Climbing the syllable peaks

Basilio Calderone
CLLE-ERSS, CNRS & Université de Toulouse II

Pier Marco Bertinetto
Scuola Normale Superiore, Pisa

The syllable in phonological theory

- Long-standing debate on the status of the syllable in phonological theory (Côté 2012).
- Increasing consensus on the syllable's **epiphenomenical character**:

- Vennemann 1988 ("preference laws of syllable structure"), Dziubalska-Kołaczyk 1995; 2002 ("Beats & Binding Model"), Ohala & Kawasaki-Fukumori 1997 …
- Browman & Goldstein's 1988 ("Articulatory Phonology", c-center effect; Gafos & Goldstein 2012; cf. Hermes et al. 2008 for Italian onset clusters)

2/36

The syllable as emerging feature

⇒ syllable as an **emerging phenomenon** yielded by the **language-specific phonotactics** (based on universal tendencies), rather than basic phonological constituent

NB: This allows to overcome the circularity problem affecting the sonority hierarchy scales

(see however Baslbøll's "Sonority Syllable Model")

- The fundamental **role of frequency** (Cholin 2011): "mental syllabary" (Levelt, Roelofs, Meyer), or perhaps consolidation of robust **articulatory routines** (presumably active also in perception)

3/36

Onset vs coda

- **Onset – coda asymmetries**

- Nam et al. 2009 (earlier acquisition of coda clusters as opposed to onset clusters; in English: less gesture variability in onset than coda clusters, i.e. more "competitive" structure; BUT in Moroccan Arabic (Shaw et al. 2011) observable degrees of interindividual variability)
- Steriade 1999; 2001 (relative perceptibility, rather than syllabic position, accounts for segment sequences; but see Stuart & Baertsch 2011)

4/36

Universality?

- **Non-universality of the syllable** as a phonological constituent?
- Hyman 2011 (and previous work in the '80s) on Gokana;
- Labrune 2012 on Japanese (mora and foot, rhather than syllable constituent)
- Arrernte as a counterexample to CV universality

- Alternatively, **universality of syllabic chunking** (as emergent feature), which may or may not support phonologically relevant behaviors

5/36

Psychological relevance

- **Psycholinguistic experimentation** has largely proven the relevance of the syllable in various languages (see recapitulation in Côté 2012)
- However, **metalinguistic tasks** have shown that:
  - the salience of the syllable varies from language to language (Bertinetto 1999)
  - the internal constituency of the syllable is not universally identical (Derwing's on Korean as a 'left-branching' language)
- Further support from **speech error analyses**

6/36

The present approach

⇒ Aim of this presentation: **modeling syllabic structures** in terms of phonotactic preferences based on a **probabilistic input model**

- The syllable is defined by the **activation** values yielded by the neighboring segments **in specific phonological contexts**
- In our study, the syllabification task was simulated by means of a feedforward two-level neural network with a hidden layer

7/36

Computational framework

Learning procedure:

– Mapping input-output vectors (x, $F(x)$) with given parameters (learning rate and loops).

– Minimizing the error (E) between the target values and network outputs by means of a BP algorithm (back-error propagation).

– Stopping the learning when E reaches a level of acceptability

8/36

Segments representation

	voc	cons	cont	obst	later	nasal	strid	inter	round	front	high	labial	dental	palat	velar
a	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
e	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0
o	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0
i	1	0	1	0	0	0	0	0	0	1	1	0	0	0	0
u	1	0	1	0	0	0	0	0	1	0	1	0	0	0	0
j	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0
w	0	1	1	0	0	0	0	0	1	0	1	0	0	0	0
r	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0
l	0	1	1	0	1	0	0	0	0	0	0	0	1	0	0
L	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0
n	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
M	0	1	1	0	0	1	0	0	0	0	0	1	0	0	0
N	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0
s	0	1	1	1	0	0	1	0	0	0	0	0	1	0	0
S	0	1	1	1	0	0	1	0	0	0	0	0	0	1	0
f	0	1	1	1	0	0	1	0	0	0	0	1	1	0	0
v	0	1	1	1	0	0	1	0	0	0	0	1	1	0	0
p	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0
b	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0
t	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0
d	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0
k	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1
G	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1
c	0	1	0	1	0	0	1	0	0	0	0	0	0	1	0
g	0	1	0	1	0	0	1	0	0	0	0	0	0	1	0
Z	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0
z	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0

9/36

Activation *continuum*

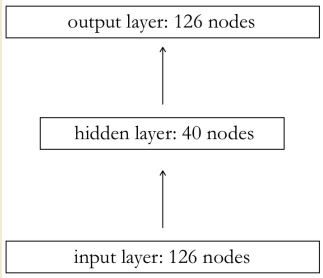
- The system yields **activation values** ranging from 0.0 to 1.0. **Initial values** are set to:
  - **1.0** for positive featural values
  - **0** for negative featural values
- NB: although Manner features are (in general) phonotactically more relevant than Place features, the system was allowed full freedom to find its equilibrium
- Output activation cannot reach top values (0.0 or 1.0) as final status, but can at most approximate them

10/36

Feeding the automaton

The network is trained to approximate a function F associating a set of input patterns (*phonotactic contexts*) with a set of output patterns (*syllabic structures*) so that $F: R^n \rightarrow R^m$ (n and m inputs and outputs respectively)

```
s_c= syllabic context
p_c= phonotactic context
```



	LEFT				FOCUS	RIGHT			
c_s(1)	#	#	#	#	t	i	#	#	#
c_s(2)	#	#	#	t	i	#	#	#	#
c_s(3)	#	#	#	#	r	a	#	#	#
c_s(4)	#	#	#	r	a	#	#	#	#
c_s(5)	#	#	#	#	m	i	#	#	#
c_s(6)	#	#	#	m	i	#	#	#	#
c_s(7)	#	#	#	#	s	u	#	#	#
c_s(8)	#	#	#	s	u	#	#	#	#
c_p(1)	#	#	#	#	t	i	r	a	m
c_p(2)	#	#	#	t	i	r	a	m	i
c_p(3)	#	#	t	i	r	a	m	i	s
c_p(4)	#	t	i	r	a	m	i	s	u
c_p(5)	t	i	r	a	m	i	s	u	#
c_p(6)	i	r	a	m	i	s	u	#	#
c_p(7)	r	a	m	i	s	u	#	#	#
c_p(8)	a	m	i	s	u	#	#	#	#

11/3

Data and training

- **Training set**: 3700 **Italian** words phonologically encoded (as detailed above)
- **Syllabic types**:

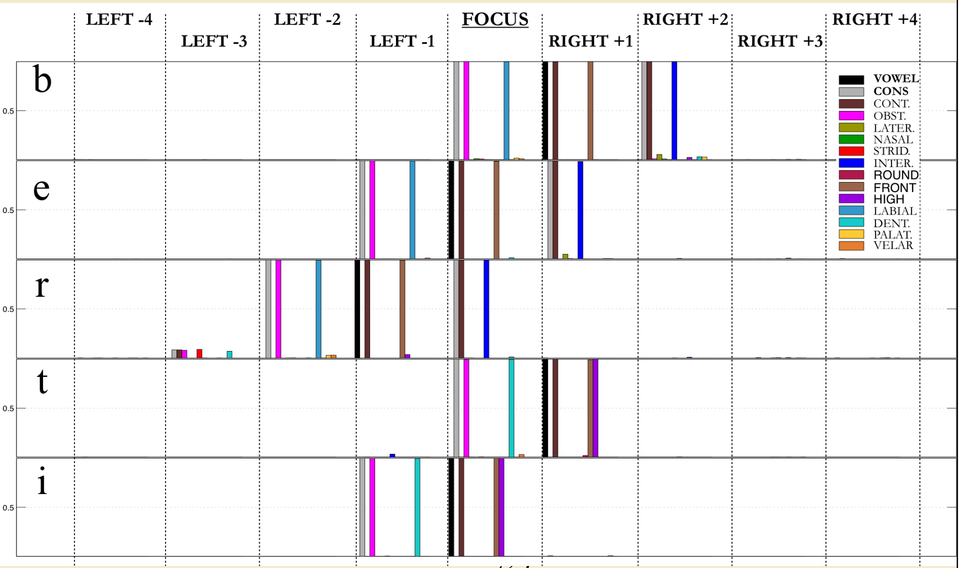
  CV = 2050; CVC(including geminates) = 697;

  V = 482 …
- The type distribution mirrors the *Italian Phonetic Lexicon* by Goslin, Galuzzi & Romani, based on *CoLFIS* (Italian Frequency Corpus and Lexicon)
- **NB**: /s/+C cluster not included in the training set (but included in the generalization phase)

