acoustic feature with the highest degree of correlation between natural class and sonority (Parker, 2002)

ROADMAP

- All English sounds included in the TIMIT database (see *Methods II*) were grouped into the 6 sonority classes mentioned above
- Spectral complexity and intensity were measured for each sound
- Accuracy for sorting speech sounds into the sonority hierarchy was estimated by two ANOVAs, with sonority class as the IV and either spectral complexity or intensity as the DV

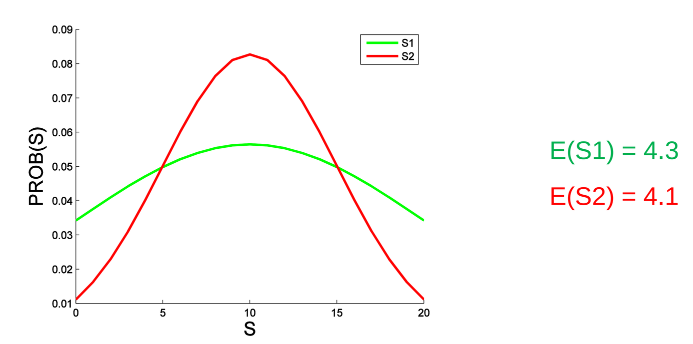
METHODS I

SPECTRAL COMPLEXITY

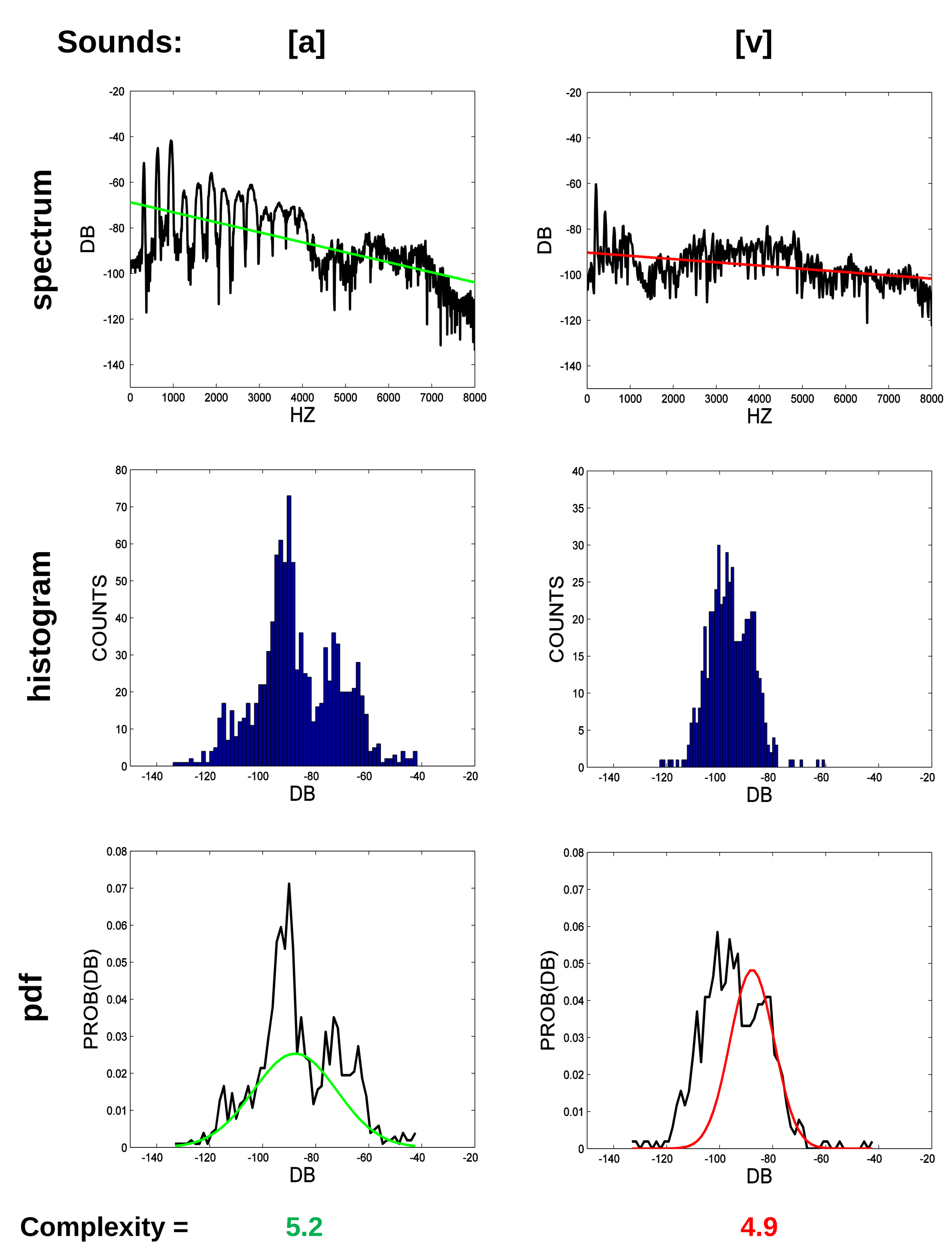
- Our measure of spectral complexity is inspired by previous applications of **Information Theory** to speech (Stilp et al, 2010)
- **Shannon entropy** (*Equation 1*; Shannon, 1949) can be used to estimate the average degree of uncertainty (or information) for a set of possible events $S = \{s_1, \ldots, s_n\}$, such that the higher the entropy, the more uncertain (or informative) the outcome

