

Language acquisition

Neurocognitive development

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Language acquisition

What is language?

What is language **like?**

What is language **for?**

Where does language come **from?**

What is language?

No easy, complete, specific way to define language

- **Complete:** captures *all* features of language
- **Specific:** captures *only* features of language

What is language?

<https://www.youtube.com/watch?v=FqJf1mB5PjQ>

What is language?

<https://www.youtube.com/watch?v=ldYkFdu5FJk>

What is language?

Language as an object

Finite system of symbols (words) that can be combined using rules to make a virtually infinite number of distinct sentences.

What is language?

<https://www.youtube.com/watch?v=8im72wFTa9Y>

What is language?

<https://www.youtube.com/watch?v=C0CIRCjoICA>

What is language?

<https://www.youtube.com/watch?v=l117wfB0g3o>

What is language?

Language as an object

Finite system of symbols (words) that can be combined using rules to make a virtually infinite number of distinct sentences.

Words (symbols, in general) hold arbitrary relationship between form and meaning¹.

Does the word *tree* sound, look, or feel like a tree?



With few exceptions ↪

What is language?

Language as an object

Finite system of symbols (words) that can be combined using rules to make a virtually infinite number of distinct sentences.

Limited number of words in a language.

Adapted from Brysbaert et al. (2016).

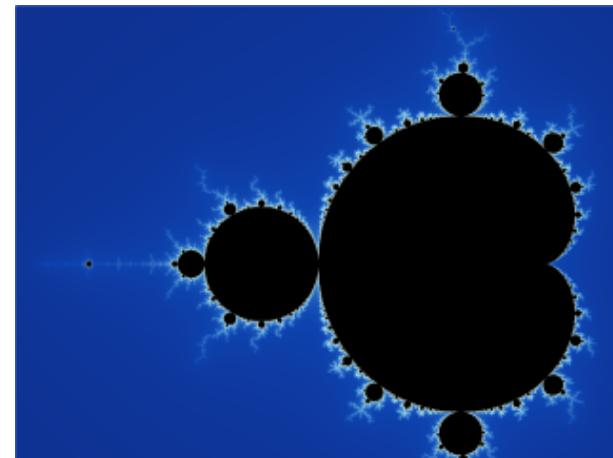
Person	Words	Lemmas	Base words
<i>20-year-old</i>			
Low end	84,000	27,100	6,100
Median		42,000	11,100
High end	292,000	51,700	14,900
<i>60-year-old</i>			
Low end	157,000	35,100	9,000
Median		48,200	13,400
High end	543,000	56,400	16,700

What is language?

Language as an object

Finite system of symbols (words) that can be combined using rules to make a virtually infinite number of distinct sentences.

Words (and other linguistic units) are
combined in systematic ways, following
rules we know as grammar.



What is language?

Language as an object

7,745 identified languages ([Glottolog](#))

Agglomerated Endangerment Status ([Hammarström et al., 2025](#))

AES status	# of languages	% of languages
not endangered	2643	34.13%
threatened	1595	20.59%
shifting	1805	23.31%
moribund	422	5.45%
nearly extinct	299	3.86%
extinct	981	12.67%

What is language?

Language as a function

Ability to systematically combine (**grammar**) a finite set of symbols (**words**) provided by a language so that a virtually unlimited number of sentences can be created (**productivity**).

- Can Koko combine signs **productively** to communicate complex ideas?
- Can speakers of silbo gomero combine different whistles **productively**?
- Is Alex's communication **symbolic**?
- Are tactile cues in protactile language **symbolic**?

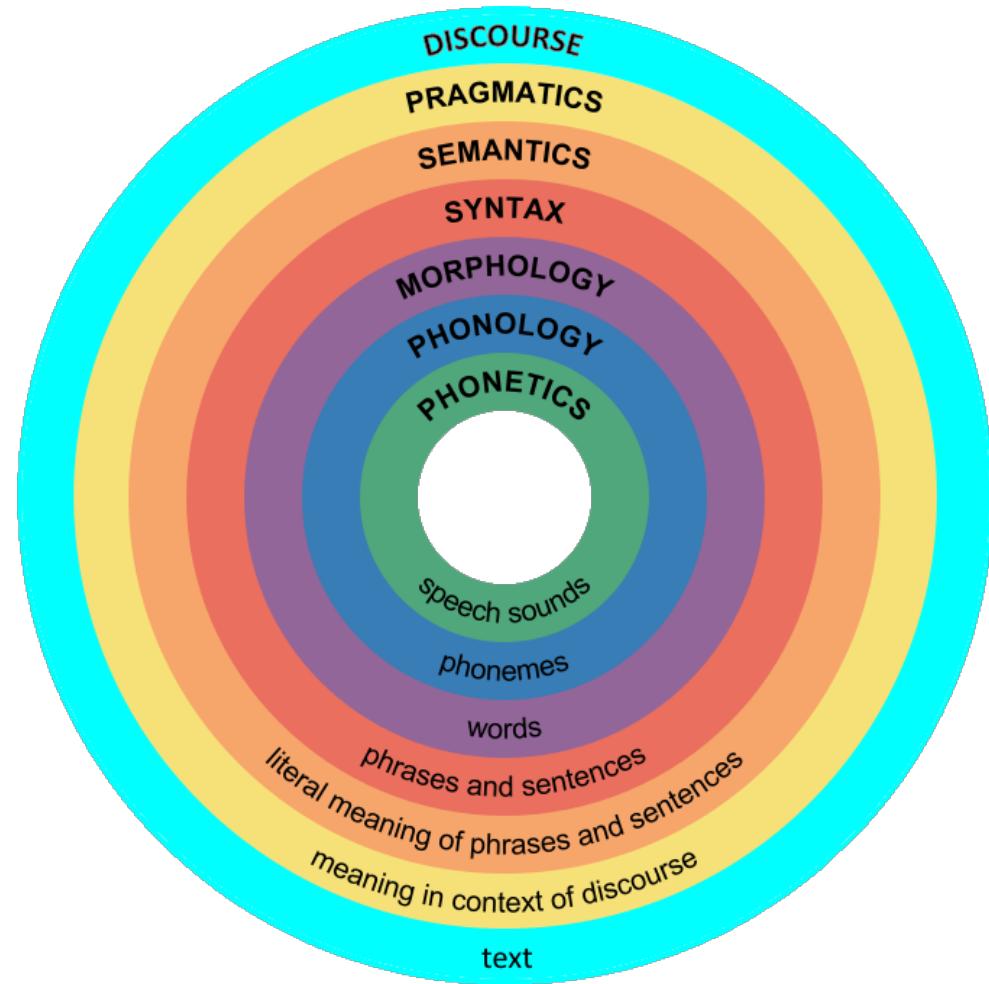
What is language like?

Linguistics

Scientific study of language(s)

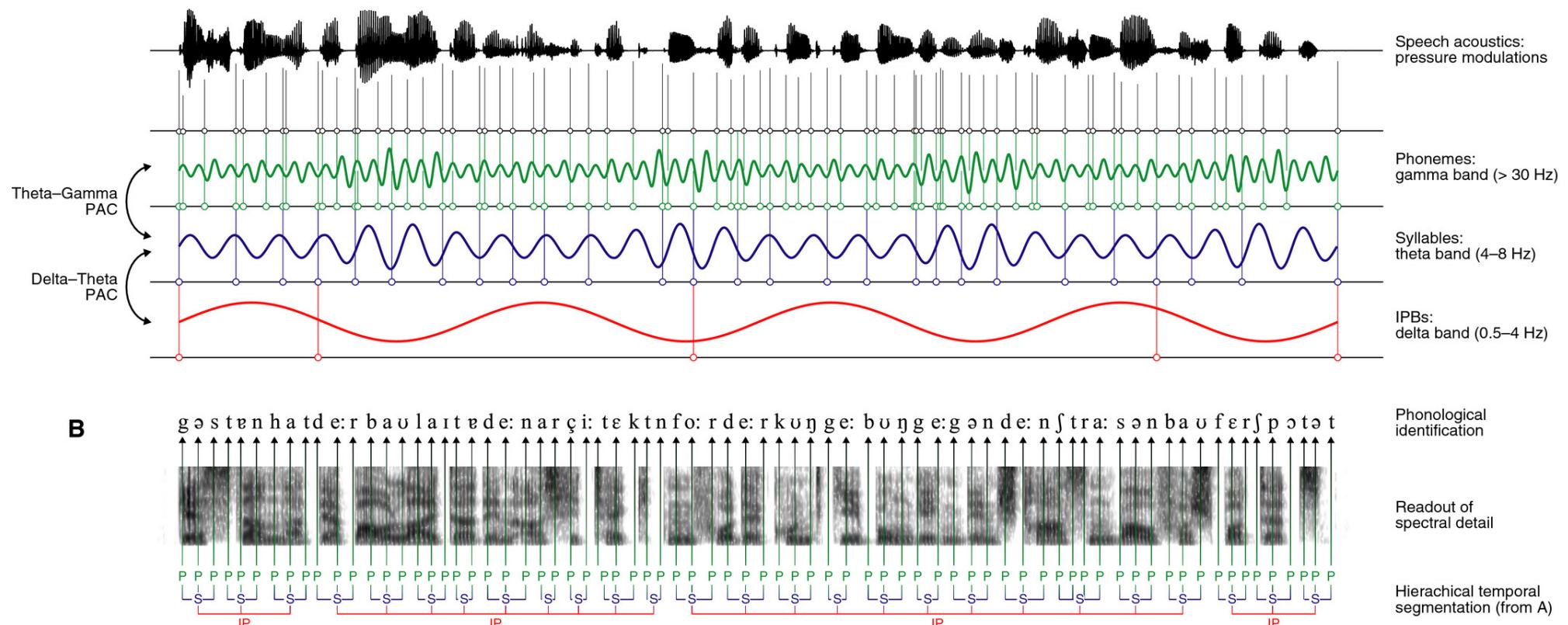
Languages are made of different linguistic units, which are organised hierarchically:

- Phonemes
- Syllables
- Words
- Sentences



What is language like?

A Gestern hat der Bauleiter den Architekten vor der Kundgebung gegen den Straßenbau verspottet.
Yesterday, before the demonstration against the roadworks, the construction manager made fun of the architect.



(Meyer, 2018)

What is language like?

Phonemes

Speech sounds that distinguish words with different meaning in a particular language

International Phonology Association (IPA)

- In Catalan and Spanish, do /d/ and /ð/ distinguish meanings?
 - Do /dedo/ and /deðo/ mean different things in Spanish?
- In Catalan and Spanish, do /o/ and /ɔ/ distinguish meanings?
 - Do /os/ and /ɔs/ mean different things in Catalan? And in Spanish?

What is language like?

Phonemes

Speech sounds that distinguish words with different meaning.

