Mechanisms for parsing speech into syllables in early infancy

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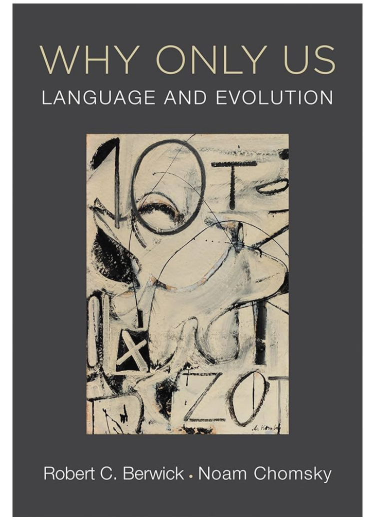
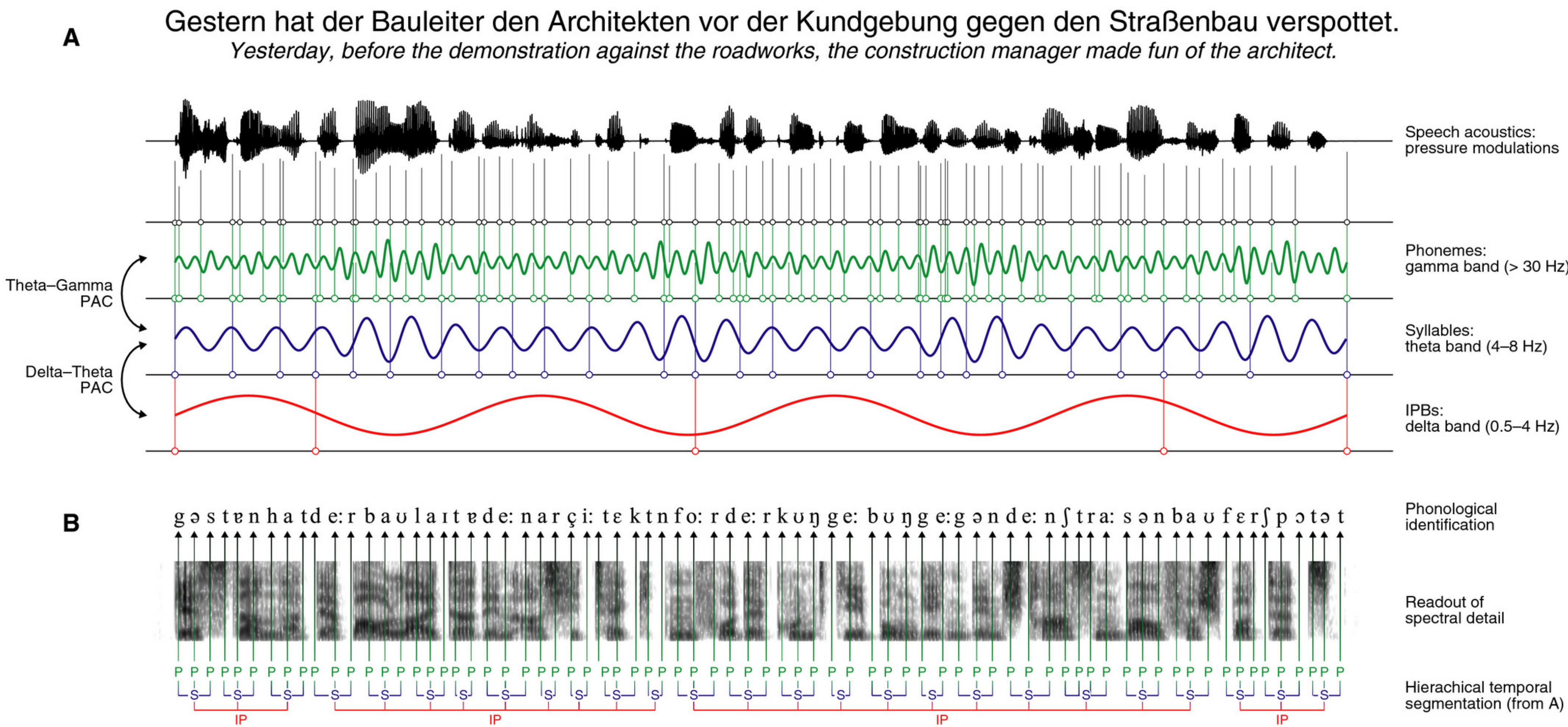
(Why) only us?

- Humans develop linguistic abilities unparalelled to non-human animals
- But some animals show certain ability to process some aspects of language (e.g., Christiansen and Kirby 2003; Fitch 2018; Santolin and Saffran 2018; Petkov and Ten Cate 2020; Toro 2016)
- Shared mechanisms: entry gate to human language acquisition?



Gates to Language (GALA) ERC project (Chiara Santolin)