$$(1) \quad E(S) = \sum_{i=1}^{n} \mathrm{prob}(s_i) \times \log(1/s_i)$$

Shannon entropy increases for flatter (platykurtic; more uncertain) distributions and decreases for peakier (leptokurtic; less uncertain) distributions



- We used Shannon entropy to measure the average degree of **spectral information** by applying the *Equation 1* to the distribution of relative amplitudes (dB) included in a given spectrum. To this view, spectral complexity was taken as the average degree of uncertainty provided by the energy of the spectrum



METHODS II

SPEECH SAMPLES

Texas Instrument-MIT (TIMIT; Garofolo et al, 1993). 630 speakers from 8 American English dialects. 6300 phonetically labelled sentences

Table 1. Sounds (as classified by TIMIT)

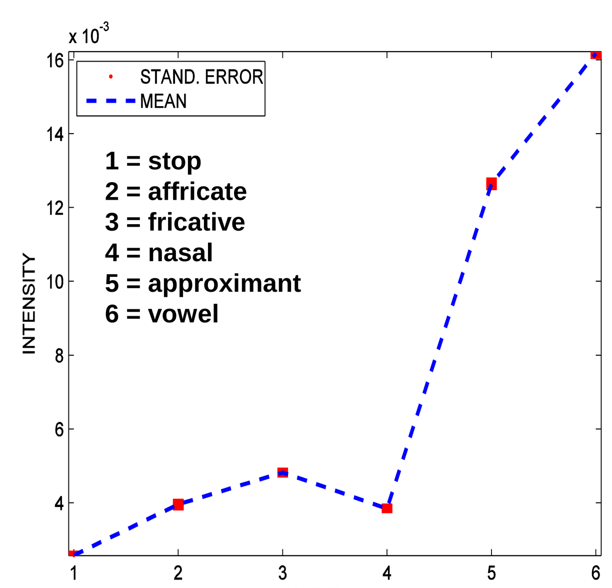
Vowel		Approximant		Nasal	Fricative	Affricate	Stop
		Glide semivowel	Lateral				
i	ə	w	l	m	s	tʃ	p
ɪ	o	ɹ	r	n	z	ʤ	t
ɛ	u	h	l̩	ŋ	f		k
æ	ɨ	ɦ		ŋ̍	v		b
ɑ	aɪ			n̩	ʃ		d
ɔ	aʊ			m̩	ʒ		g
ʌ	eɪ			ɾ̃	θ		ɾ
ʊ	oʊ				ð		ʔ
ɚ	oɪ						
ɝ	y						

ACOUSTIC ANALYSES

- Each sound was divided into 20ms FFT segments (10 ms overlap, 512 FFT points)
- For each segment, intensity and spectral complexity were estimated by calculating the RMS amplitude in the time domain and the spectral complexity in the spectral domain, respectively
- Spectral complexity and intensity were then averaged for each sound across segments