Phonemes ≠ Letters

casa [Catalan for *house*]

4 letters, 4 phonemes: /k a z a/

cotxe [Catalan for *car*]

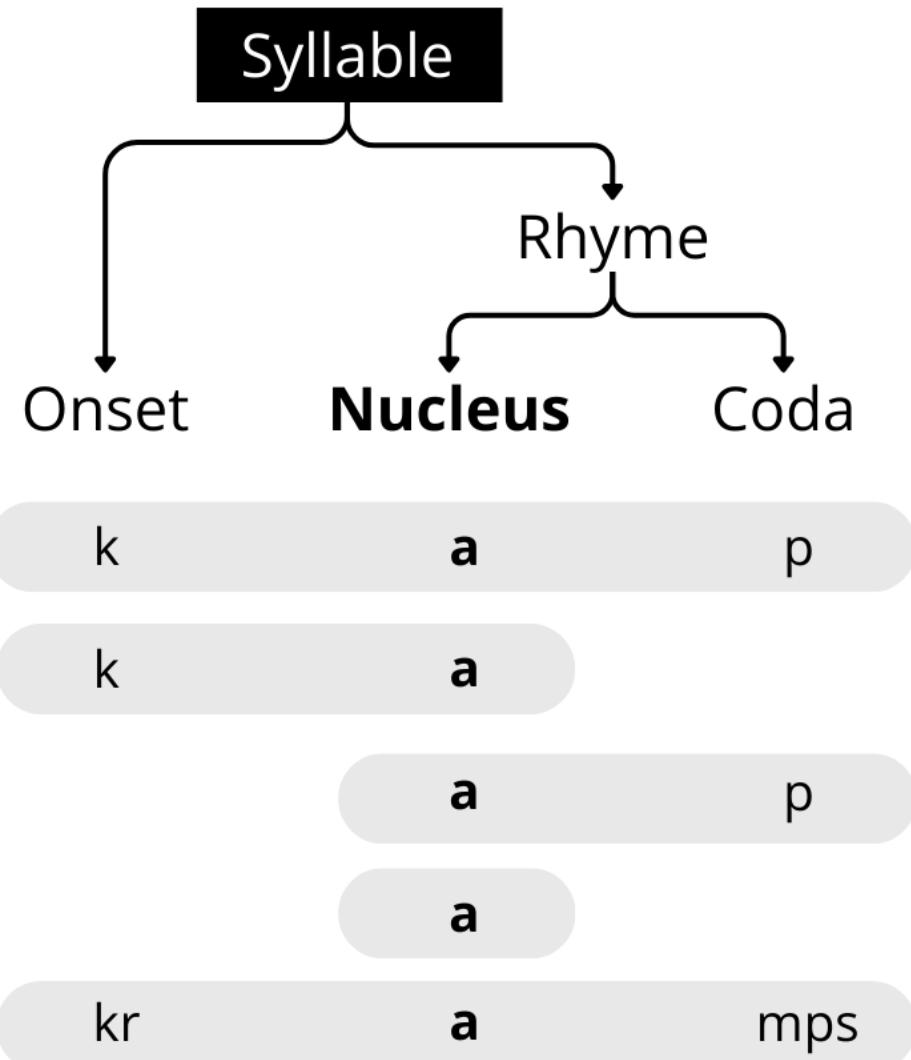
5 letters, 4 phonemes: /k o tʃ e/

What is language like?

Syllables

Minimal unit of pronunciation.

Universal structure!



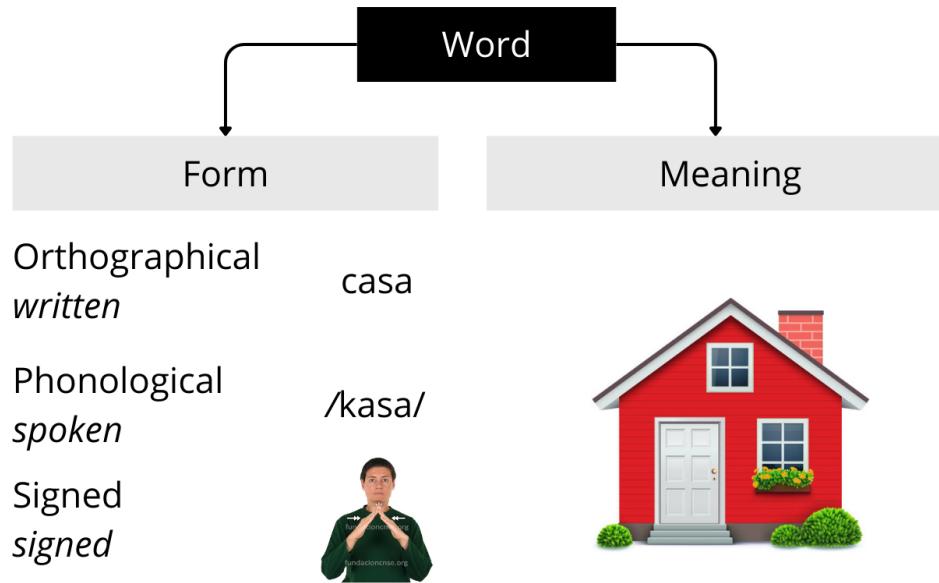
What is language like?

Words

Form-meaning association (minimal unit of meaning).

Mental lexicon

“Mental dictionary” that contains information about the form, meaning, and grammatical function of every word known by a person.



What is language like?

Adapted from Brysbaert et al. (2016).

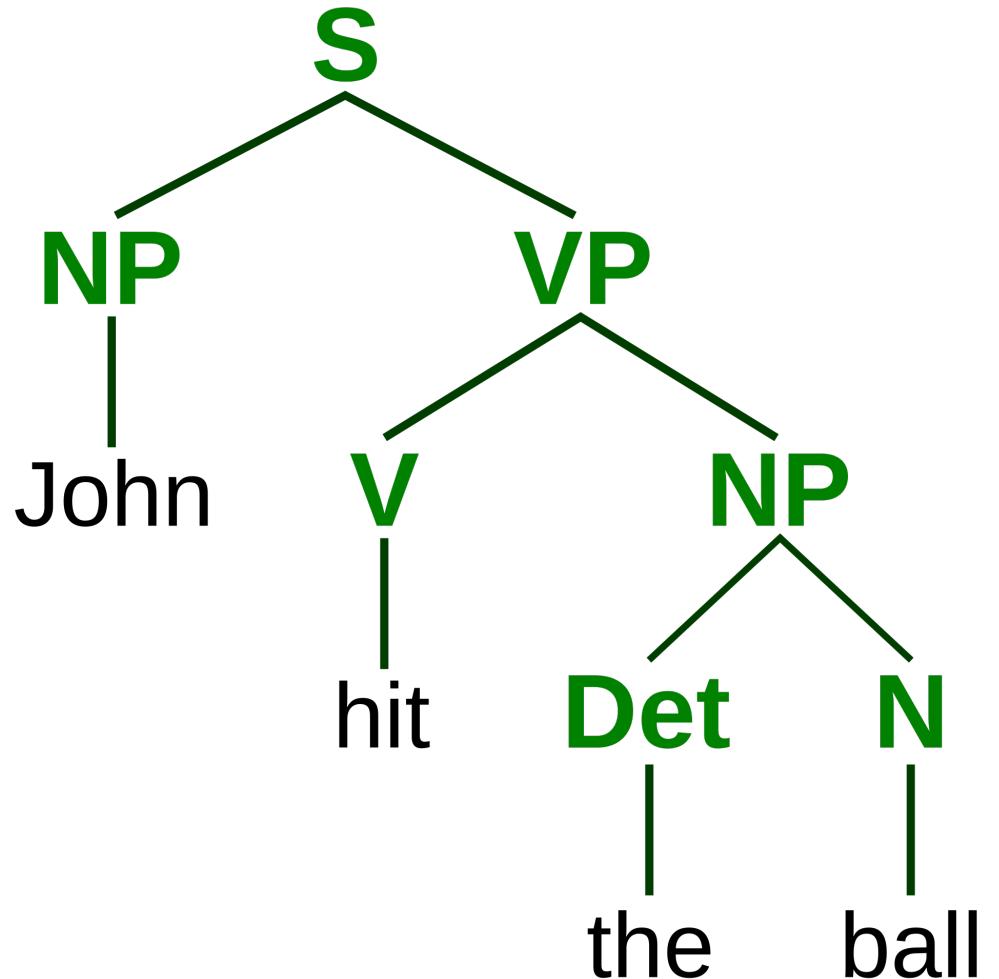
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What is language like?

Sentence

Words organised into grammatically coherent structures. Maximal unit of speech production.

Grammar provides the **rules** that allow speakers of a language to combine words in a **productive** way, to express virtually any possible meaning.



What is language for?

Language as a tool for *communication*

The ability for complex thinking provided humans with the ability to learn language ([Fedorenko et al., 2024](#); [Hockett & Hockett, 1960](#); [Kirby et al., 2008](#)).

Complex thinking does not necessarily engage language-related brain areas and vice versa (double dissociation) ([Fedorenko et al., 2024](#))

Language as a tool for *thinking*

The ability to use language provided humans with complex thinking ([Chomsky, 1995](#); [Goldin-Meadow, 2003](#)).

Some forms of thinking require or are facilitated by language (e.g., [Lupyan et al., 2007](#))

Where does language come from?

Symbolic communication appears between 1,000,000 and 100,000 years ago (*Homo erectus*) (Barham & Everett, 2021).

Why? How? Two approaches:

- Language “appears”

(Berwick & Chomsky, 2016; Chomsky, 1995)

- Language develops

(Christiansen & Kirby, 2003; Tomasello, 2003)

Can only be investigated *indirectly*:

- Sparse archaeological evidence
- Cultural transmission and evolution
- Evolutionary biology

Language acquisition

Is language learned?

- Humans need **exposure** to language to acquire language
- Not all humans speak the same language, and genes do not explain cross-linguistic differences
- There is an obvious learning component to language acquisition

Is language *inherited*?

- Language acquisition is **efficient**: Humans acquire their native language(s) in little time, without effort, and without explicit instruction
- **Stimulus poverty**: language cannot be possibly learned from experience alone (lack of positive and negative evidence)
- Language is **unique to humans**, non-human animals do not acquire language even after intensive training

Current directions

Which aspects are more **experience dependent**?

Which **experience** do they depend on?

Which **mechanisms** underlie language learning?

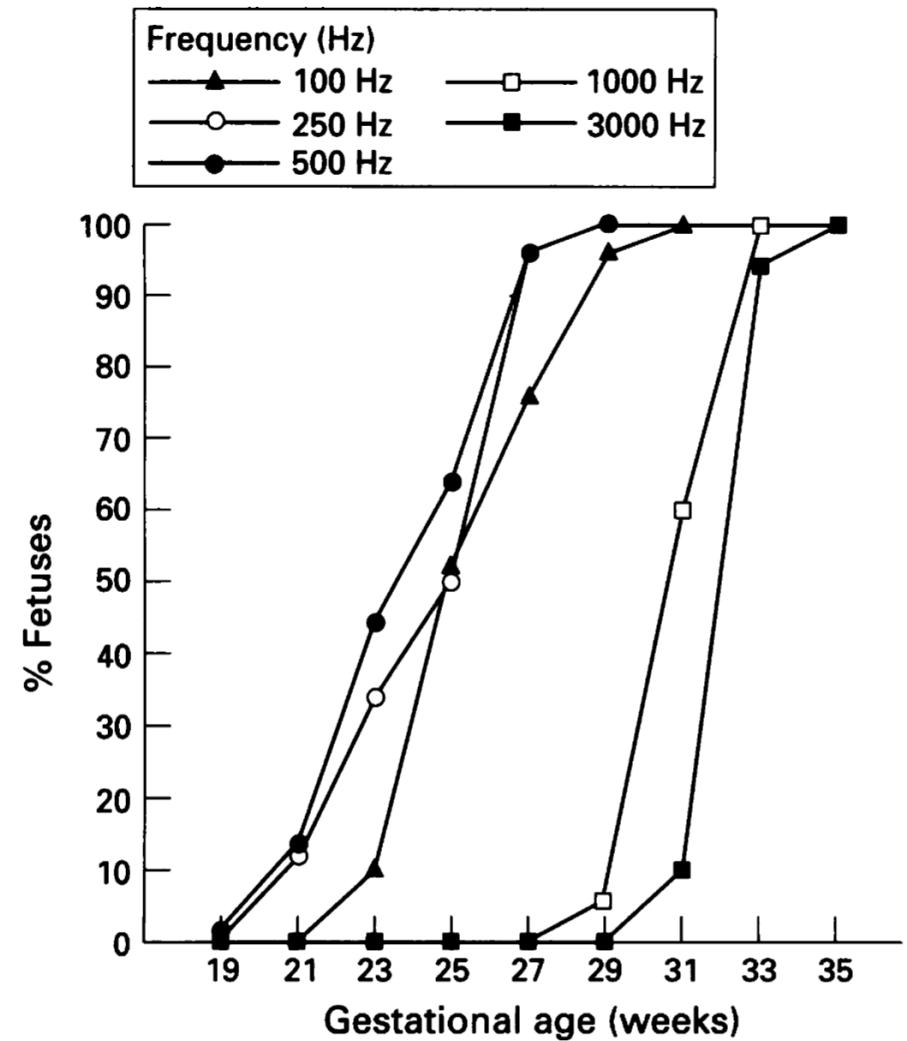
To what extent do humans share these mechanisms with **other species**?