12/3

Output of the model

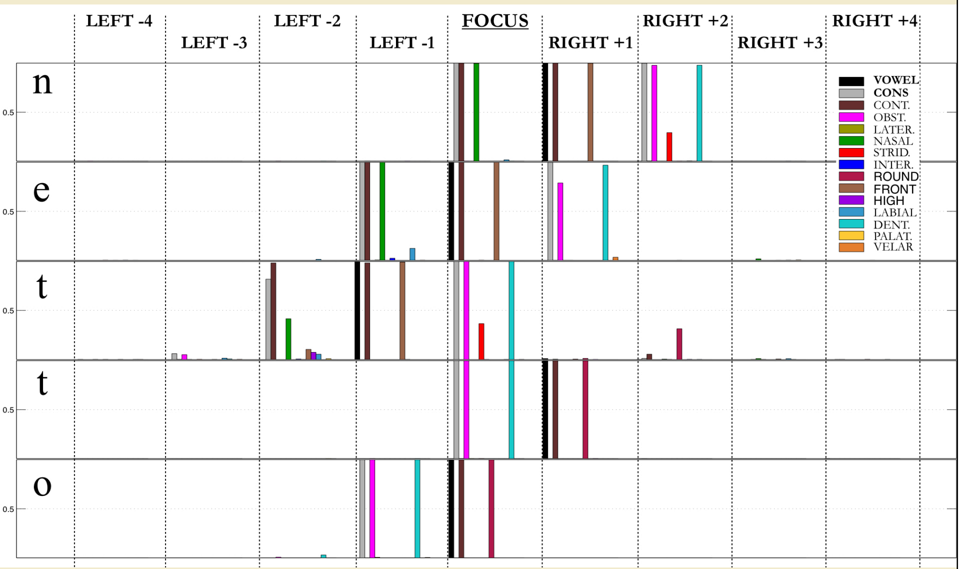
/bertinetto/ 'surname'



cont´d

Output of the model

/bertinetto/ 'surname'



Testing the model

1. Exploiting the system's knowledge to analyze data which are **similar but not identical** to the learned data

2. Testing the ability to discover new syllable types and yield a successful syllabification

⇒ this system should not be viewed as a syllabator, but rather as a **detector of relative syllabic attractions** between adjacent segments

15/30

Testing the model

⇒ Testing identical syllable types with **different segmental content**:

Example: FGV

FGV•V /swoi/ 'yours' ⟶ **LEARNED**

S L V F•F G V /graffjo/ 'scratch' ⟶ **UNSEEN**

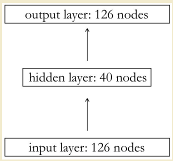
⇒ Testing **novel sequences**, not present in the training set?

16/30

Testing the model

Ex: FVG

FVG LV FVG SV FVG SV



(UNSEEN) NEW SYLLABLE TYPE

/sawro/	/fajda/	/fewdo/
‘sorrel’	‘feoff’	‘ feud’

17/36

Discovering new syllabic structures

- Although **Italian syllabification** is relatively simple, it cannot be dealt with by a purely deterministic approach; with unsual structures, the **probabilistic approach** emerges as the only viable strategy (Bertinetto 2004)
- **“Difficult” clusters**:

- /s/C clusters (both word-initial and word-internal)
- rare clusters in adapted loanwords (*optare*, *ectoplasma*, *nafta*, *instabile* …)
- sandhi clusters (*per* [ʎ]*i amici*, *col pneumatico, tram rosso*…)

18/36

Climbing the syllable peaks

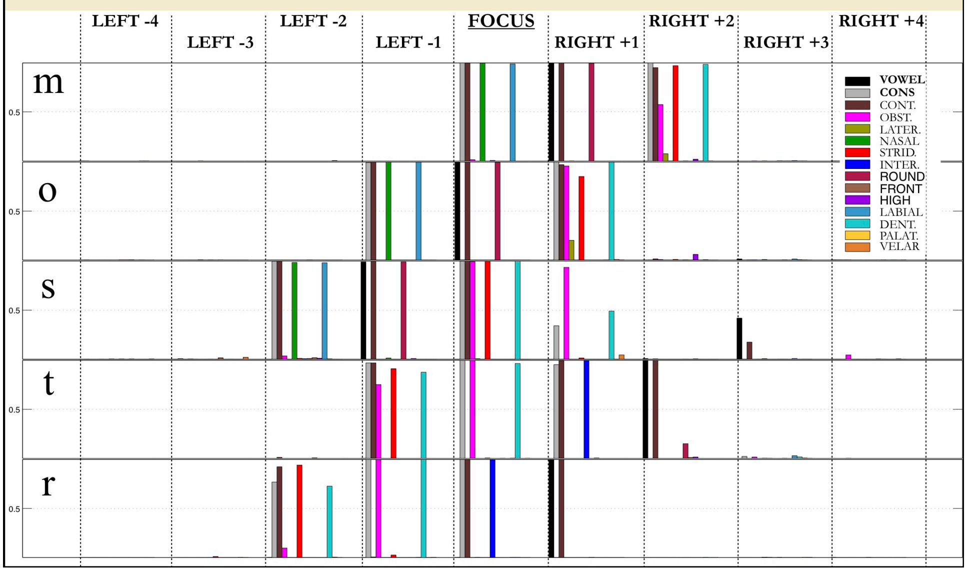
- The climber's *vademecum*:
  - the peak is a necessary, but insufficient precondition for the syllable's existence (cf. the Gokana's situation!)
  - thus, only the alternation of peaks (Vs) and valleys (Cs) can give rise to the syllable
  - however, the "steepness" of the syllable margins depends on phonotactics: it is maximal in CV sequences, minimal in highly complex C clusters (sharp vs smooth boundaries).
- Syllabic "orography":
  - the sharper the syllable's boundary, the narrower the visibility on the adjacent landscape (syllabic isolationism)
  - the blurrier the syllable's boundary, the wider the visibility on the adjacent landscape (syllabic anti-isolationism).

5/36

Inside the model

/s/+C cluster

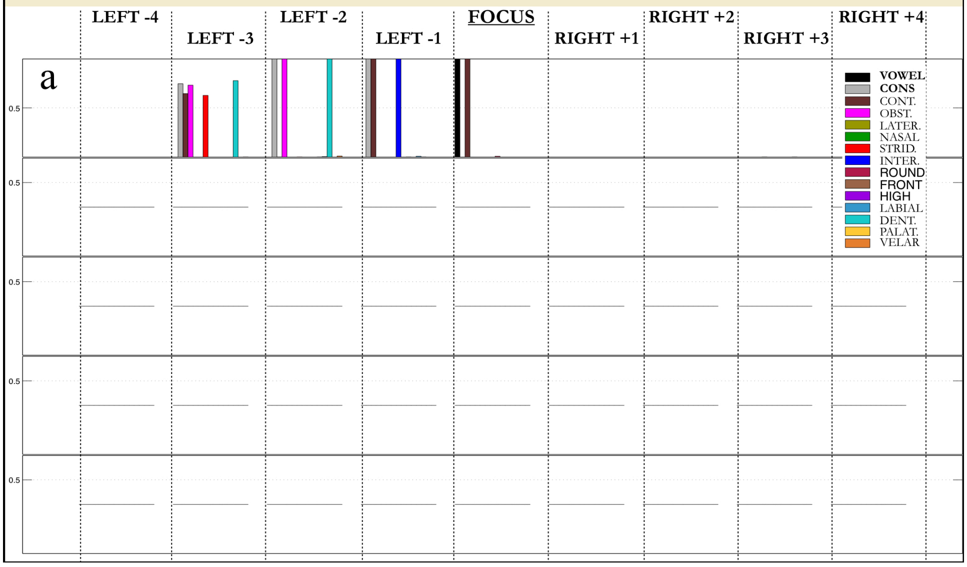
/mostra/ 'exhibition'



Inside the model

/s/+C cluster

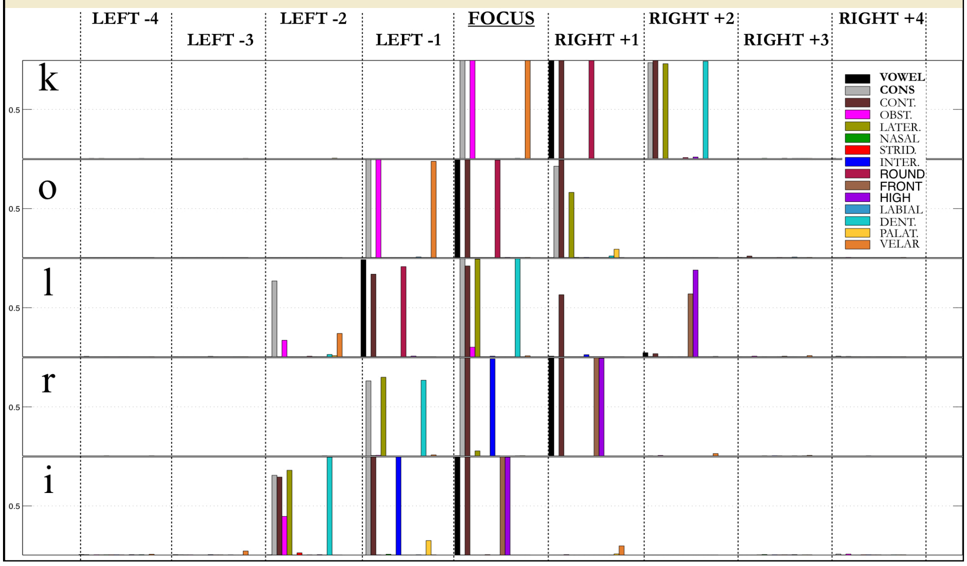
/mostra/ ‘exhibition’