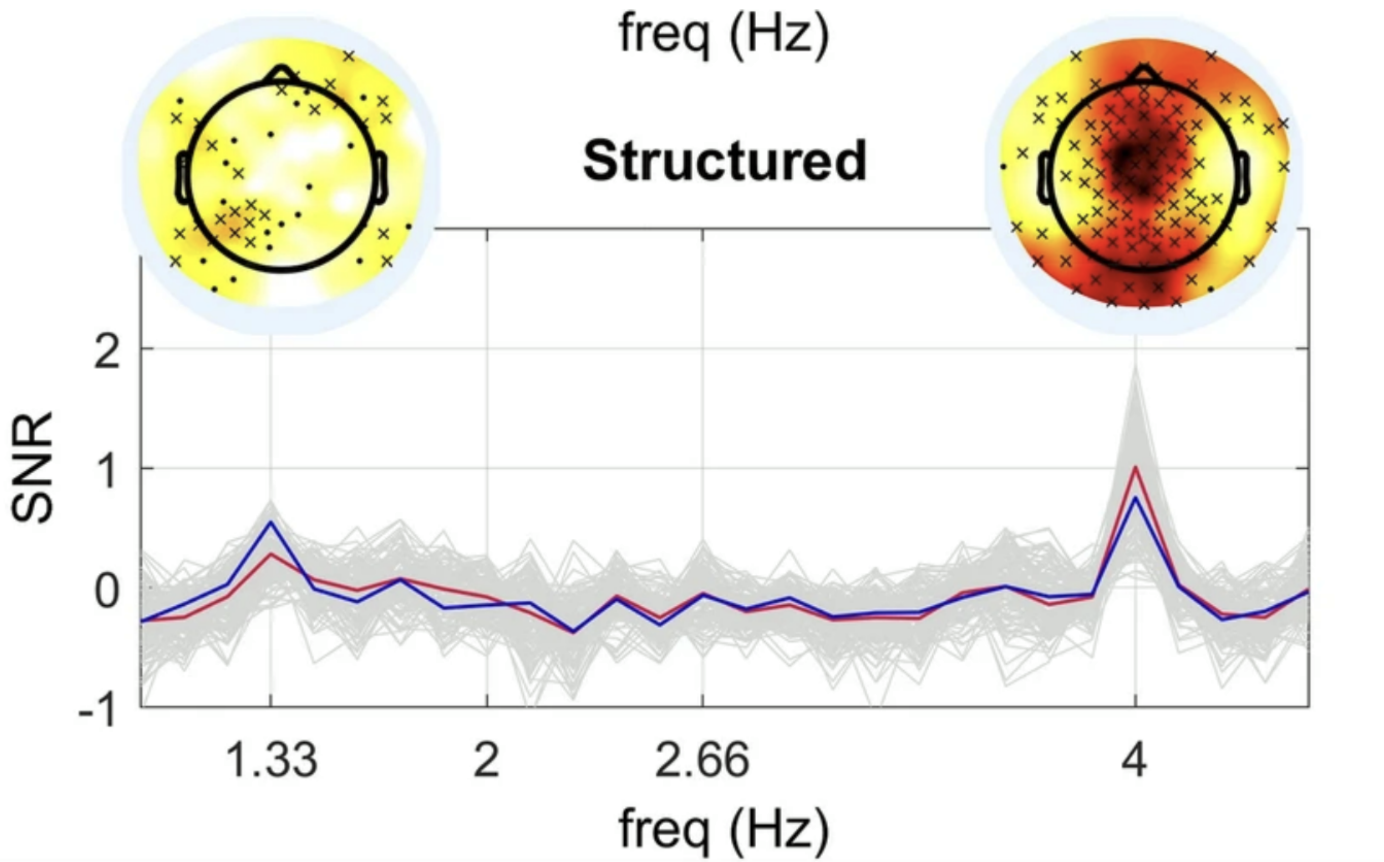
Discrete units in the continuous speech signal



From Meyer (2018).

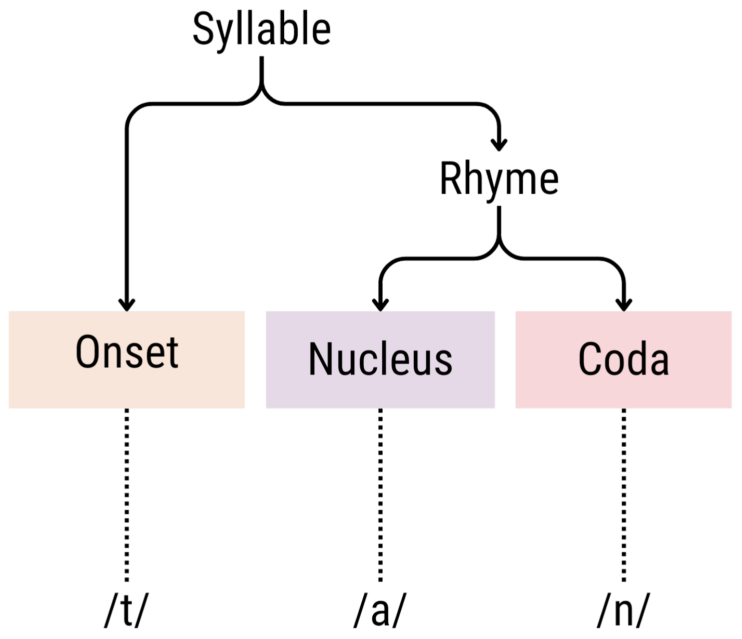
The syllable: a privileged linguistic unit?

Newborns (and adults) preferentially parse the speech signal into syllable-sized units (e.g, Bijeljac-Babic, Bertoncini, and Mehler 1993; Fló et al. 2022; Luo and Poeppel 2007; Jusczyk and Derrah 1987; Bertoncini et al. 1988)

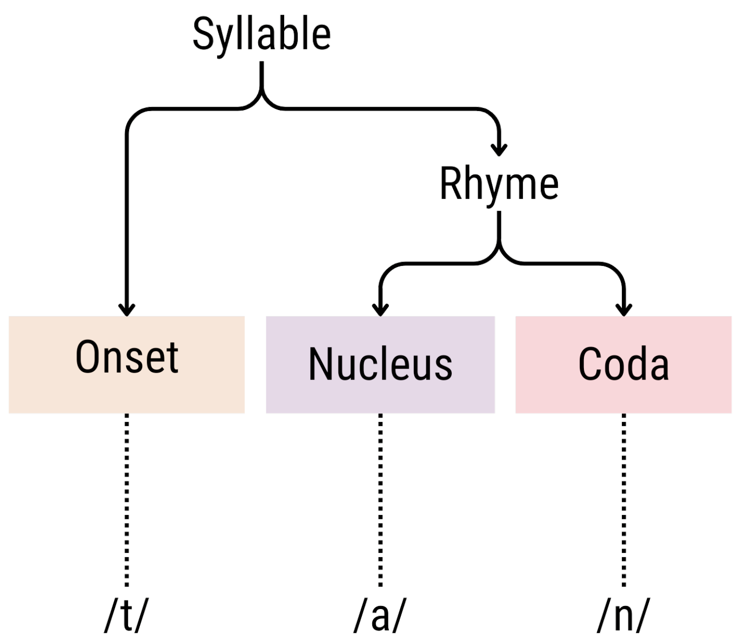


From Fló et al. (2022).

Syllabic structure



Syllabic structure



Structure	Onset	Nucleus	Coda
V		a	
CV	t	a	
CVC	t	a	n
VC		a	n

Language-specific constraints to syllabic structure

Adapted from Özer (2024).