Before-birth

Pre-natal language exposure

Fetal auditory development

- The fetal auditory system is **functional from 20 weeks of gestation**
- **Biological tissues** (skin, muscle, amniotic liquid) filter the acoustic signal
- **Low-pass filter:** frequencies lower than 550 Hz reach the fetus' ears, higher frequencies do not



Hepper & Shahidullah (1994)

Fetal language exposure

Acoustics in the womb

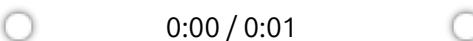
<https://www.youtube.com/watch?v=yWBgy55EkIM>

Fetal language exposure

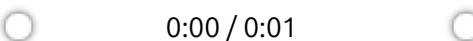
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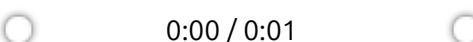
Low-pass filtered signal



Original signal



High-pass filtered signal



Fetal language exposure

- Fetus' get familiarized with prosodic features of their native language(s)
 - **Intonation:** modulation of the frequency of speech sounds across segments
 - **Rhythm:** rate at which linguistic units are produced per unit of time
- Still quite **unfamiliar with segmental information** (i.e., different consonants)

Fetal language exposure

Auditory learning is already present at 33 gestational weeks.

DeCasper et al. (1994)

- 28 pregnant women in their 33 gestational week recited a poem 3 consecutive times per day for 4 weeks.
- At test, fetuses auditory stimulated with familiar poem or an unfamiliar poem (control).
- Beat-to-beat intervals of the fetal heart were recorded (doppler cardiotocograph).
- The familiar poem decreased heartbeat rate, the unfamiliar poem did not.

0-6 months of age

First encounters with language

Newborns prefer speech over non-speech sounds.

Vouloumanos, Christophe, and Bertoni (1997)

First encounters with language

Vouloumanos, Christophe, and Bertoniini (1997)

High Amplitude Sucking (HAS) procedure

([Floccia et al., 1997](#))

- Newborns are trained to **increase their sucking rate** in order to continue listening to some auditory stimulus.
- Sucking rate is compared for two or more types of stimuli.
- If newborns **prefer** some type of stimuli over the others, sucking rate should be higher for that type of stimulus.

First encounters with language

<https://www.youtube.com/watch?v=psgv41HVdaE>

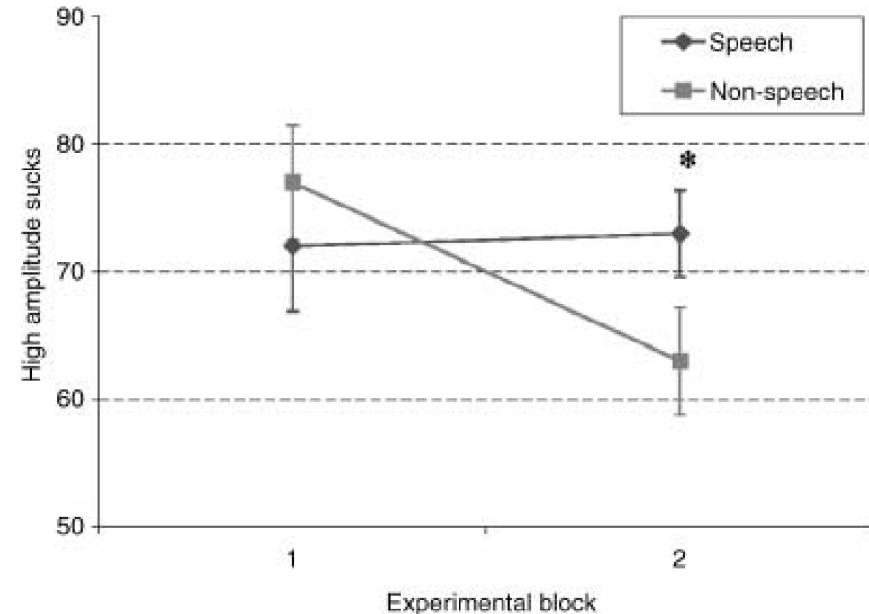
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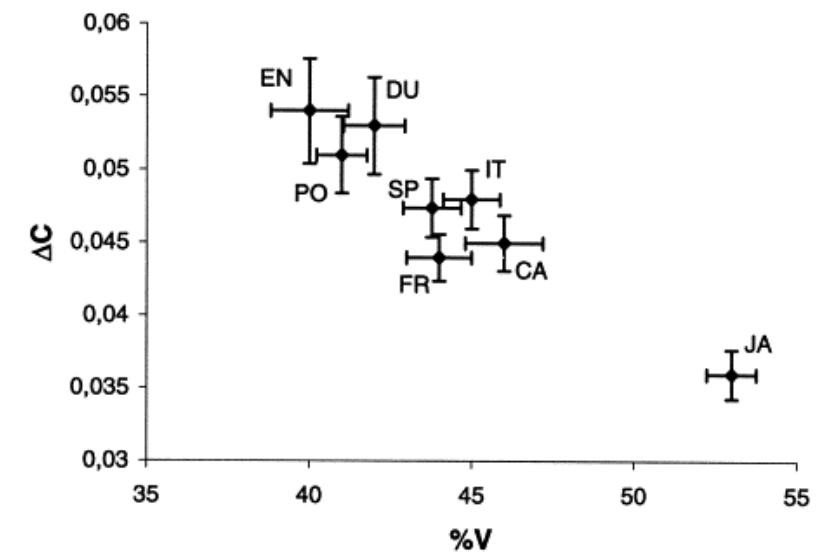
Language discrimination

Newborns can discriminate between languages from different rhythm classes

Nazzi et al. (1998)

Language discrimination

Rhythm group	Examples	
<i>Syllable-timed</i>	Catalan, Spanish	H O N - D A
<i>Stress-timed</i>	English, Dutch	H O N D A
<i>Mora-timed</i>	Japanese, Tamil	H O - N - D A



Ramus et al. (1999)

Language discrimination

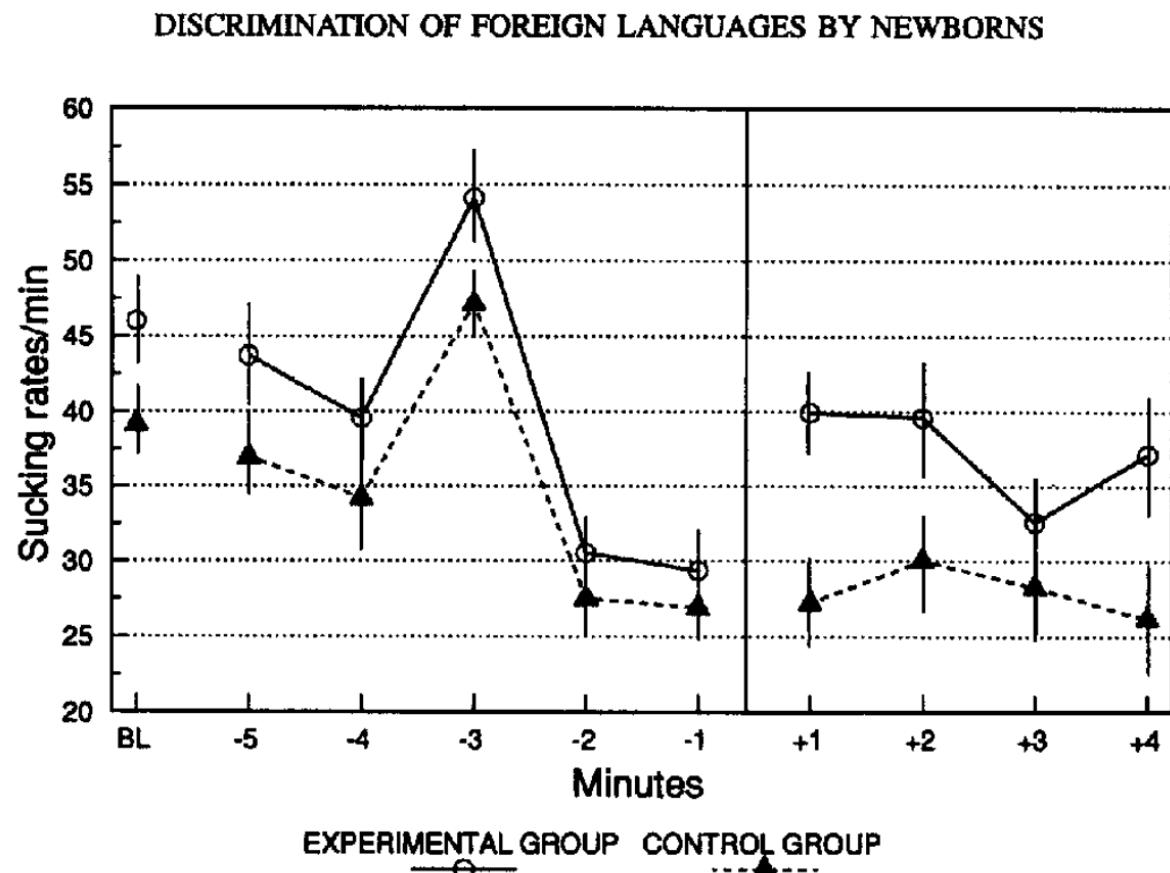
Nazzi et al. (1998)

- Presented newborns with low-pass filtered sentences produced by natural speakers (keeping prosodic but not segmental information)
- Sentences belonged to a stress-timed language(English, Dutch) or a mora-timed language (Japanese)

Language discrimination

Nazzi et al. (1998)