Inside the model

/lr/ cluster

col righello ‘with the ruler’



Inside the model

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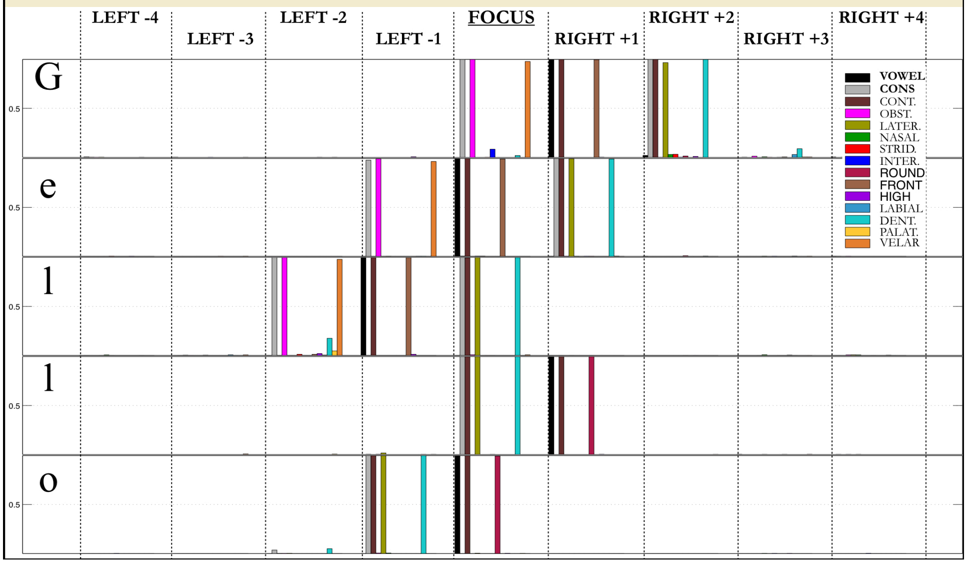
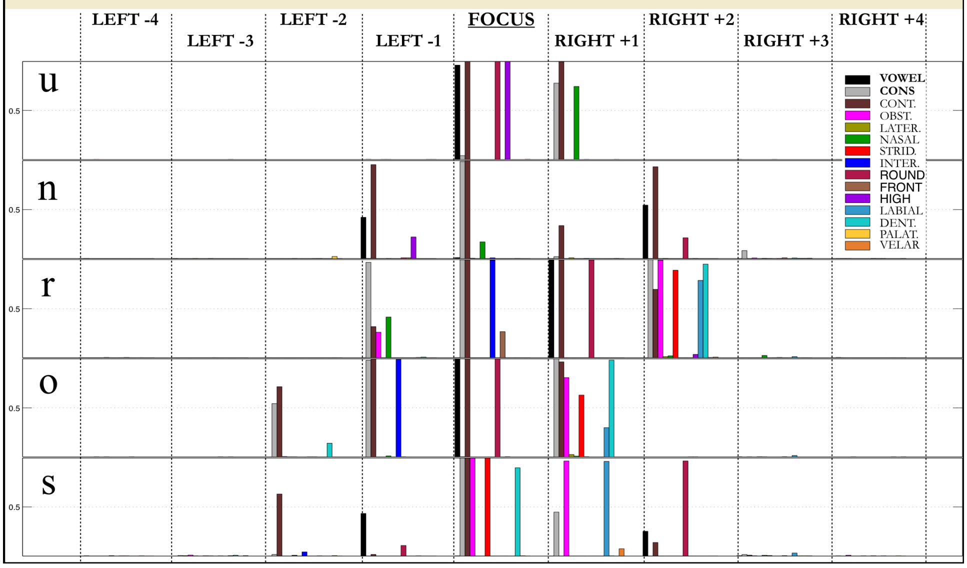


Inside the model

/nr/ cluster

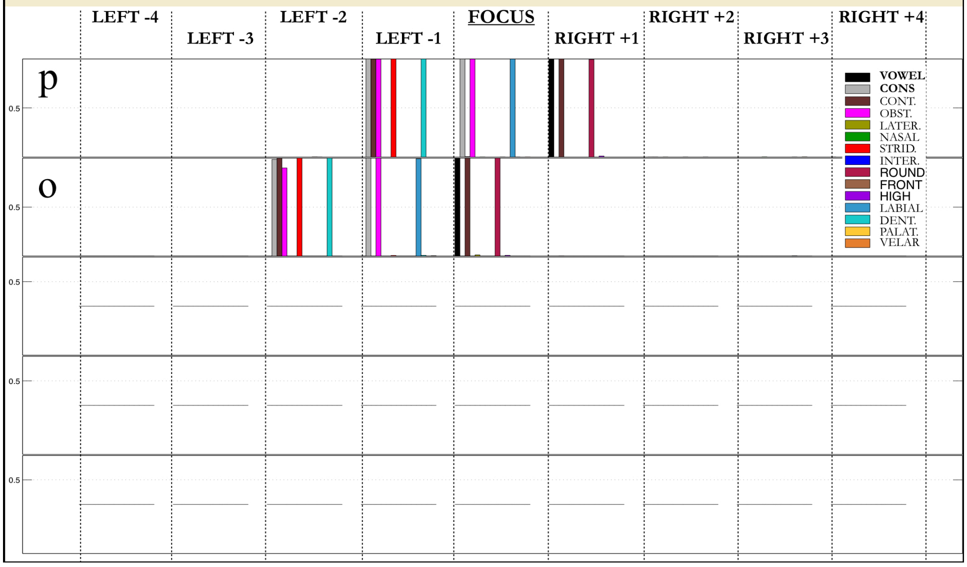
un rospo ‘a toad’



Inside the model

/nr/ cluster

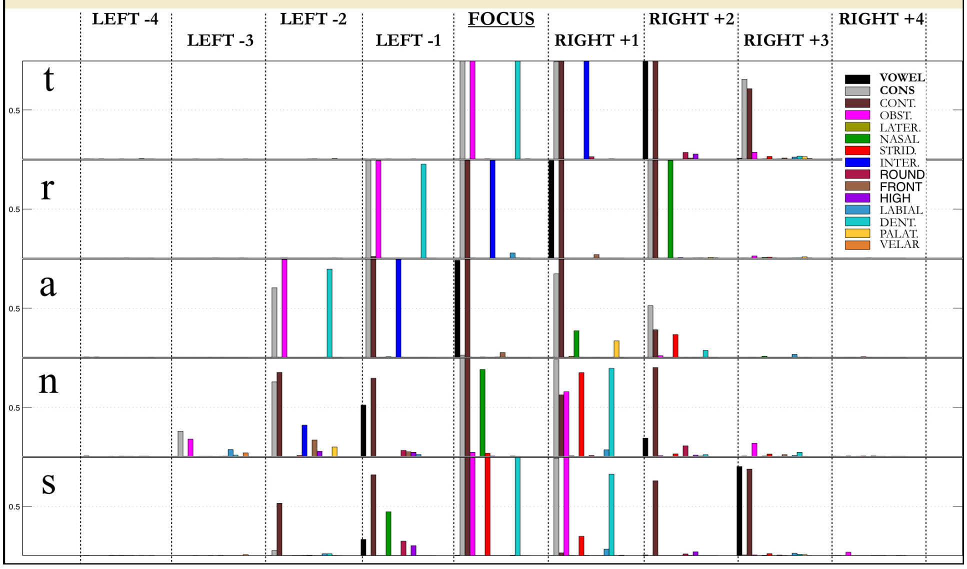
un rospo ‘a toad’



Inside the model

/nsfr/ cluster

transfrontaliero ‘border-crossing’