Structure	Japanese	Spanish	English
V	u.mi	o.jo	a.ny
CV	ya.ma.ha	ca.sa	fai.ry
CVC	hon.da	rin.cón	con.trol
CCVC		fres.co	fresh
CCVCC		trans.por.te	shrink
CCCVCCC			strengths

Universal constraints to syllabic structure

Can you chunk this word into syllables?

> /likla/

Maximal Onset Principle (MOP):

Consonants are preferably grouped at syllabic onset

- MOP+: CV.CCV - /li.kla/
- MOP-: CVC.CV - /lik.la/

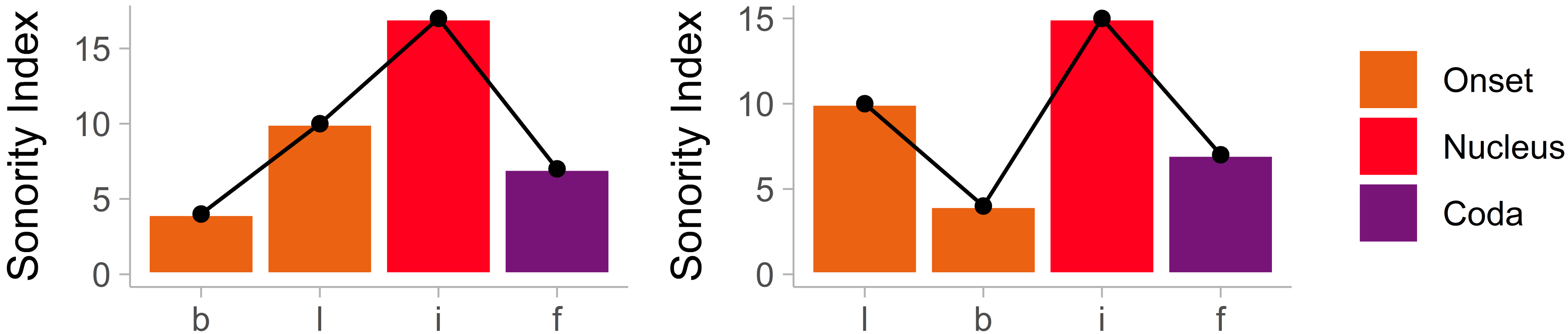
Universal constraints to syllabic structure

Which of these syllables sound good to you?

> /blif/ vs. /lbif/

Sonority Sequencing Principle (SSP):

Sonority increases at onset, peaks at nucleus, decreases in coda


Sonority Index
15
10
5
0
b
l
i
f
Sonority Index
15
10
5
0
l
b
i
f
Onset
Nucleus
Coda

The Gates to Language (GALA) project

- Do newborns rely on MOP and SSP to detect syllable boundaries?

> Syllables as an entry gate to language

- Are these mechanisms shared with non-human animals? (e.g., production)

> Syllables as phylogenetically relevant linguistic units

The Gates to Language (GALA) project

Two lines of research: MOP and SSP

- Neonates (fNIRS)
- Infants (fNIRS, eye-tracking, behaviour)
- Adults (behavioural)
- Long-Evans rats (behavioural)

Maximal Onset Principle (MOP)

Research line 1

Study 1: are newborns sensitive to (violations of) the MOP?

Consonants are preferably grouped at syllable onset.

- MOP+: CV.CCV - /li.kla/
- MOP-: CVC.CV - /lik.la/

Participants

- Hearing, full term neonates (fNIRS) and 6-10 mo infants (fNIRS + behavioural)
- Born/living in the Metropolitan Area of Barcelona (Spain)
- Mostly Catalan and/or Spanish linguistic background

fNIRS setup

- NIRSport2 (NIRx), CW 760 nm & 850 nm
- Sampling frequency 20.345 Hz (~0.05 s samples)
- NIRScap: 8 channels LH, 8 channels RH
- ROIs: L and R temporal regions
- Crib testing in neonates, parents’ lap in infants (watching cartoons)
- MNE-NIRS (Python): (1) OD, (2) motion correction (TDDR), (3) band-pass filtering, (4) block segmentation, (5) block averaging, (6) block rejection, (7) participant rejection.

Proposed block design (feed-back!)

Familiarisation/discrimination task:

1. Familiarise participants with disyllabic CVCCV words
   - 10 blocks, 6 words each (working on generating as many words as possible)

2. Test discrimination of artificially segmented familiar words as MOP+ (CV.CCV) vs. MOP- (CVC.CV):
   - 4 alternating blocks (MOP+/MOP-)
   - 4 non-alternating blocks (2 MOP+ blocks, 2 MOP- blocks)