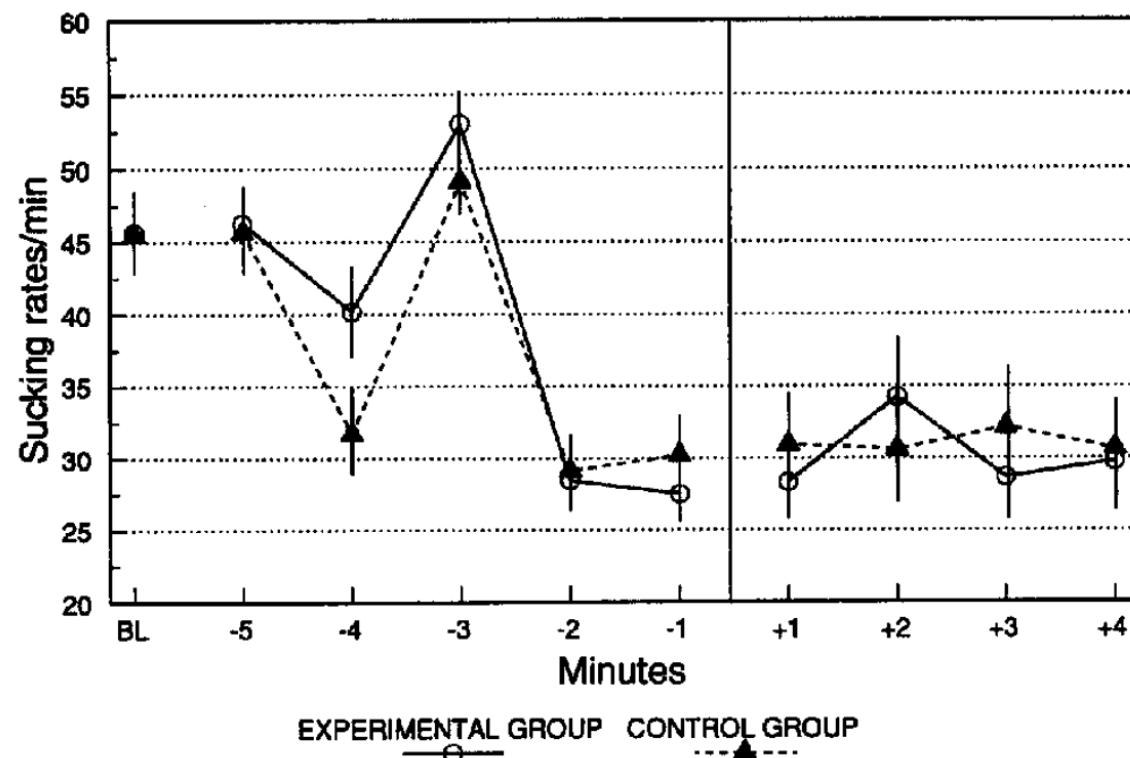
English (stress-timed) vs. Japanese (mora-timed)



Language discrimination

Nazzi et al. (1998)

English (stress-timed) vs. Dutch (stress-timed)



(Bilingual) language discrimination

Bilingual infants discriminate their native languages, even if they belong to the same rhythmic group.

Bosch and Sebastian-Galles (2001)

(Bilingual) language discrimination

Bilingual infants discriminate their native languages, even if they belong to the same rhythmic group.

Bosch and Sebastian-Galles (2001)

Three groups of participants:

- 4 month-old **Catalan monolinguals**
- 4 month-old **Spanish monolinguals**
- 4 month-old **Catalan-Spanish bilinguals**

(Bilingual) language discrimination

Bosch and Sebastian-Galles (2001)

Familiarization-preference

Procedure ([Jusczyk & Aslin, 1995](#))

1. *Familiarization phase:*
sentences in the native/
dominant language
2. *Test phase:* sentences in both
languages

Which sentences do infants
prefer to listen to?

(Bilingual) language discrimination

Bosch and Sebastian-Galles (2001)

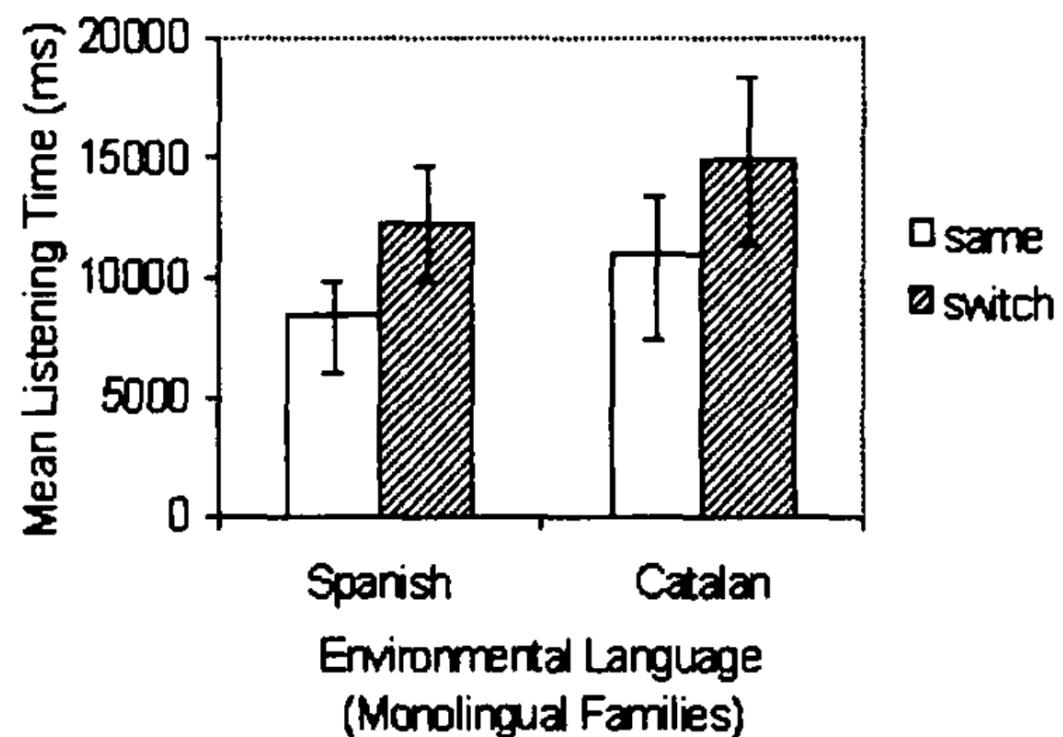
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Monolinguals



(Bilingual) language discrimination

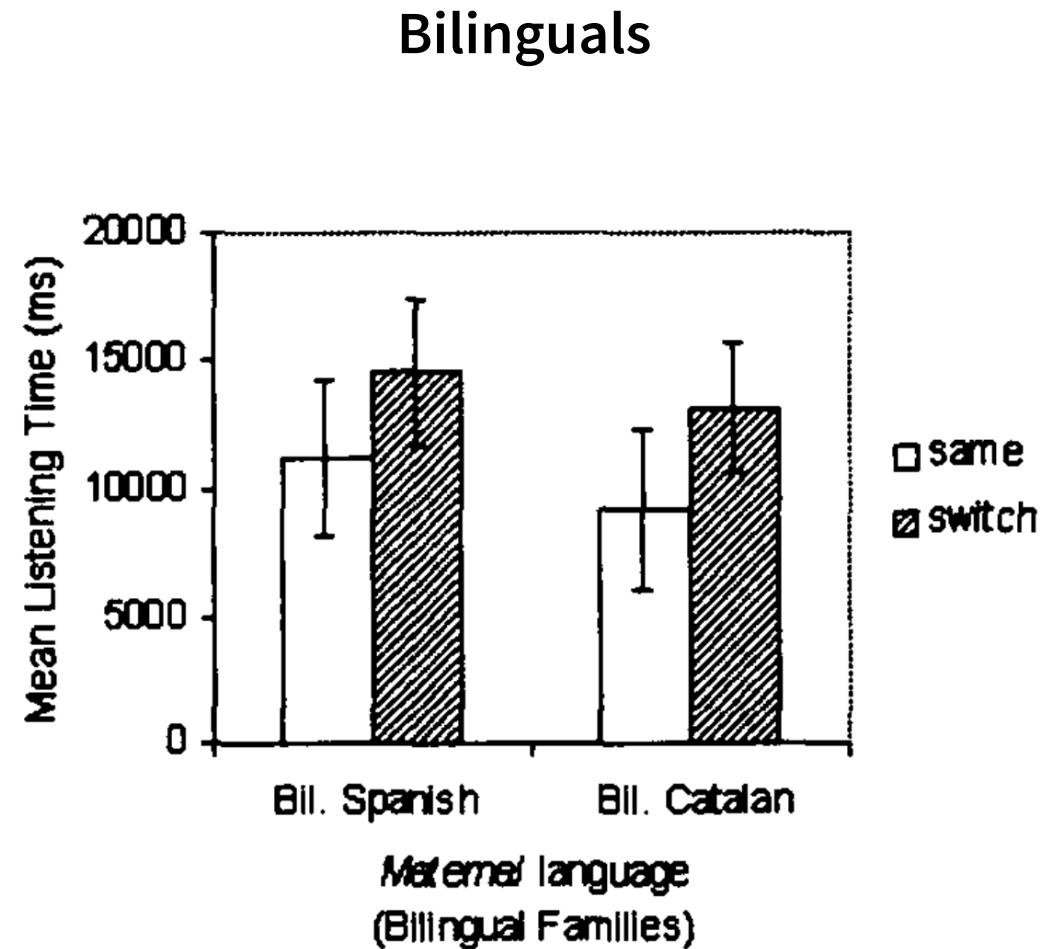
Bosch and Sebastian-Galles (2001)

Familiarization-preference

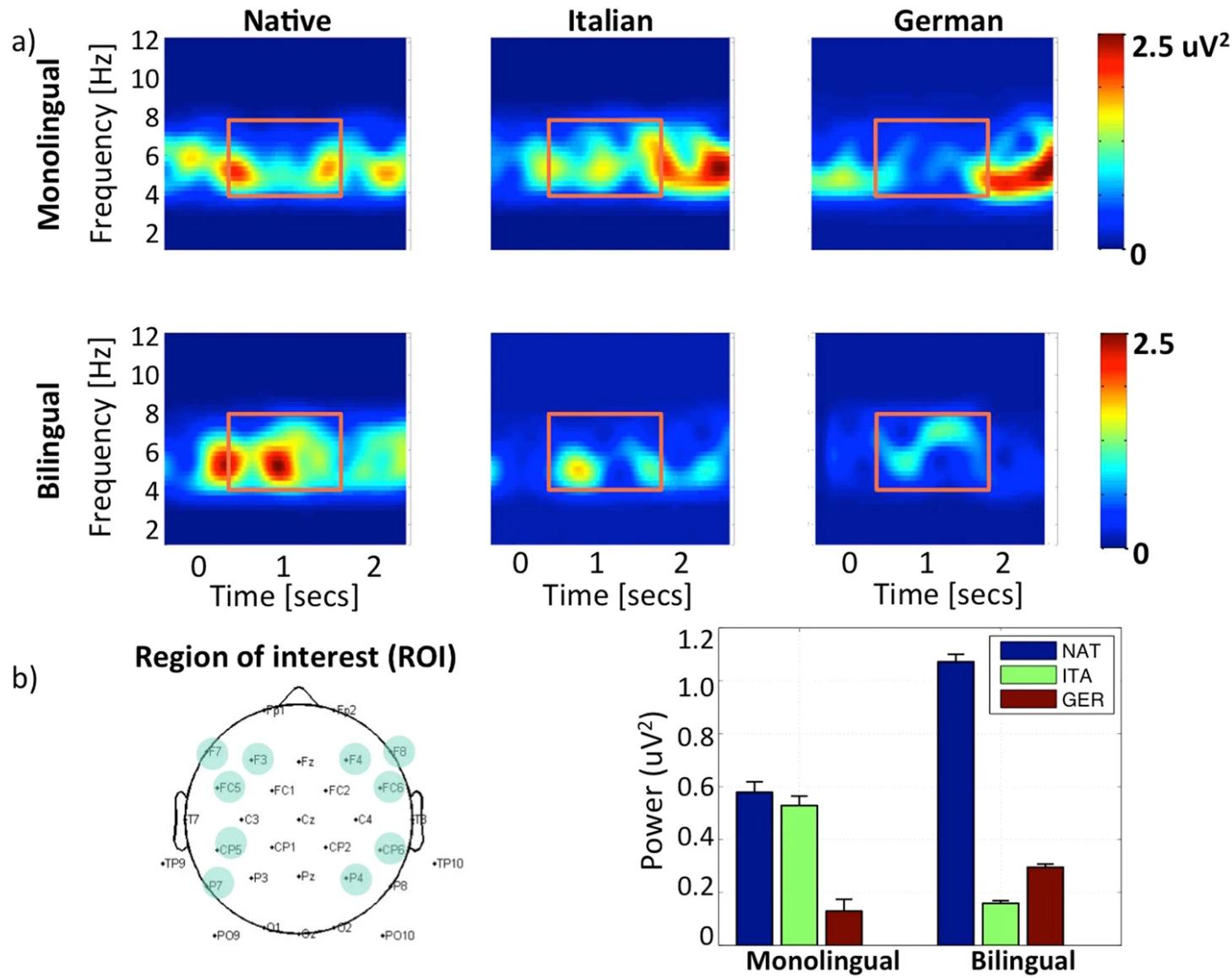
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(Bilingual) language discrimination