RESULTS I

❑ INTENSITY



ANOVA

$F(5,189349) = 15035$

$p < 0.001$

TUKEY HSD ($p<0.05$)

All means were significantly different from each other except for *nasal* and *affricate*

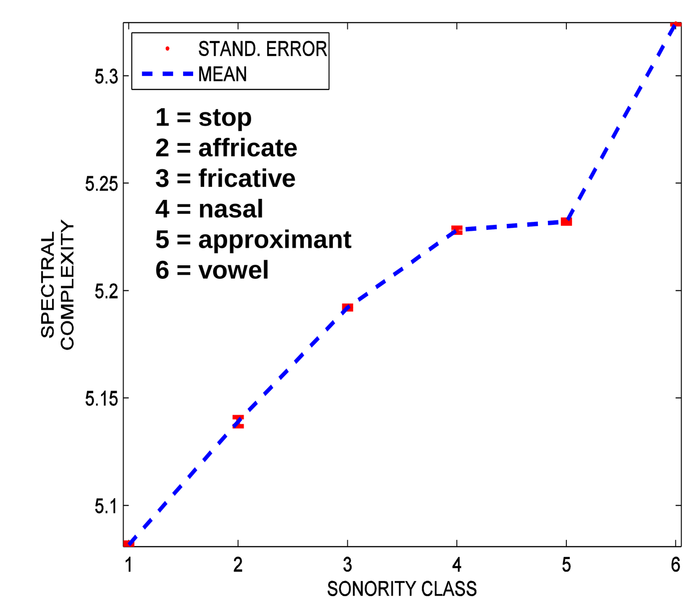
RANKING

vowel > approximant > fricative > ***nasal**, affricate > stop

* Intensity does not sort the nasal class properly in the sonority scale

RESULTS II

❑ SPECTRAL COMPLEXITY



ANOVA

$F(5,189349) = 15715$

$p < 0.001$

TUKEY HSD ($p<005$)

All means were significantly different from each other

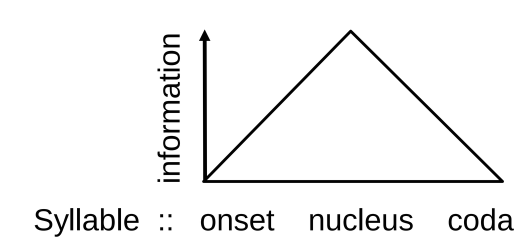
RANKING

vowel > approximant > nasal > fricative > affricate > stop

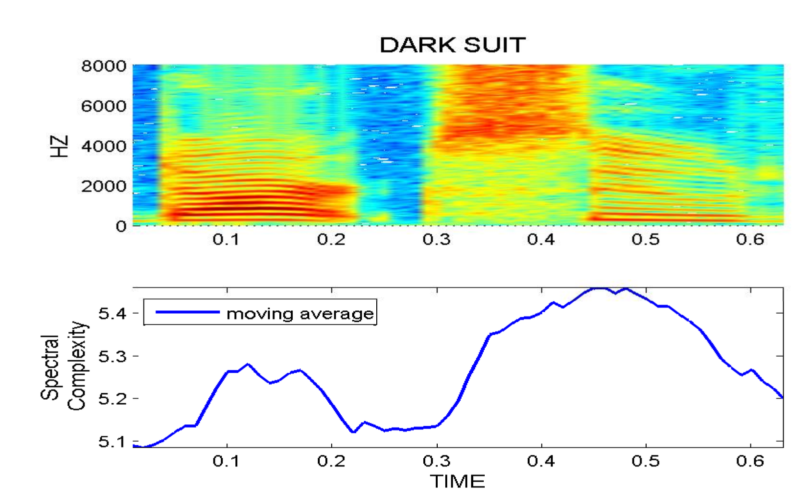
Spectral complexity sorts all classes properly in sonority

DISCUSSION

1. While spectral complexity sorts all sonority classes properly, intensity fails to sort nasals and fricatives. Thus, spectral complexity seems to be a better estimator of sonority than intensity for American English
2. Our results provide an information-theoretic account for syllable structure, with sounds closer to the nucleus bearing more information than those that are further away



3. From this framework, the speech stream can be described by the informational wave that results from the concatenation of syllables



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