Stimuli

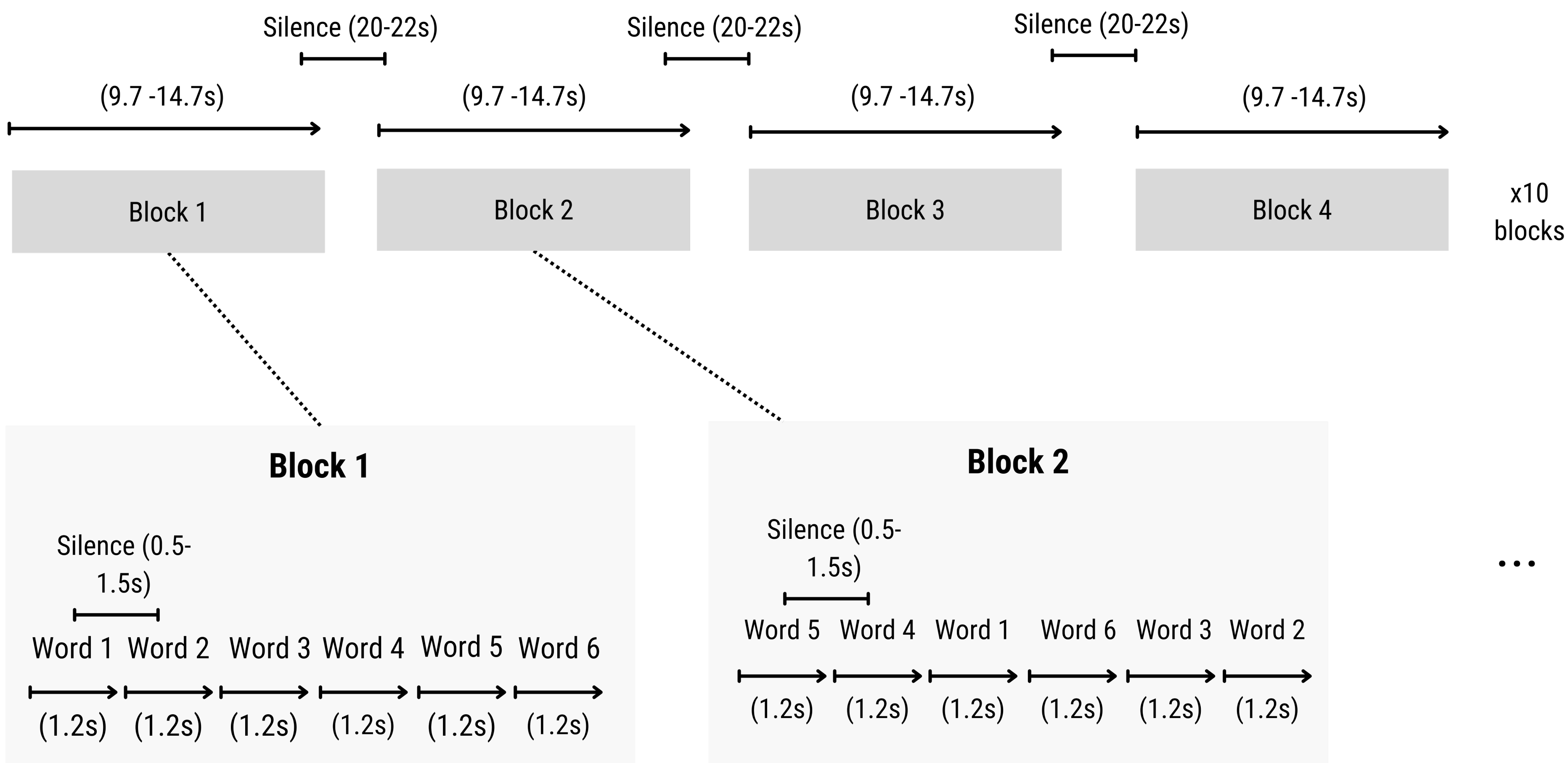
CVCCV words: Onset + Vowel + Consonant cluster (CC) + Vowel

MOP+ (CV.CCV)	MOP- (CVC.CV)
li.kla	lik.la
ro.tri	rot.ri
po.glu	pog.lu

Some constraints:

- MOP+: CC follows SSP
- MOP+: CC is phonotactical at onset in speakers' and participants' native language(s)
- MOP-: C is allowed in coda in speakers' and participants' native language(s)

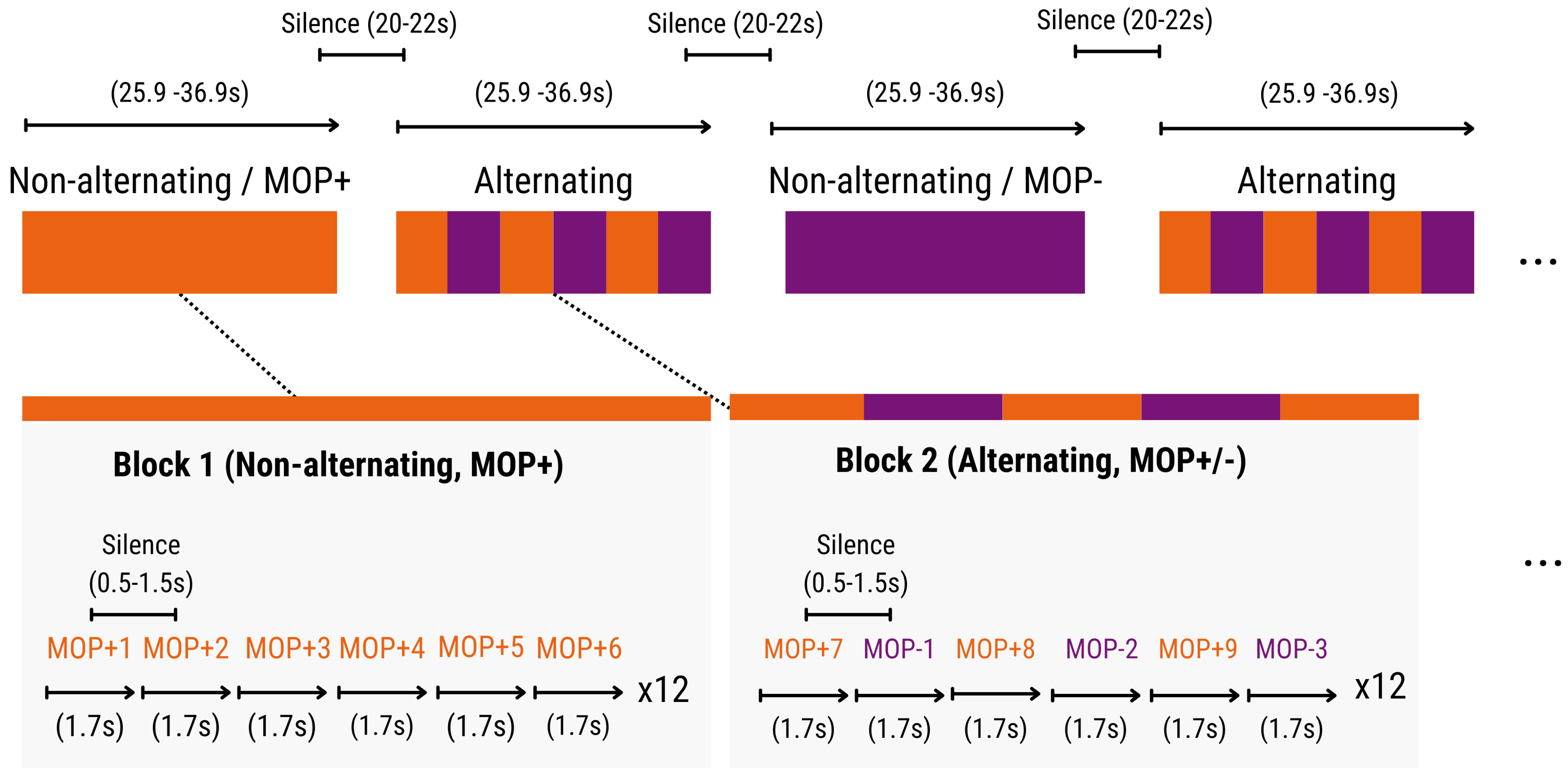
Familiarisation phase



EXAMPLES: LIKLA, ROTRI

Syllable expected duration: 0.6s
Word expected duration (S1 + S2): 1.2
x10 blocks: 4.61-5.75-min