Nacar Garcia et al. (2018)

6-12 months of age

Perceptual narrowing

From 6 to 12 months of age, infants attune their perceptual abilities to the sounds of their native language.

Werker and Tees (1984)

Perceptual narrowing

Werker and Tees (1984)

Three groups of participants exposed to exemplars of the /k/-/q/ consonant contrast

(Mayes, 1979):

- 6 month-old infants
- English native adults
- Thompson (*Nlaka'pamuctsin*, native American) native adults

Perceptual narrowing

Werker and Tees (1984)

<https://www.firstvoices.com/nlekepmxcin>

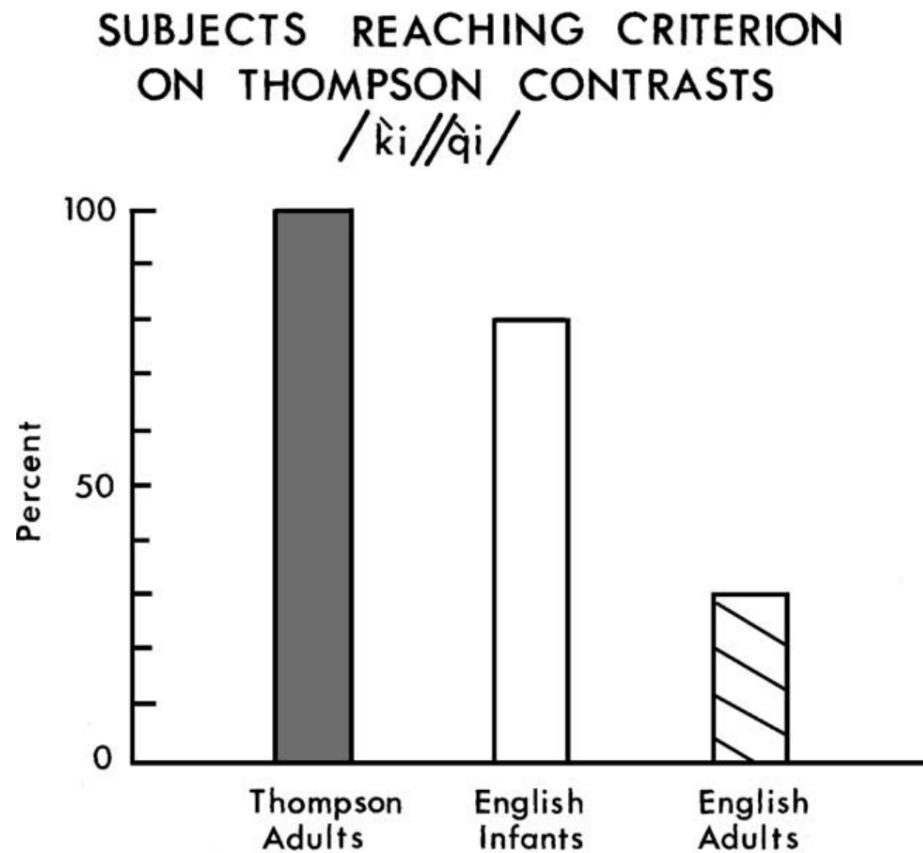
/k/ → k?és [nostalgia] ►

/q/ → qipéwstn [belt] ►



Perceptual narrowing

Werker and Tees (1984)



Perceptual narrowing

Werker and Tees (1984)

(Bilingual) perceptual narrowing

Perceptual narrowing also happens in bilinguals, but is evidenced in different ways than in monolinguals.

Bosch and Sebastian-Galles (2003)

(Bilingual) perceptual narrowing

Bosch and Sebastian-Galles (2003)

Three groups of infants:

- 4.5 month-old **Catalan monolinguals**
- 4.5 month-old **Spanish monolinguals**
- 4.5 month-old **Catalan/Spanish bilinguals**

(Bilingual) perceptual narrowing

Bosch and Sebastian-Galles (2003)

*Familiarization-preference
procedure*

1. Familiarization phase:

/dəðɪ/ or /dɛðɪ/

2. Test phase:

/dəðɪ/ and /dɛðɪ/

Which sentences do infants
prefer to listen to?

(Bilingual) perceptual narrowing

Bosch and Sebastian-Galles (2003)

Familiarization-preference procedure

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Which sentences do infants prefer to listen to?

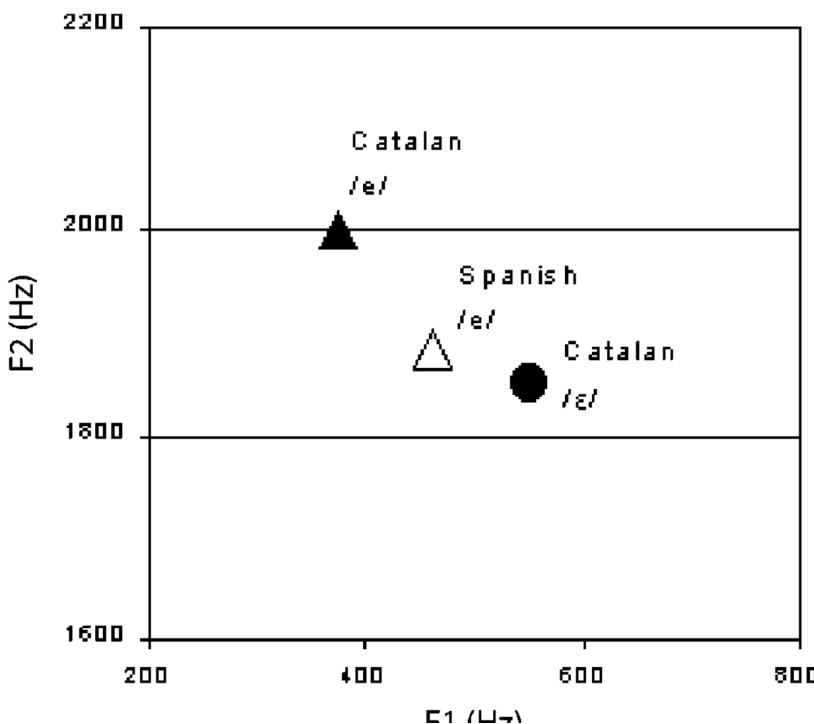


Figure 1

Average values for the frequency of F1 and F2 for Spanish [e] and Catalan [e]-[ɛ] vowels, as suggested in phonetic analyses of production studies (Martínez Celdrán, 1984, and Recasens, 1991, for Spanish and Catalan data respectively)

(Bilingual) perceptual narrowing

Bosch and Sebastian-Galles (2003)

*Familiarization-preference
procedure*

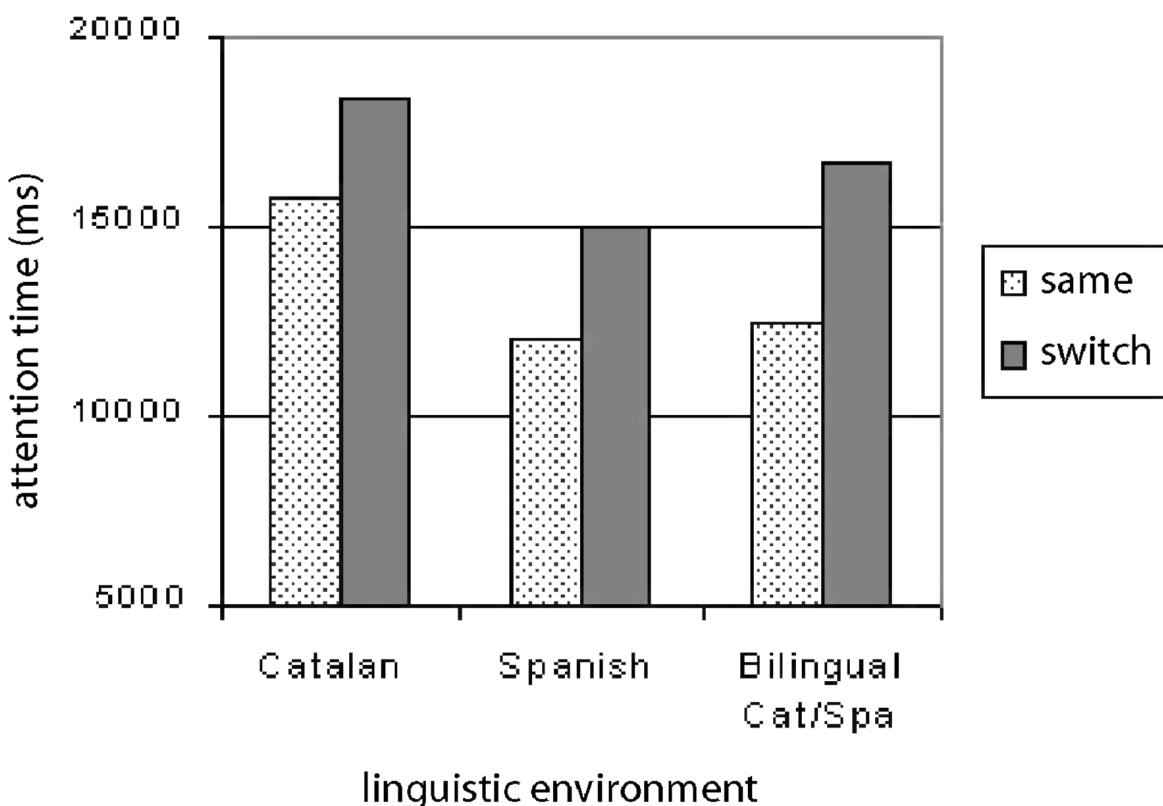
1. Familiarization phase:

/deði/ or /dɛði/

2. Test phase:

/deði/ and /dɛði/

Which sentences do infants
prefer to listen to?



(Bilingual) perceptual narrowing

Perceptual narrowing also happens in bilinguals, but is evidenced in different ways than in monolinguals.