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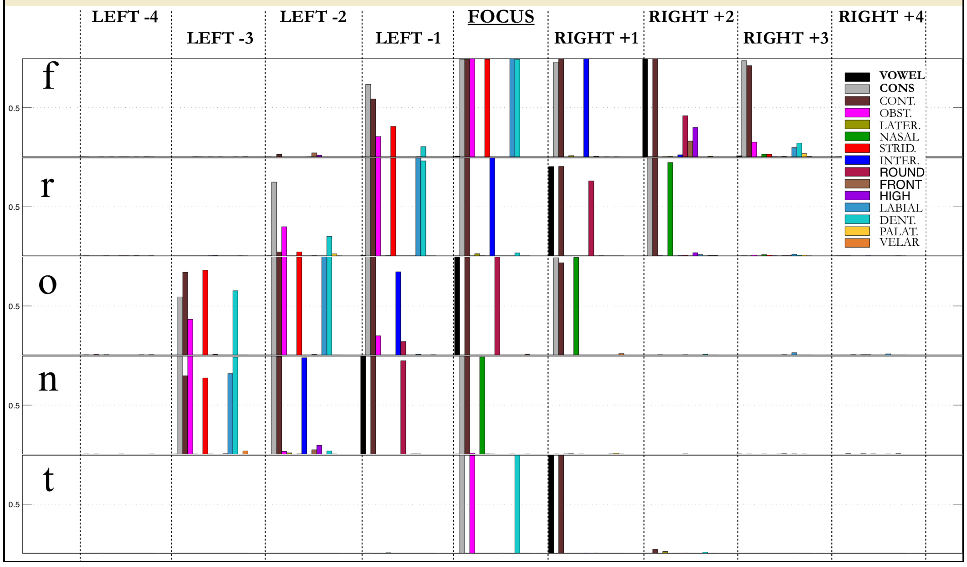

Inside the model

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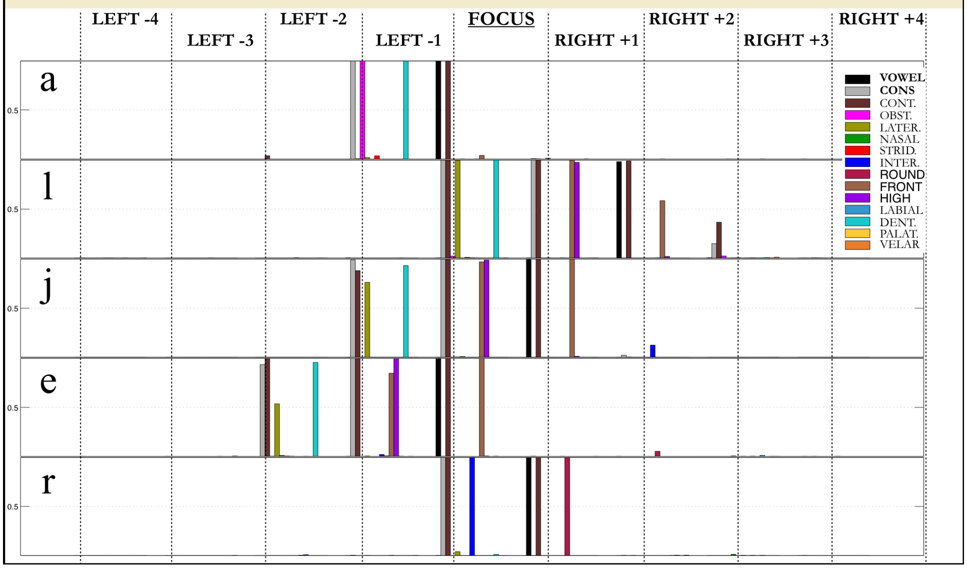
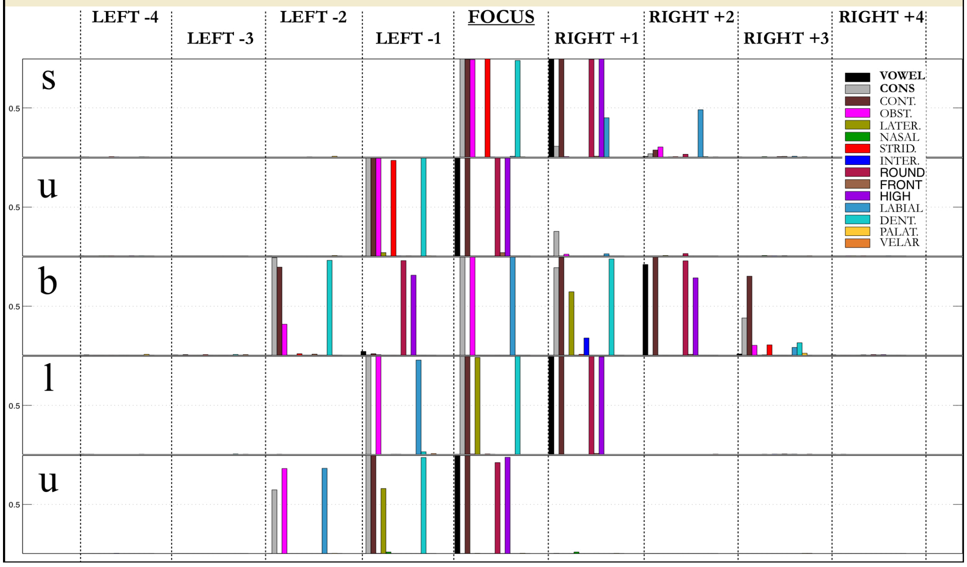
transfrontaliero 'border-crossing'



Inside the model

/bl/ cluster

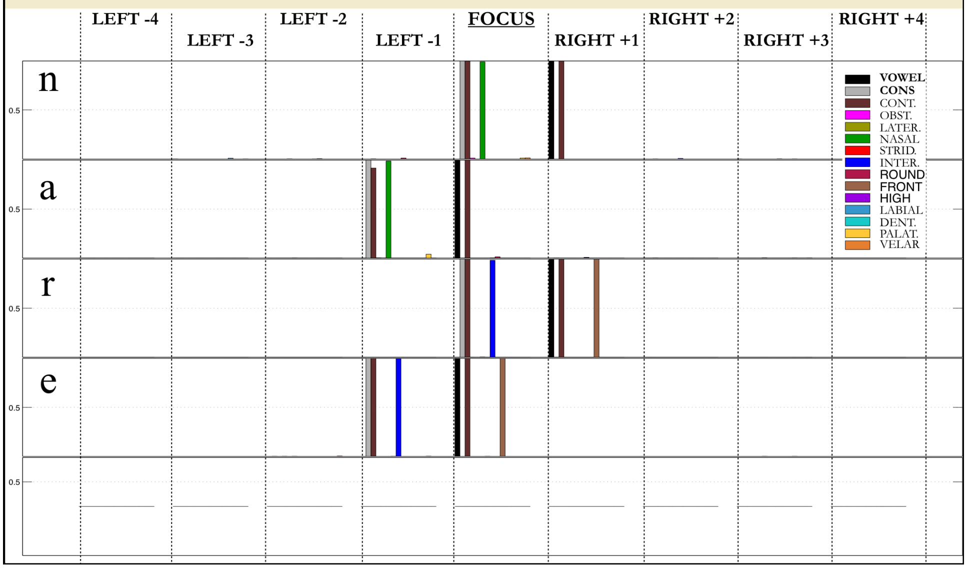
sublunare 'sublunar'



Inside the model

/bl/ cluster

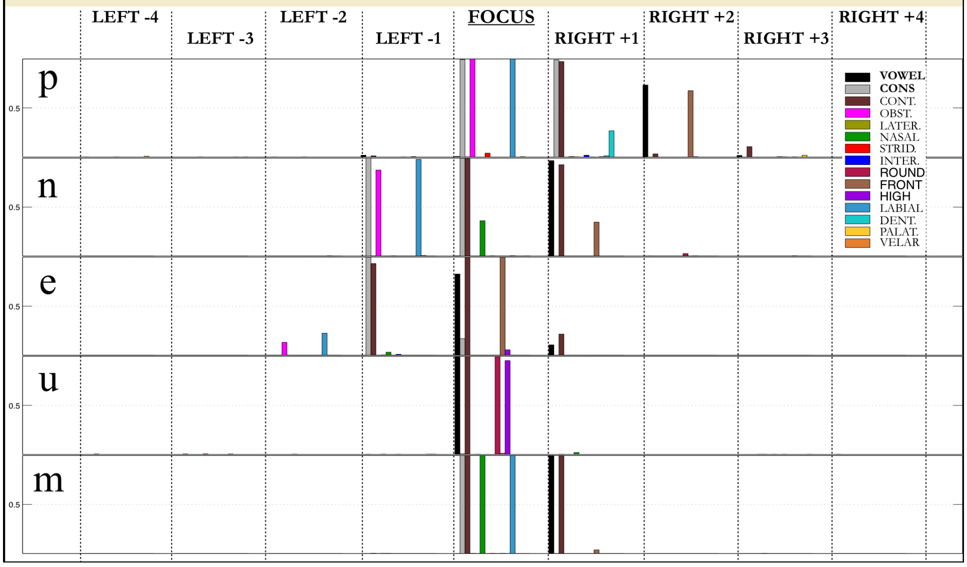
sublunare 'sublunar'