Test phase



EXAMPLES: MOP+n: LI.KLA MOP-n: LIK.LA

Syllable expected duration: 0.6s
Word expected duration (S1 + 0.5s + S2): 1.7
Every x4 blocks: 163.6-213.6s, x12 blocks: ~8.85-11.41 min

Questions

- Natural speaker or synthesised speech (e.g., MBROLA)?
- Variability vs. repetition? More vs. less consonant clusters
- Linguistic experience at 8-12 months?
- Familiarisation phase: how many blocks is enough/too much?
- fNIRS recording during familiarisation? (e.g., capping in between phases)

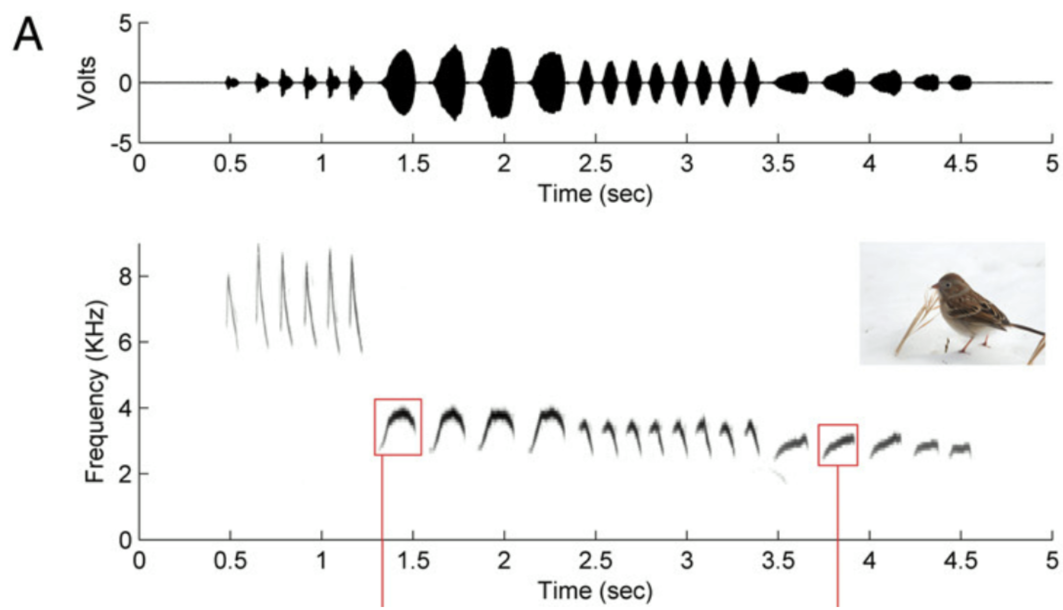
Sonority Sequencing Principle (SSP)

Research line 2

Study 2: testing the sensory basis of the SSP in non-linguistic inputs

> In a syllable, sonority increases toward the peak and decreases toward the margins. (Morelli 2003)

The biomecanics of the phonatory system constrain the properties of the acoustic signal of (exhalated) animal vocalisations.



From Tierney, Russo, and Patel (2011)