Albareda-Castellot, Pons and Sebastian-Galles (2010)

Can Catalan/Spanish bilinguals really not discriminate the native, Catalan contrast?

(Bilingual) perceptual narrowing

Albareda-Castellot, Pons and Sebastian-Galles (2010)

Anticipatory eye movement paradigm

Eye-tracking

Can infants anticipate the trajectory of an object based on its associated speech sounds?

E.g.: /dɛðj/ → left, /dɛðj/ → right

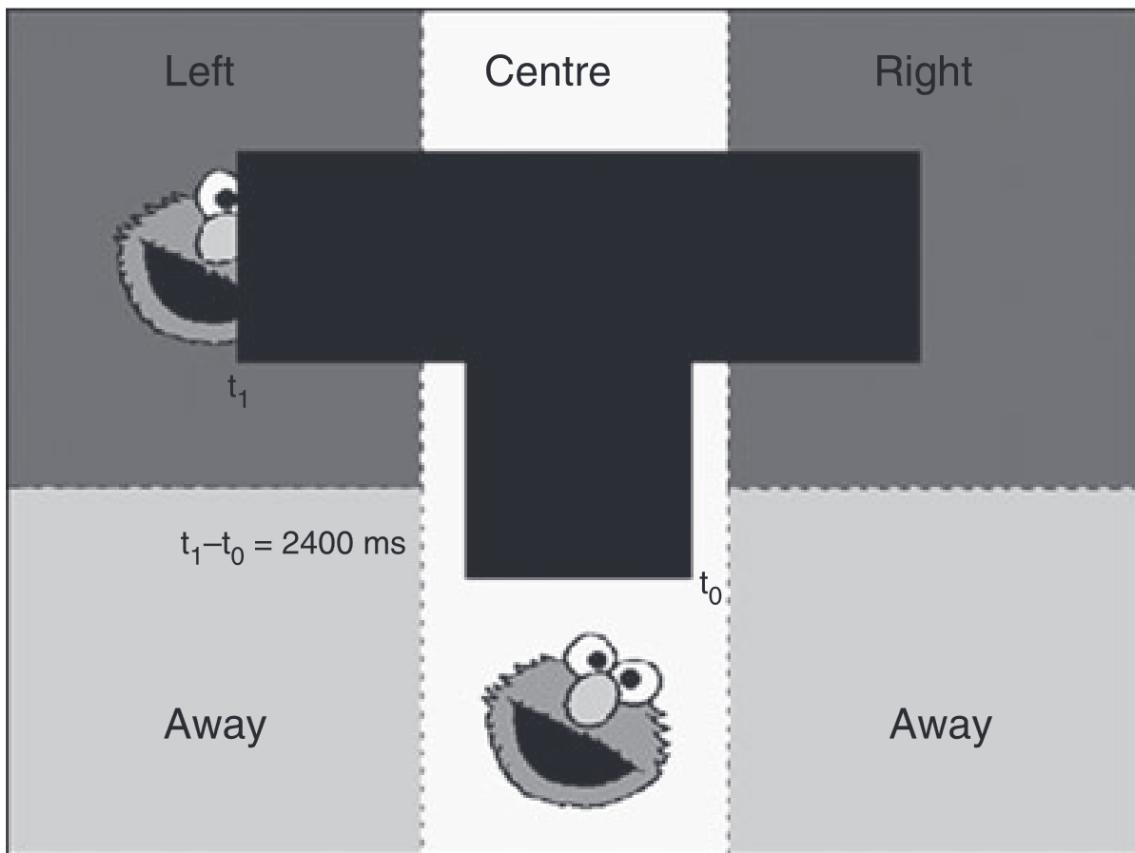


Figure 1 Visual stimulus, T-shaped occluder and coding areas.

(Bilingual) perceptual narrowing

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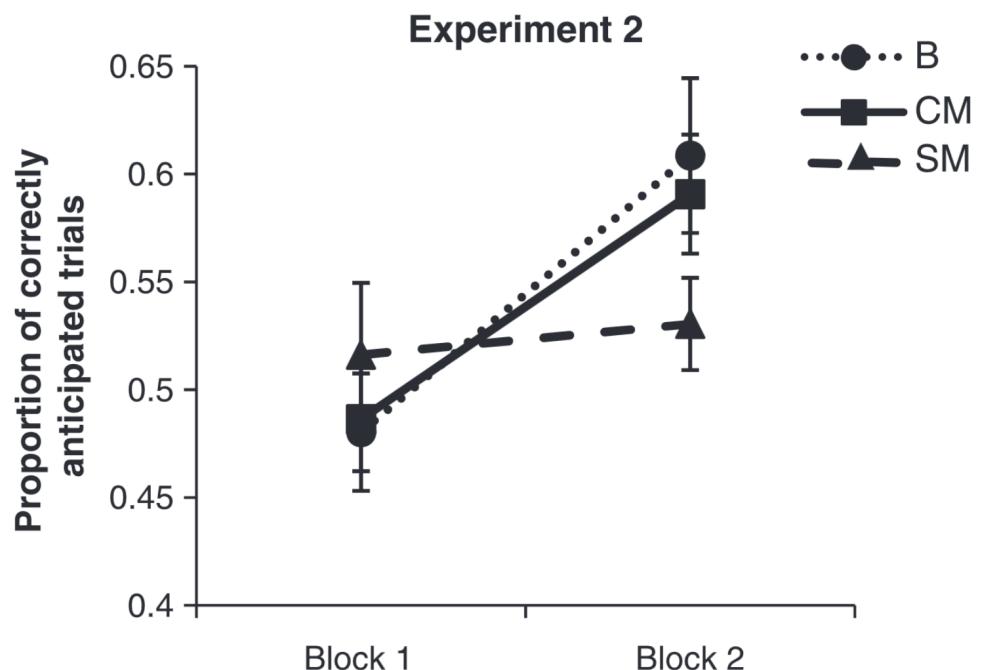
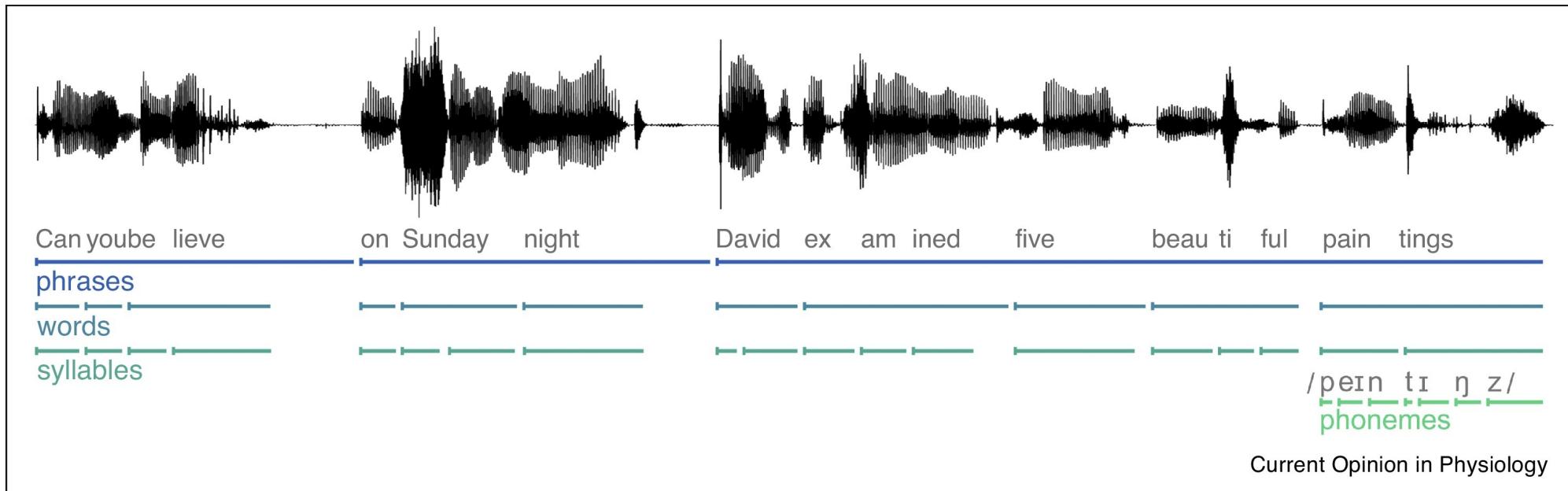


Figure 3 Proportion of correctly anticipated trials in blocks 1 and 2 for the three language groups (SM = Spanish monolinguals; CM = Catalan monolinguals; B = bilinguals).

Statistical learning



Brodbeck & Simon (2020)

How can infants learn new **words** in the absence of clear **word boundaries** in the **continuous speech stream**?

Statistical learning

whataprettybabyyouare

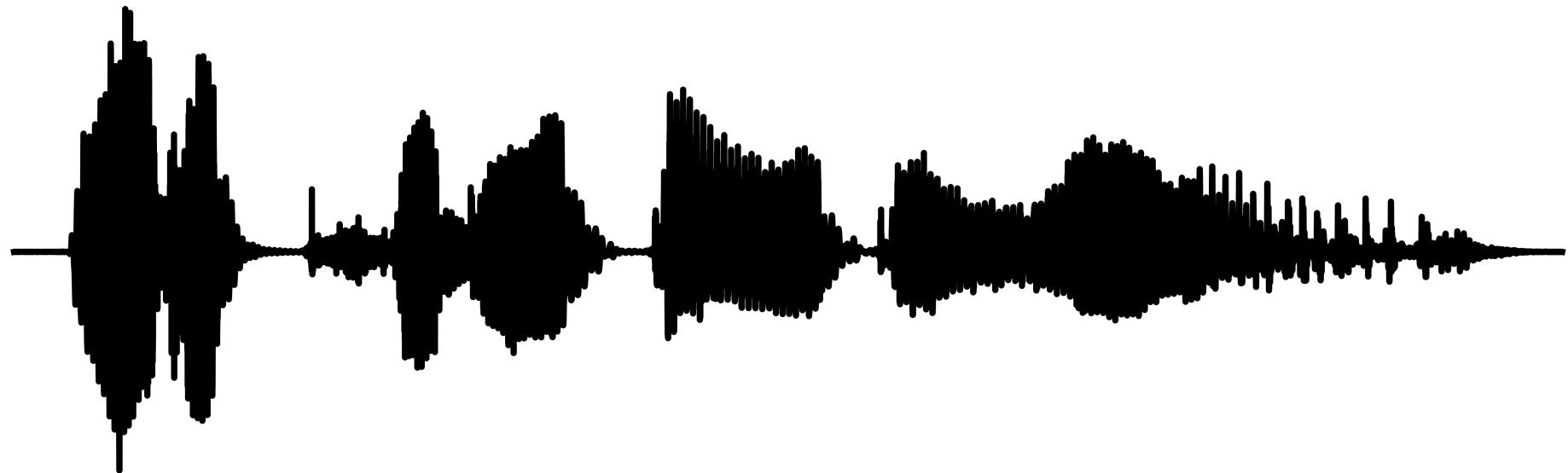


0:00 / 0:01



Statistical learning

whataprettybabyyouare



Statistical learning

whataprettybabyyouare

what-a-pretty-baby-you-are

Statistical learning

whataprettybabyyouare

what-a-pretty-baby-you-are

whatapre-ttyba-bbyouare

Statistical learning

whataprettybabyyouare

what-a-pretty-baby-you-are

whatapre-ttyba-bbyouare

whata-prettyba-by-youare

Statistical learning

whataprettybabyyouare

what-a-pretty-baby-you-are

whatapre-ttyba-bbyouare

whata-prettyba-by-youare

what-a-pre-tty-ba-by-you-are

Statistical learning

Infants exploit **statistical regularities** to segment the continuous speech signal into discrete units.