Inside the model

/pn/ cluster

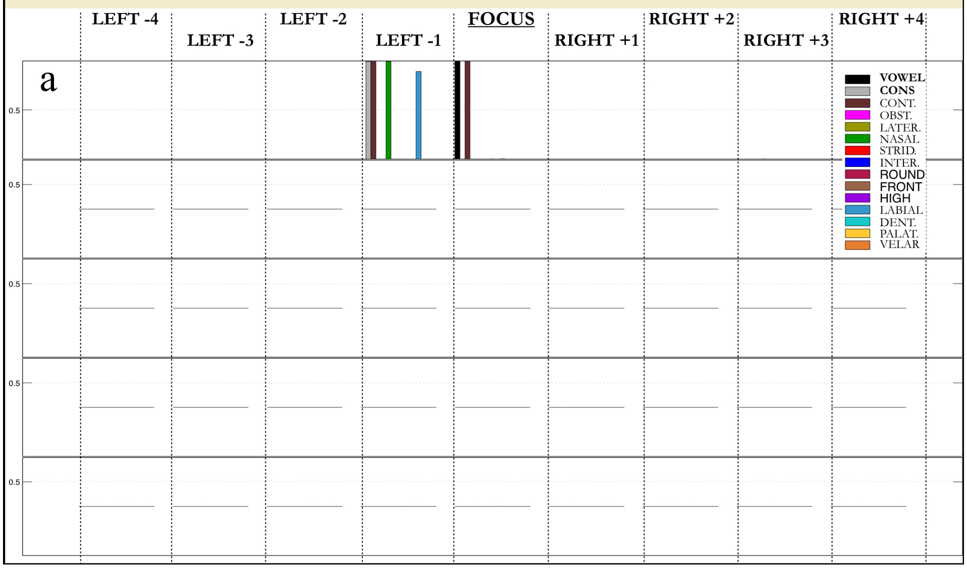
pneuma 'exhibition'



Inside the model

/pn/ cluster

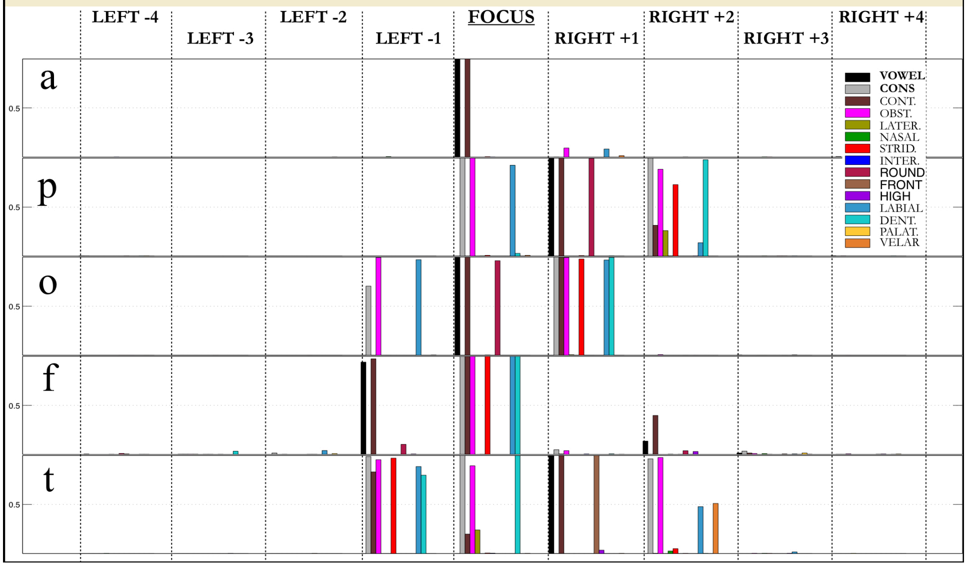
pneuma 'exhibition'



Inside the model

/ft/and /gm/ cluster

apoftegma 'sentence, verdict'



Inside the model

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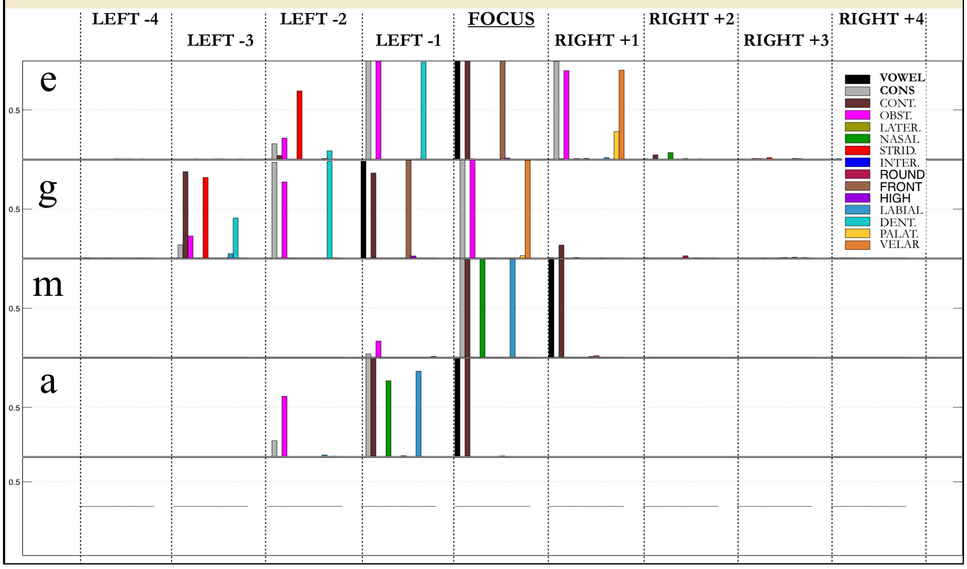
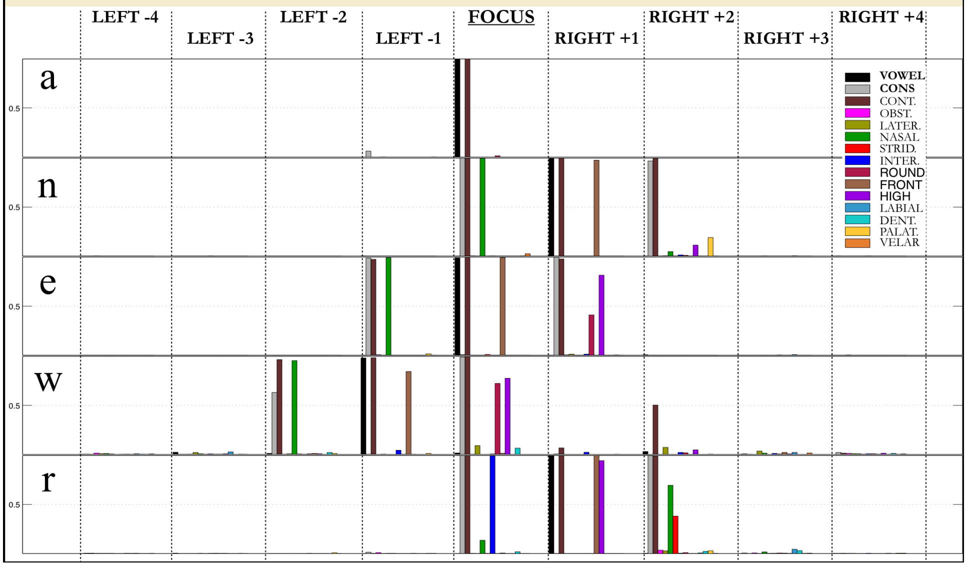


Inside the model

/sm/ cluster

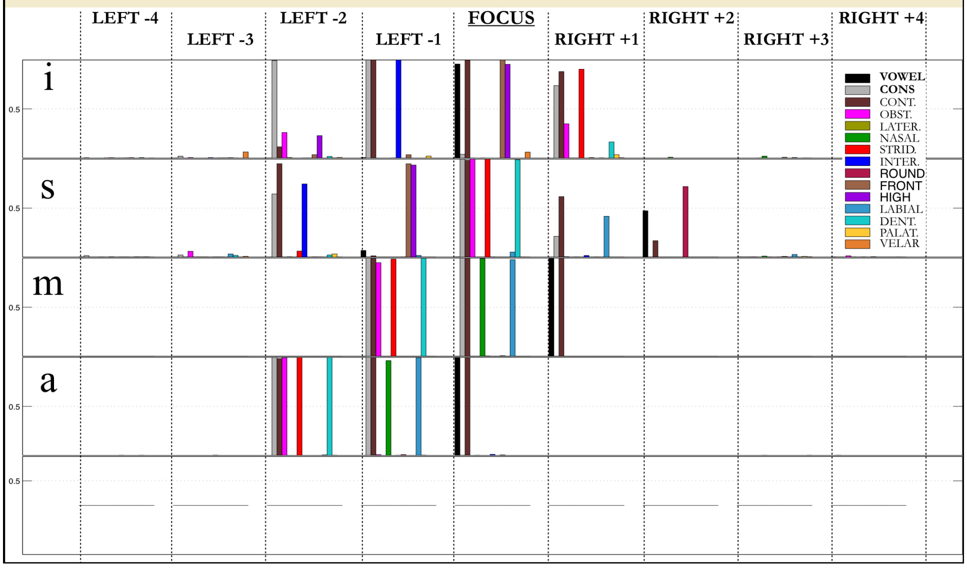
aneurisma 'aneurysm'