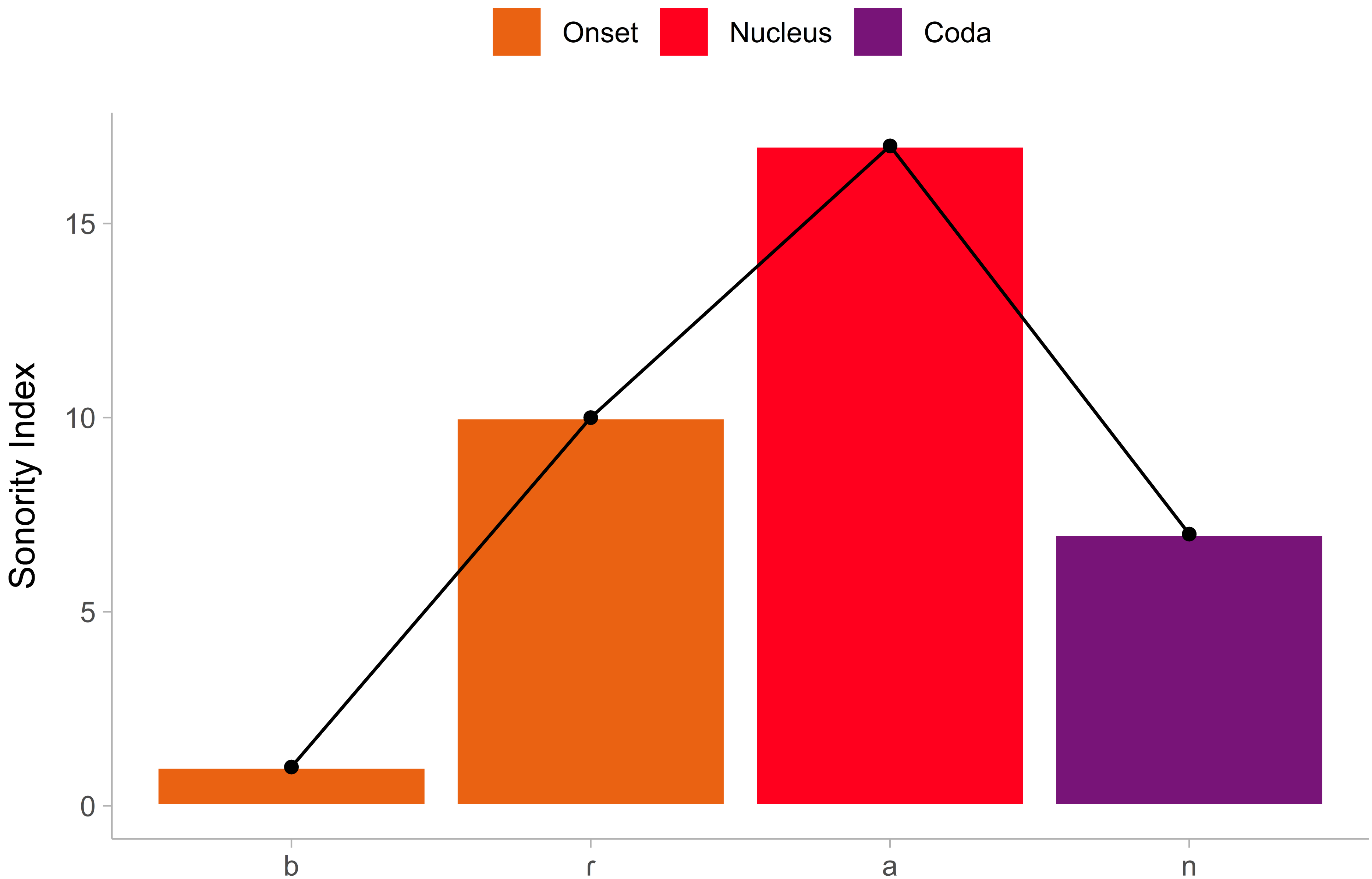


Figure 2: Sonority Sequencing Principle. Sonority values from Parker (2011)

Sonority Sequencing Principle (SSP)

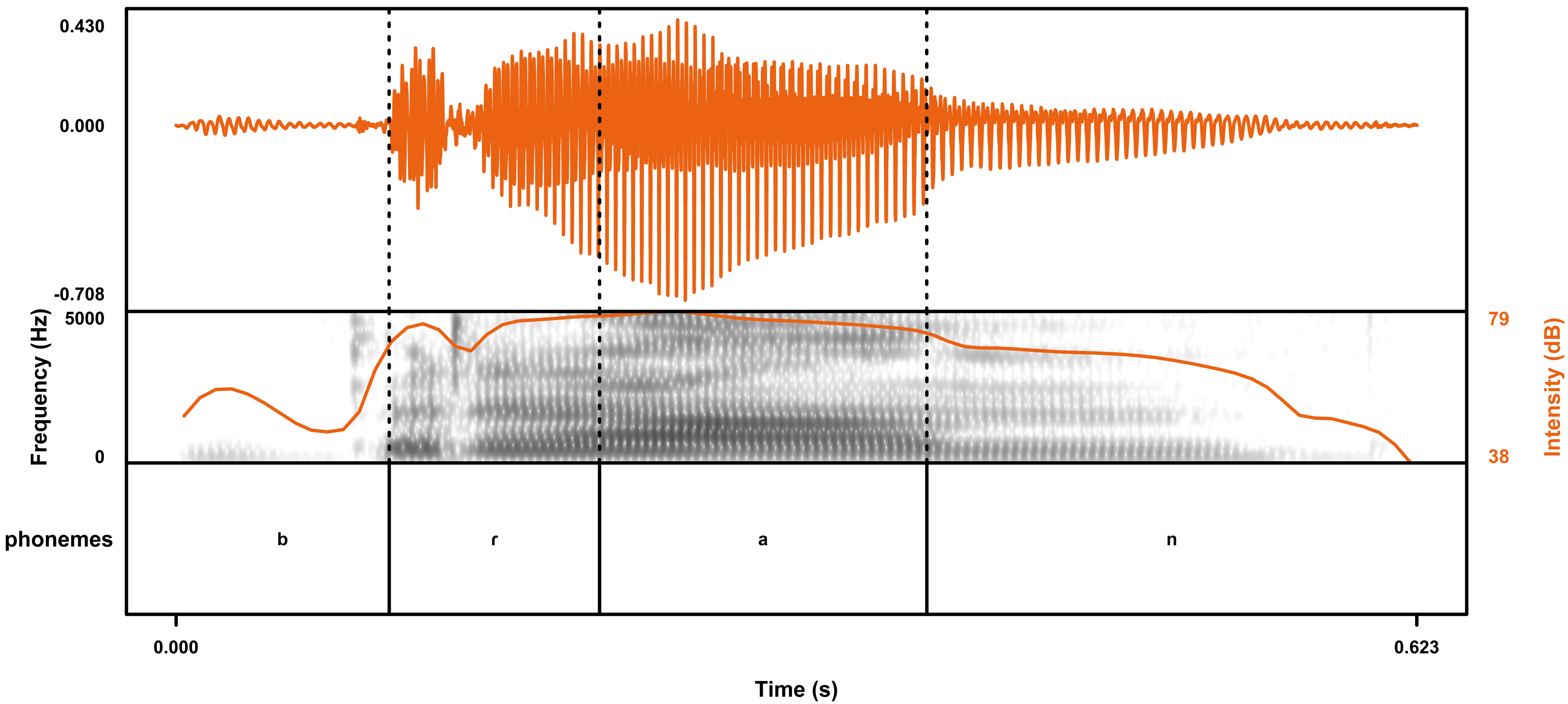


Figure 3: Sonority profile of the syllable ‘bran’

Sonority Sequencing Principle (SSP)