Statistical learning

Infants exploit **statistical regularities** to segment the continuous speech signal into discrete units.

Saffran, Aslin, and Newport (1996)

Transitional probabilities (TP)

Relative number of co-occurrences
between two syllables

$$Y|X = \frac{\text{frequency of } XY}{\text{frequency of } X}$$

Statistical learning

whataprettybabyyouare

$$TP_{pre|a} < TP_{tty|pre}$$

$$TP_{tty|pre} > TP_{ba|tty}$$

Statistical learning

Saffran, Aslin, Newport (1996)

Exposed 8 month olds to a continuous string of syllables during 2 minutes.

...tupirogolabubidakupadotigolabutupiropadotibidaku...

Statistical learning

Is golabu a word?

Statistical learning

Is golabu a word?

Is labubi a word?

Statistical learning

...tupirogolabubidakupadotigolabutupiropadotibidaku...

Statistical learning

...tupirogolabubidakupadotigolabutupiropadotibidaku...

Statistical learning

...tupiro-golabu-bidaku-padoti-golabu-tupiro-padoti-bidaku...

Statistical learning

...tupiro-golabu-bidaku-padoti-golabu-tupiro-padoti-bidaku...

...tupi-rogola-bubida-kupado-tigola-butupi-ropado-tibida-ku...

Statistical learning

...tupiro-golabu-bidaku-padoti-golabu-tupiro-padoti-bidaku...

...tupi-rogola-bubida-kupado-tigola-butupi-ropado-tibida-ku...

...tu-pirogo-labubi-dakupa-dotigo-labutu-piropa-dotibi-daku...

Statistical learning

...tupirogolabubidakupadotigolabutupiropadotibidaku...

$$p(\text{la}|\text{go}) = 1.0$$

Statistical learning

...tupirogolabubidakupadotigolabutupiropadotibidaku...

$$p(\text{bu}|\text{la}) = 1.0$$

Statistical learning

...tupirogolabubidakupadotigolabutupiropadotibidaku...

$$p(\text{bi}|\text{bu}) = 0.5$$

Statistical learning

...tupirogolabubidakupadotigolabutupiropadotibidaku...

$$p(\text{da}|\text{bi}) = 1.0$$

Statistical learning

...tupirogolabubidakupadotigolabutupiropadotibidaku...

$$p(\text{ku}|\text{da}) = 1.0$$

Statistical learning

...tupirogolabubidakupadotigolabutupiropadotibidaku...

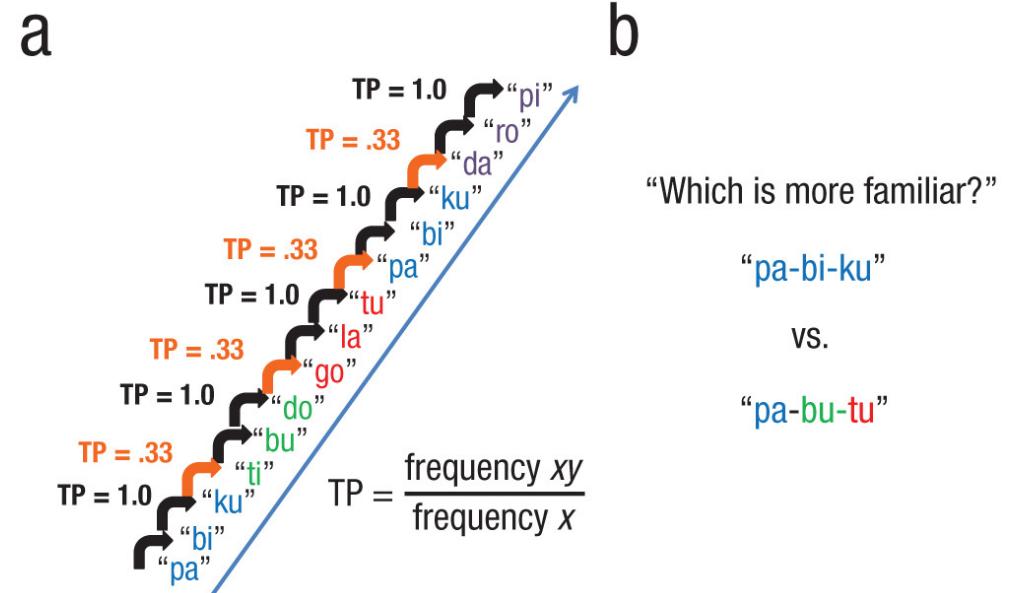
$$p(\text{pa}|\text{ku}) = 0.5$$

Statistical learning

Saffran, Aslin, Newport (1996)

Headturn Preference Procedure (HPP)

Looking times to words (e.g., pabiku)
higher than to part-words (e.g., pabutu)



Arciuli & Conway (2018)

Phonotactics

Rules governing the possible **phoneme sequences** in a (particular) language.

Can /b/ and /l/ go together in...

- **Catalan** →

Phonotactics

Rules governing the possible **phoneme sequences** in a (particular) language.

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- **Catalan** → *blanca* [Catalan for *white*] /blaŋkə/

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- **English** →

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- **English** → *blue* /blu:/

Phonotactics

Rules governing the possible **phoneme sequences** in a (particular) language.

Can /s/ and /l/ go together in...

- **Catalan** →

Phonotactics

Rules governing the possible **phoneme sequences** in a (particular) language.

Can /s/ and /l/ go together in...

- Catalan → ??

Phonotactics

Rules governing the possible **phoneme sequences** in a (particular) language.

Can /s/ and /l/ go together in...

- **Catalan** → ??
- **English** →

Phonotactics

Rules governing the possible **phoneme sequences** in a (particular) language.

Can /s/ and /l/ go together in...

- **Catalan** → ??
- **English** → *slow* /sləʊ/

Phonotactics

From 9 months of age, infants show sensitivity to phonotactics in their native language.

Friederici and Wessels (1995)

4.5, 6 and 9 month-old Dutch native infants

Three conditions, based on their phonotacticality:

- **Legal syllables** (e.g., *bref, murt*)
- **Illegal onset syllables** (e.g., *rtum*)
- **Illegal coda** (e.g., *febr*)

Phonotactics

Friederici and Wessels (1995)

9 month-old infants (but not younger infants) looked longer to trials in which legal syllables were presented, compared to illegal syllables.

Word acquisition

Infants acquire their first words around 6 months of age

Bergelson and Swingley (2012)

Word acquisition

Bergelson and Swingley (2012)

Auditory word recognition study using eye-tracking



Bergelson & Swingley ([2012](#))

Word acquisition

Bergelson and Swingley (2012)

Auditory word recognition study using eye-tracking



Word acquisition

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Word acquisition

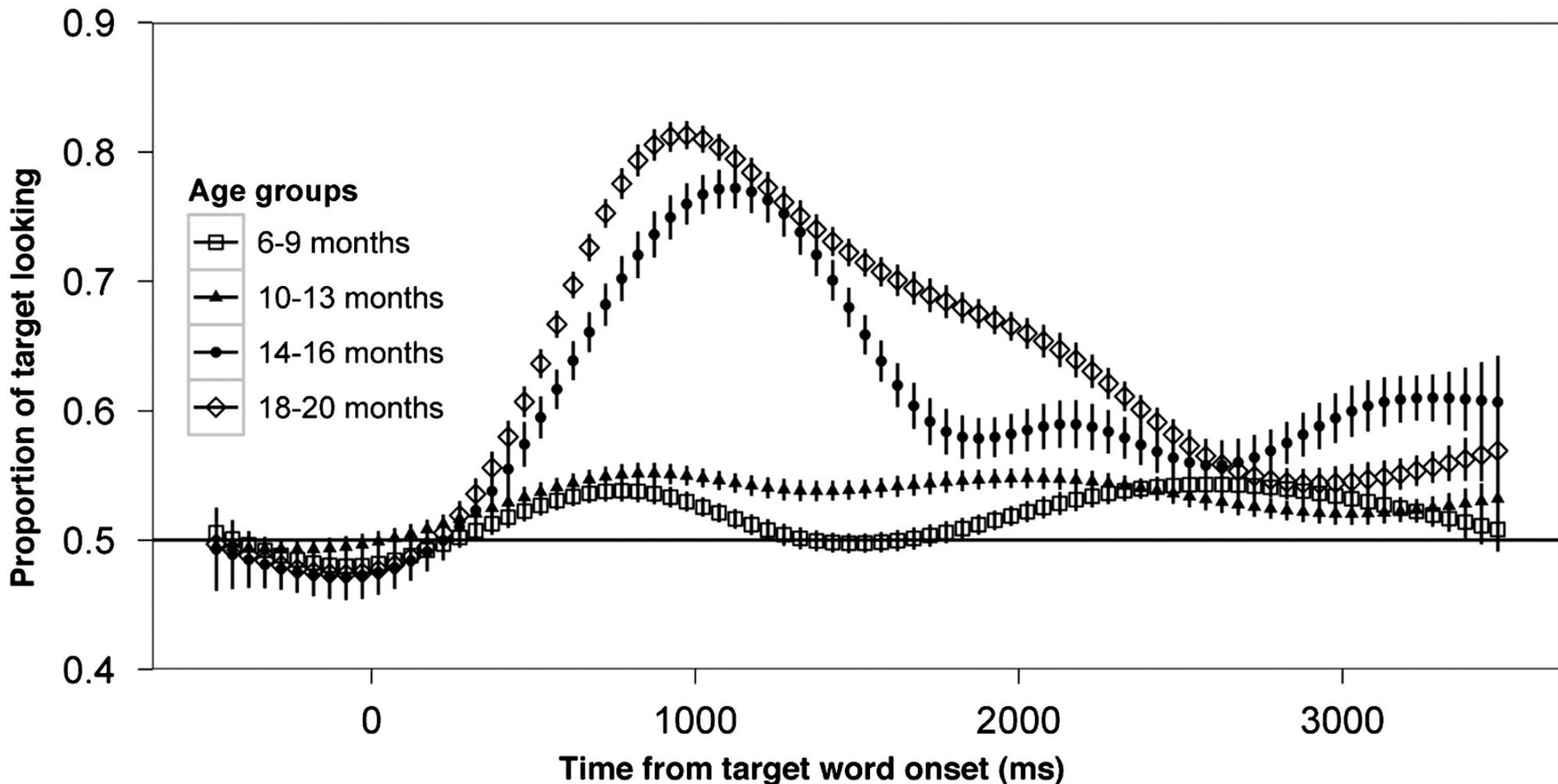
Bergelson and Swingley (2012)

Auditory word recognition study using eye-tracking



Word acquisition

Bergelson and Swingley (2012)