Inside the model

/sm/ cluster

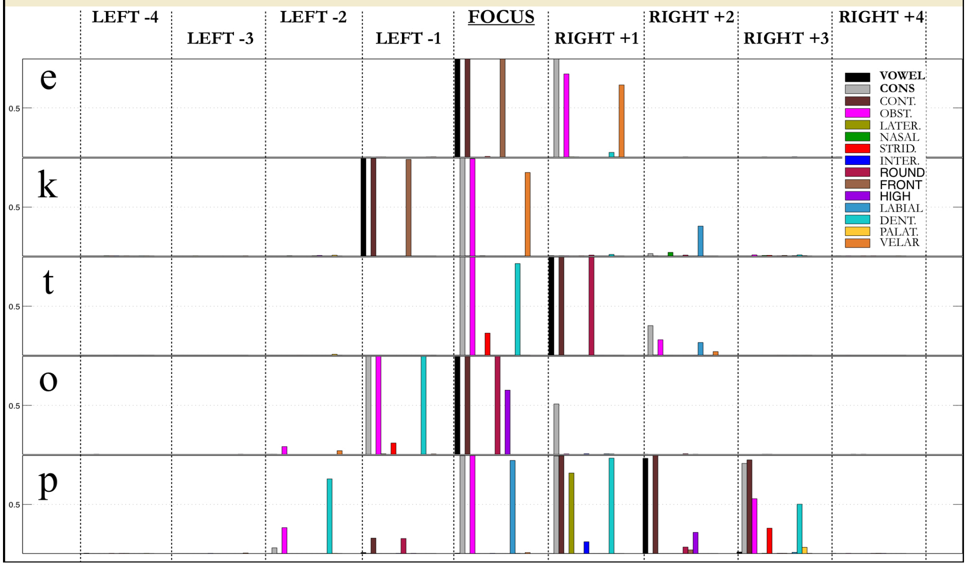
aneurisma 'aneurysm'



Inside the model

/kt/ and /sm/ cluster

ectoplasma 'ectoplasm'



Inside the model

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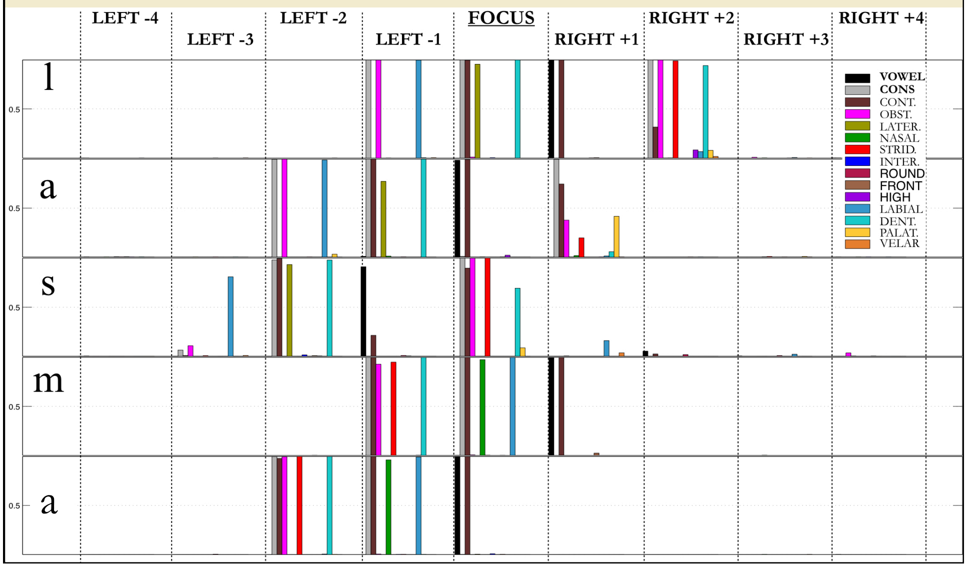
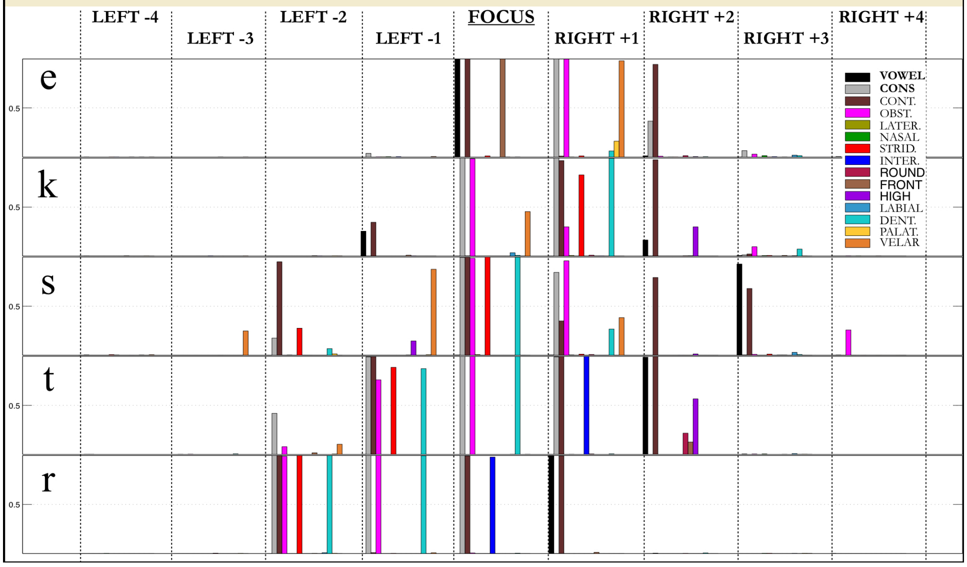


Inside the model

/kstr/ cluster

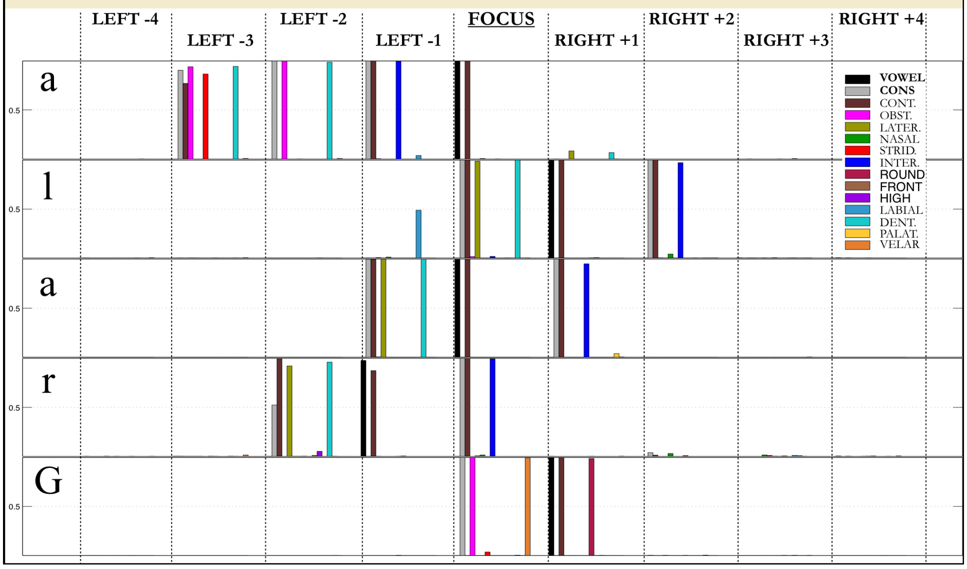
extralargo 'extralarge'



Inside the model

/kstr/ cluster

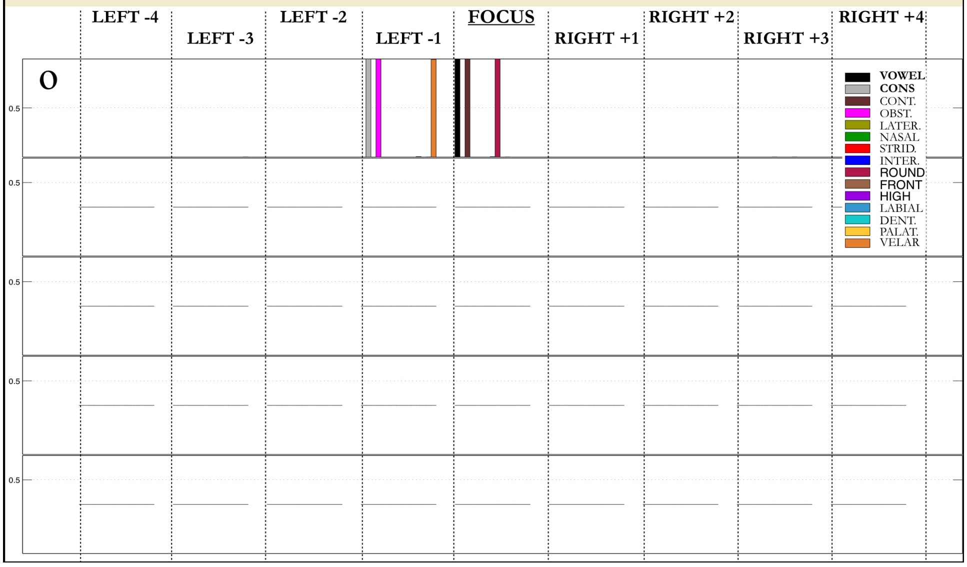
extralargo 'extralarge'