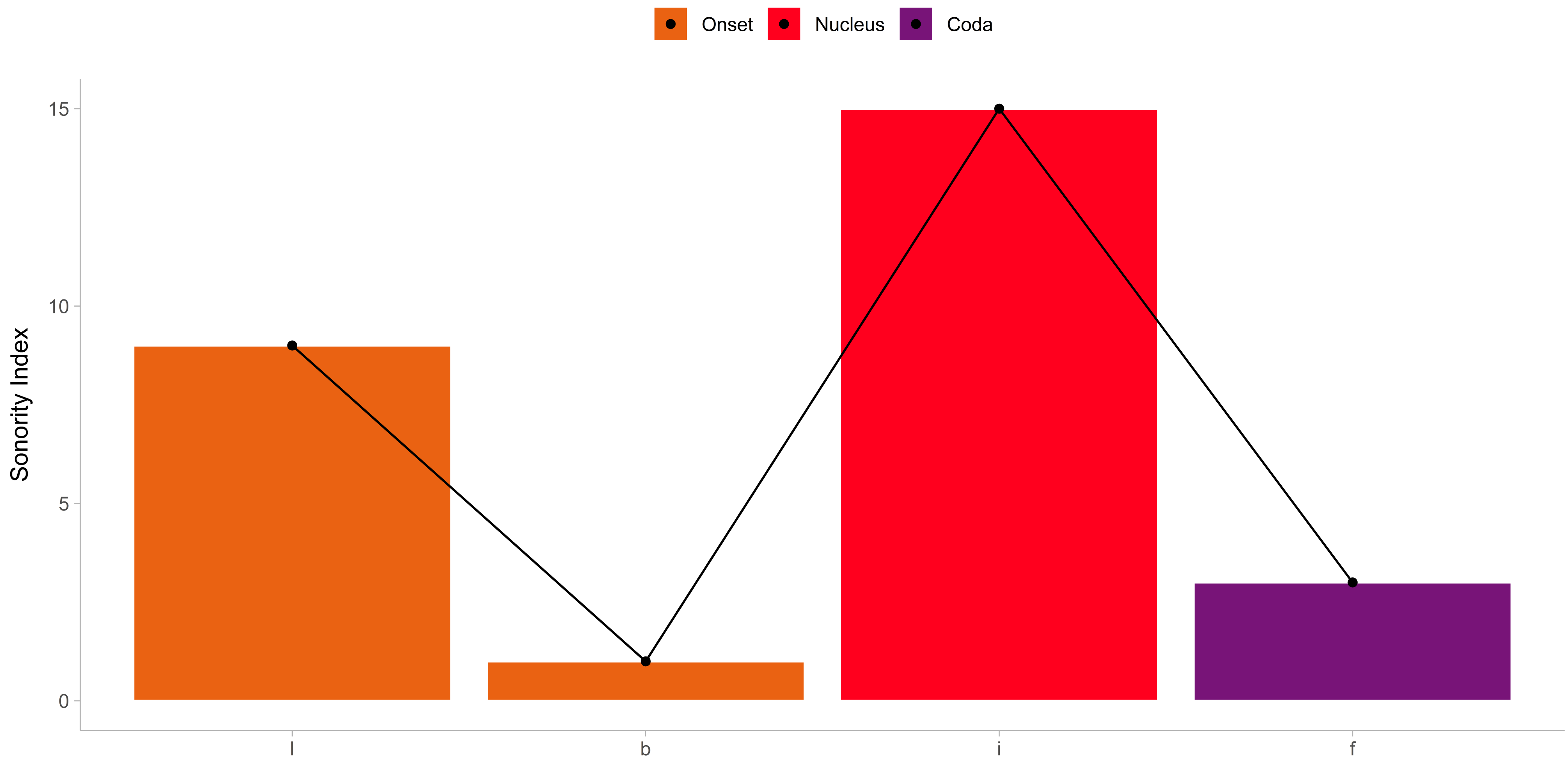


Figure 4: Sonority Sequencing Principle. Sonority values from Parker (2011)

Sonority Sequencing Principle (SSP)

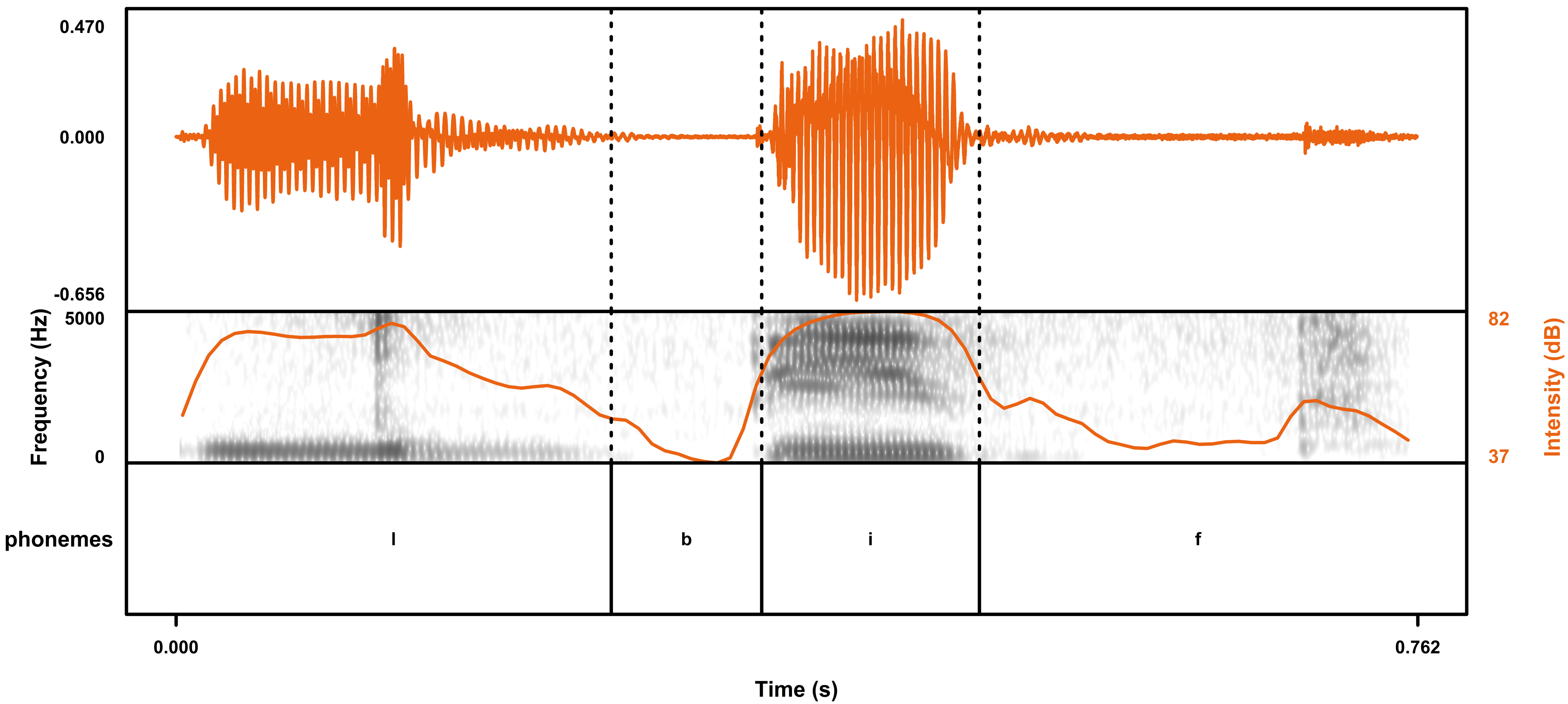


Figure 5: Sonority profile of the syllable ‘lbif’

Study 2: testing the sensory basis of the SSP in non-linguistic inputs

Proposal:

1. Syllables are biologically relevant linguistic units
2. Language processing at birth is constrained by phylogenetically acquired perception mechanisms (e.g., SSP) (Gómez et al. 2014)

Hypotheses:

- Sensitivity to SSP plays a role beyond language (non-linguistic sounds)
- Non-human animals (Long-Evans rats) are sensitive to (violations of) the SSP

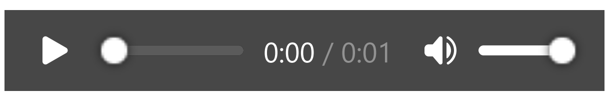
Participants

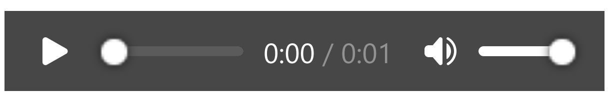
- Hearing, full term neonates (fNIRS) and 6-10 mo infants (fNIRS + behavioural)
- Born/living in the Metropolitan Area of Barcelona (Spain)
- Mostly Catalan and/or Spanish linguistic background

Stimuli

From Schutsch (2024):

- List of SSP+ (e.g., *blif*) and SSP- (e.g., *lbif*) CCVC syllables
- For each syllable:
  - Chunk acoustic signal into segments (x4 phonemes)
  - Calculate average F0/F1/F2 of each segment
  - Synthesise pure tone based on extracted pitch for each segment
  - Apply amplitude envelope of original audio

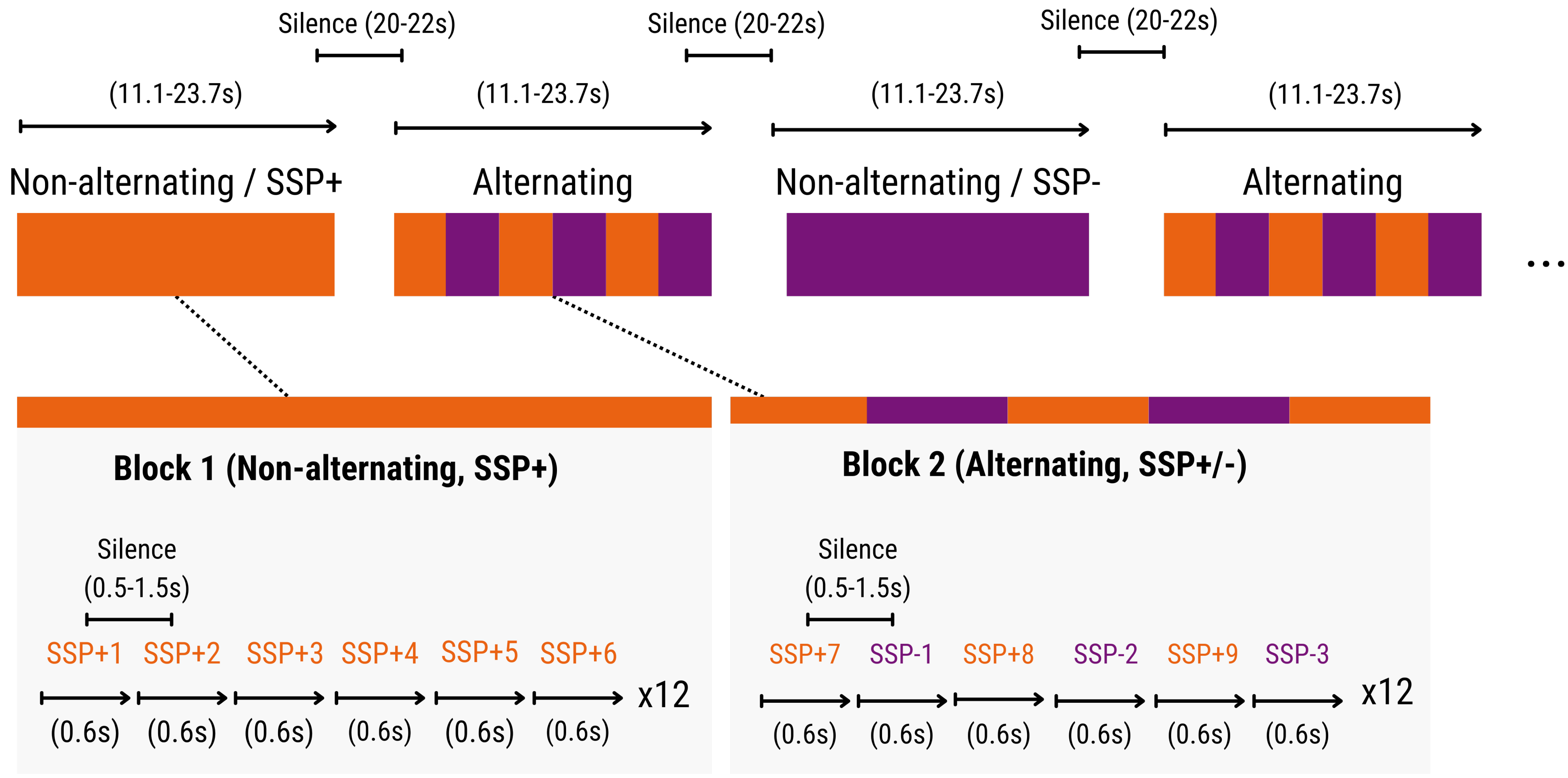




Task design (fNIRS block design)

1. Test phase:

- 4 blocks of strings of tones (20-22s silence between blocks):
  - 2 non-alternating (SSP+ *or* SSP-)
  - 2 Alt (SSP+ *and* SSP-)
- 12 strings of pure tones different words in each block (0.5-1.5s silence between words)



EXAMPLES: SSP+n: BLIF SSP-n: LBIF

"Syllable" expected duration: 0.6s

Every x4 blocks: 110.8-160.8.4s, x12 blocks: 6.21-8.77 min

Questions

- Discriminability of SSP+/SSP-: amplitude vs. pitch salience?
  - Adult experiment, artificial neural network?

Tha
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