Inside the model

/kstr/ cluster

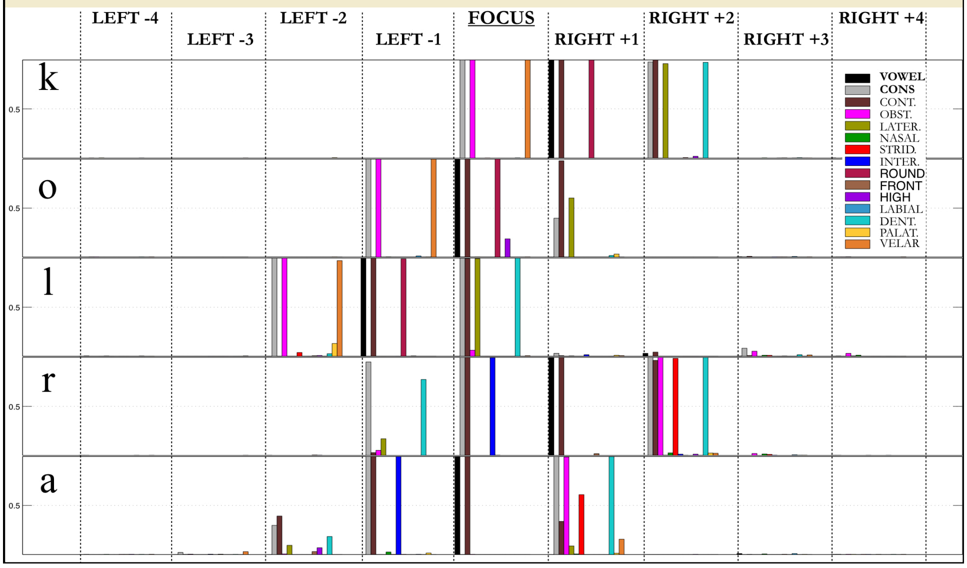
extralargo 'extralarge'



Inside the model

/lr/ and /str/ cluster

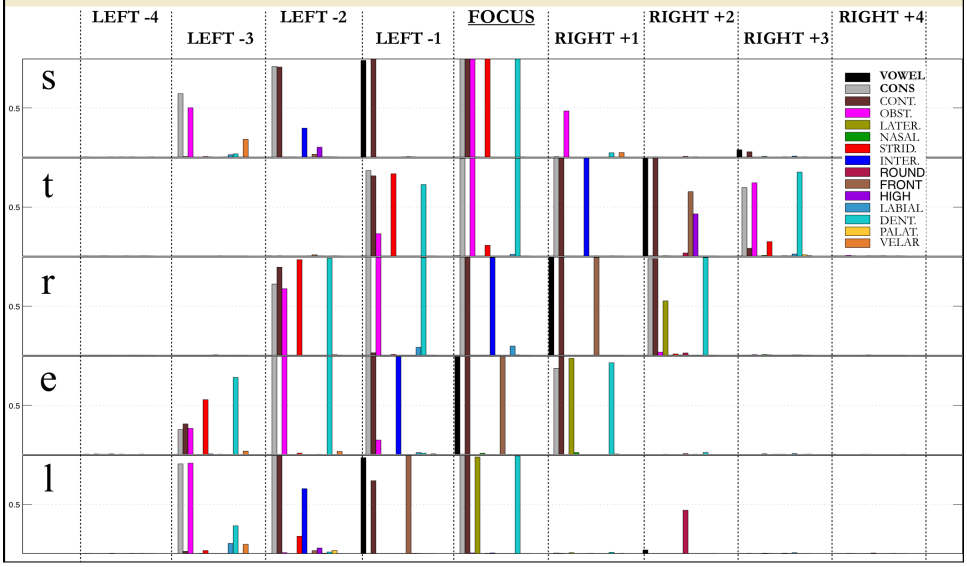
col rastrello 'with the rake'



Inside the model

/lr/ and /str/ cluster

col rastrello 'with the rake'



Inside the model

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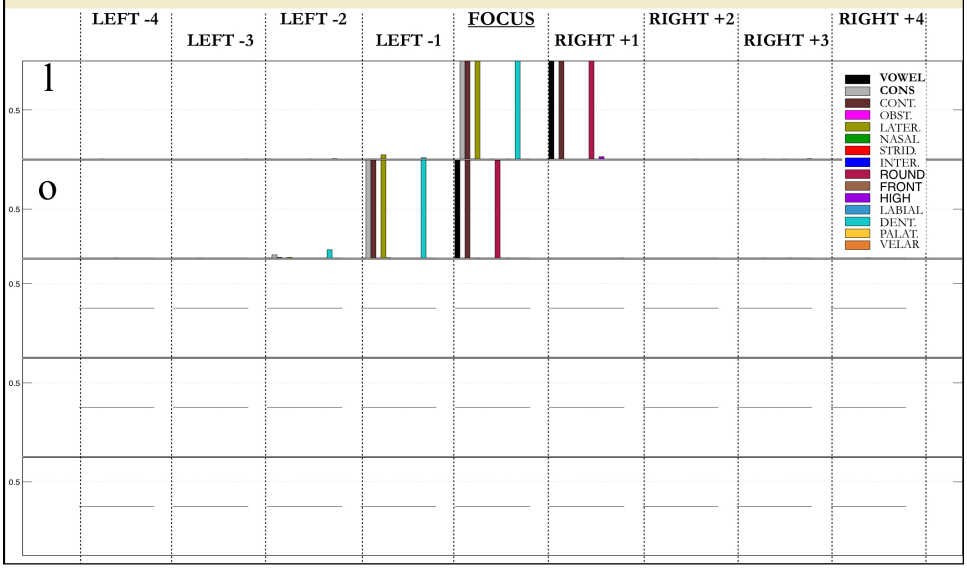
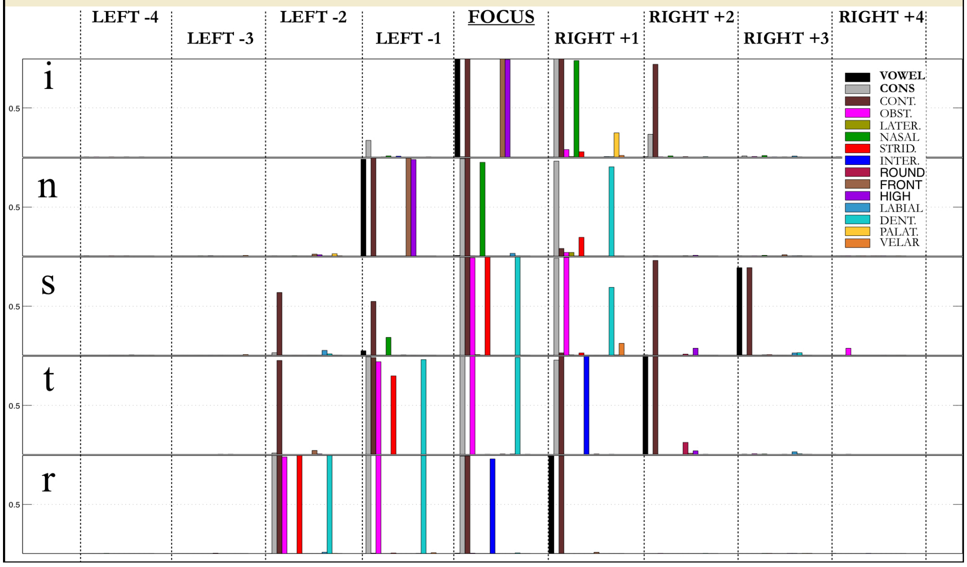


Inside the model

/nstr/ cluster

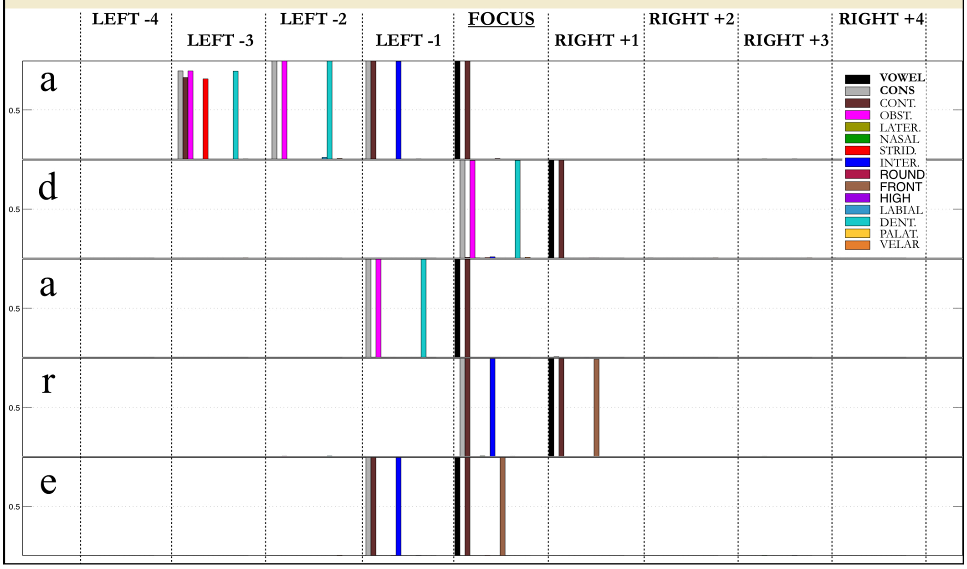
instradare 'to route'



Inside the model

/nstr/ cluster

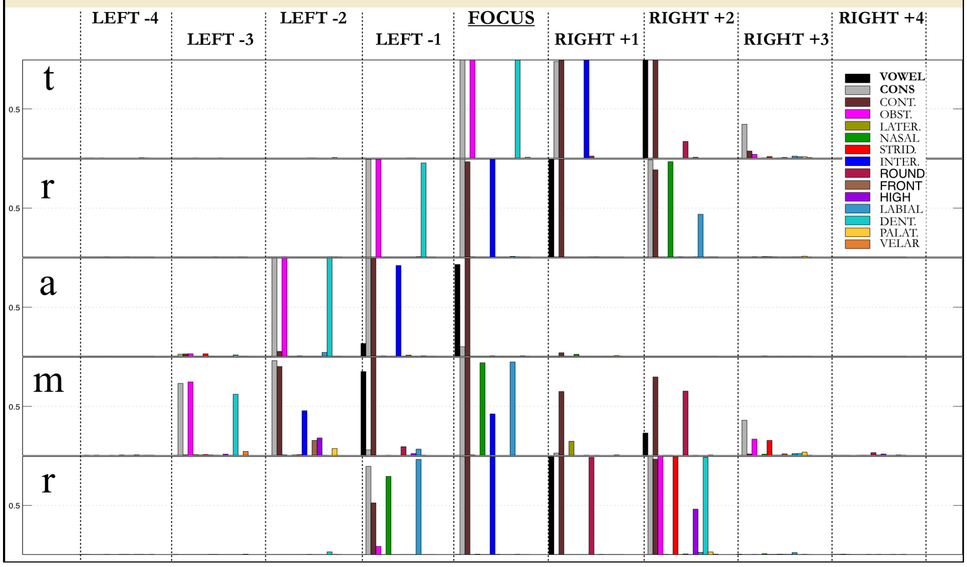
instradare 'to route'



Inside the model

/mr/ cluster

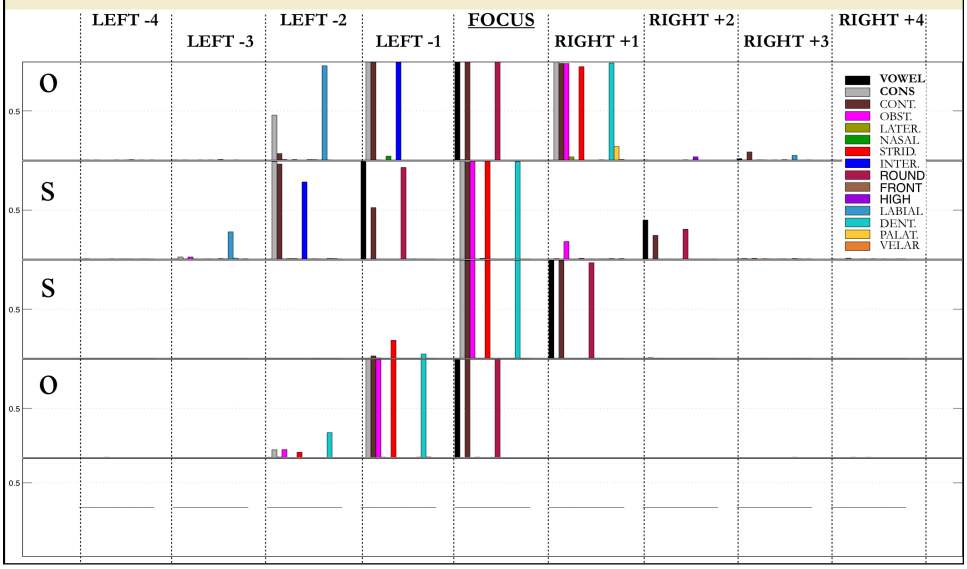
tram rosso ‘red tramway’



Inside the model

/mr/ cluster

tram rosso ‘red tramway’



Hidden representation of the syllable

The activations of the 40 hidden nodes provide an important clue as to the 'computational strategy' adopted by the system to autonomously solved the syllabification problem.

NB: there is an obvious (and planned) mismatch between the 126 digits in each input line and the 40 hidden nodes

The hidden unit activations associated with a given phonotactic context may be regarded as the network' s internal representation of that context.

32/36

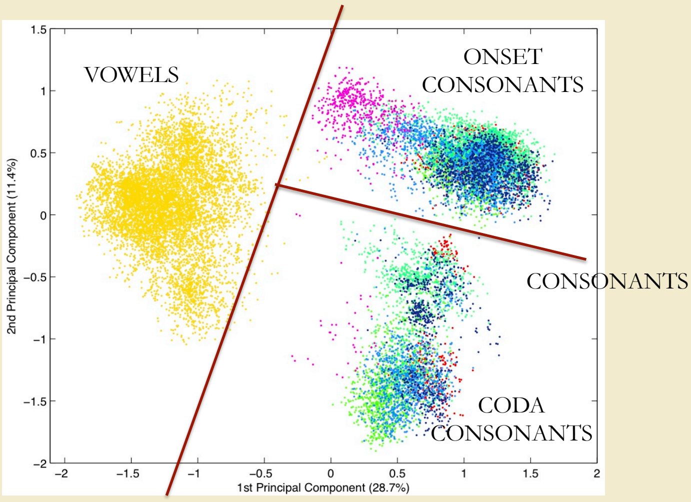
Hidden representation of the syllable

- We extracted the hidden unit activations for all the phonemes in Focus position (≅30,000)
- Dimensionality reduction was performed by means of the Principal Component Analysis, in order to reduce the original space (R^{40}) to a bi-dimensional space (i.e., the dimensions with the highest variance explanation)

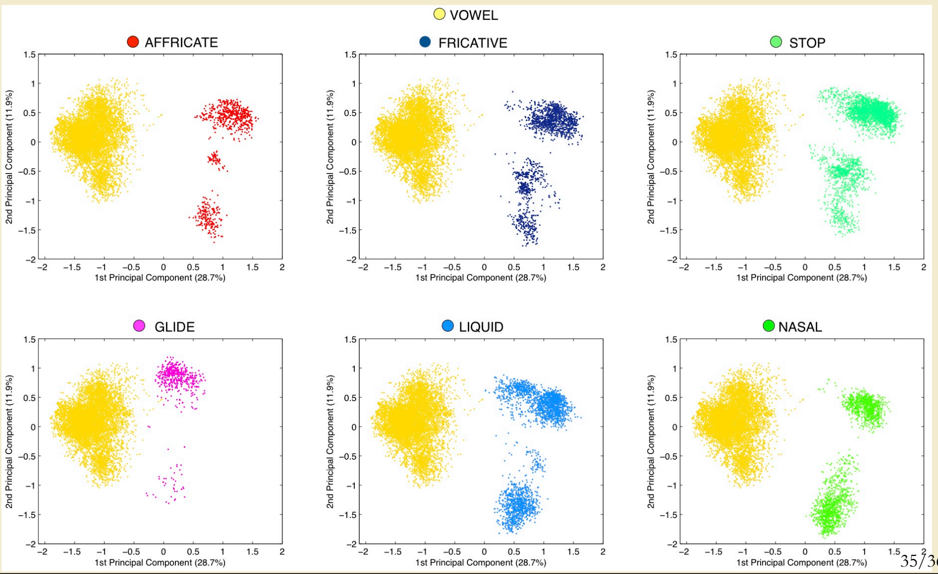
⇒ testing the existence of macro-groupings such that phonemes with similar syllabic behavior are treated alike by the system

33/36

Hidden representation of the syllable



Hidden representation of the syllable



Future work

- Testing richer featural arragements
- Assigning geminates a specific phonotactic role
- Extending the analysis to other languages (e.g.: English, Spanish, Finnish to model the diverging treatment of /s/C clusters
- …
- Your wishes are gladly acknowledged !

36/36