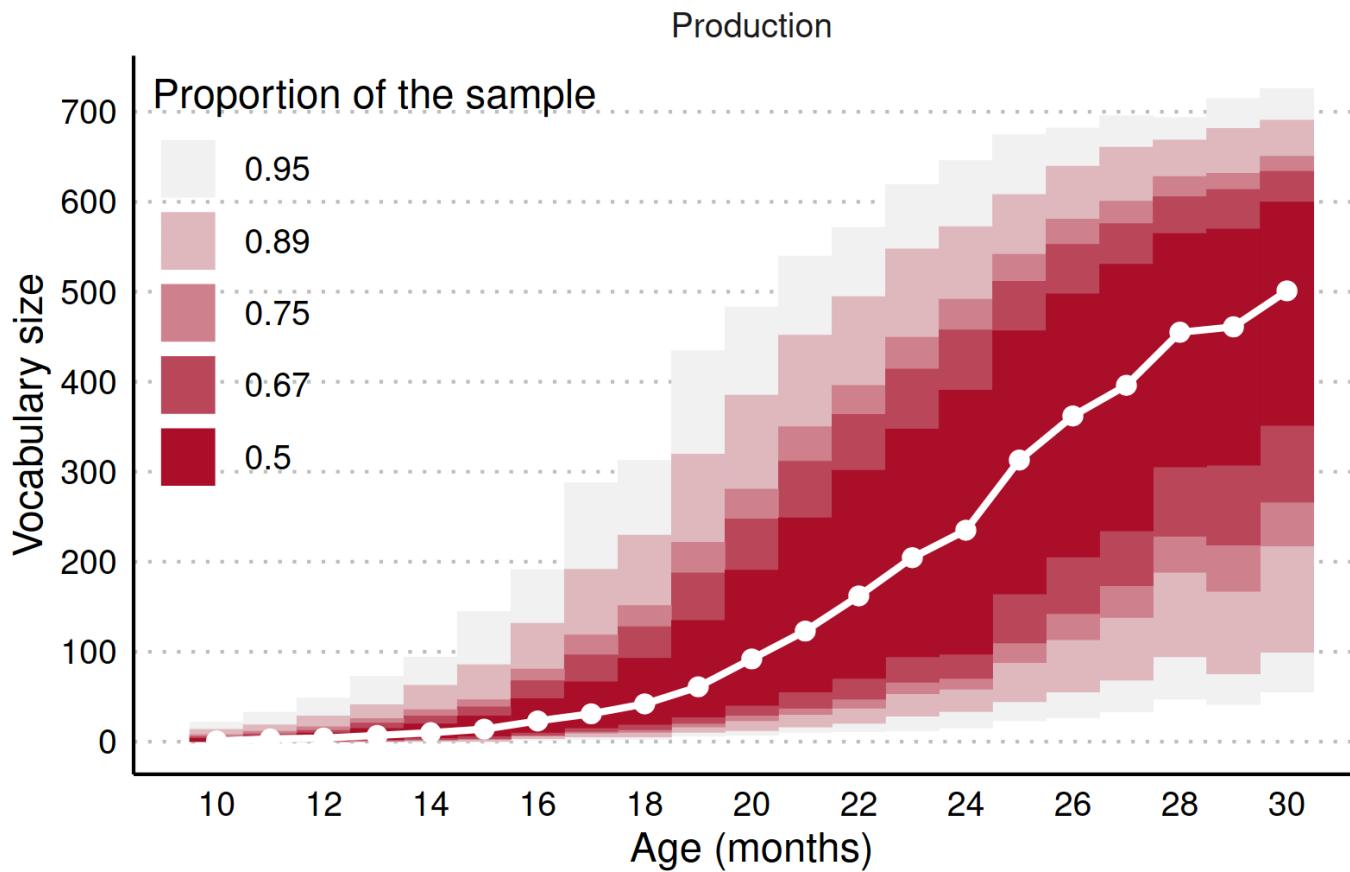


12-24 months

Vocabulary growth

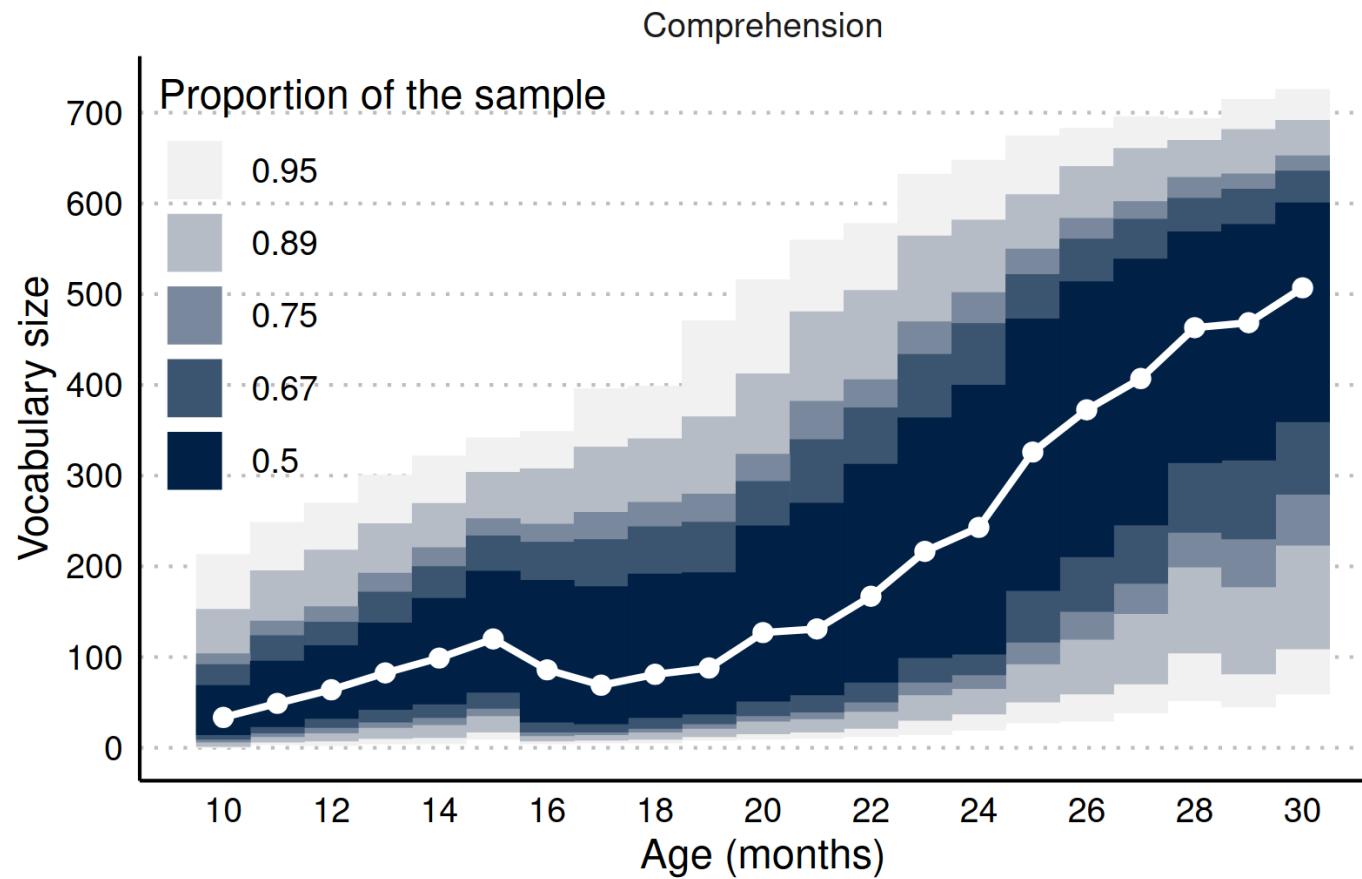
From 12 months of age onwards, infants' vocabulary grows at a steady rate until 18 months of age. From 12 to 24 months, it grows much faster (*vocabulary spurt*) ([Frank et al., 2017](#); [Goldfield & Reznick, 1990](#)).

Vocabulary growth



García-Castro (2024)

Vocabulary growth



García-Castro (2024)

(Bilingual) vocabulary growth

When both languages are taken into account, bilingual toddlers know as many words as monolinguals.

Hoff et al. (2012)

(Bilingual) vocabulary growth

Hoff et al. (2012)

Vocabulary checklists from English monolinguals and English-Spanish bilinguals in South Florida.

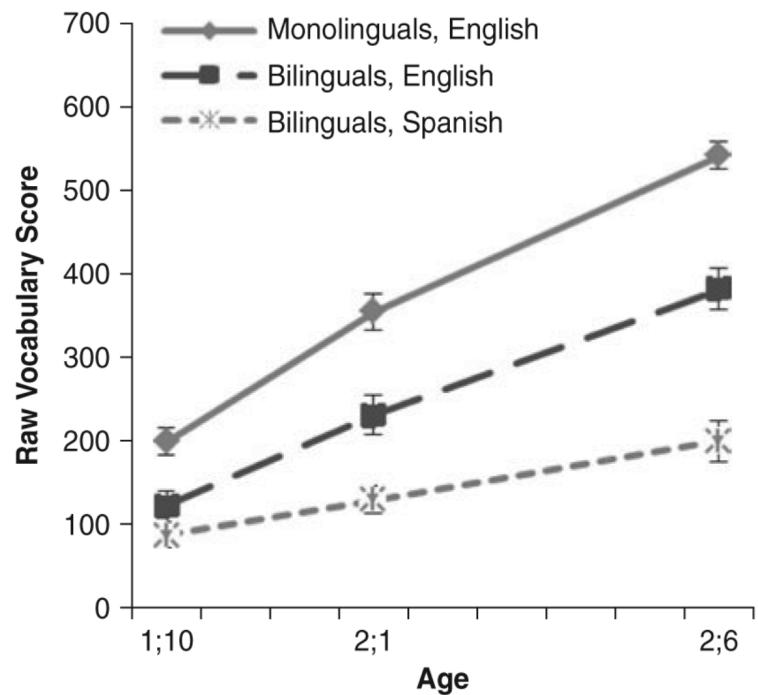


Fig. 1.
English vocabulary scores for monolingually developing children and English and Spanish vocabulary scores for bilingually developing children at 1;10, 2;1 and 2;6. Error bars represent standard errors of the means.

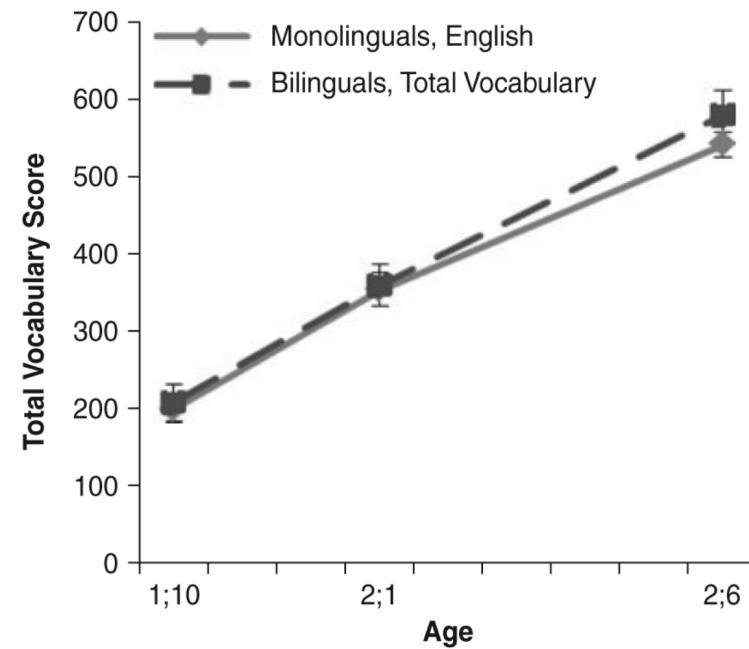
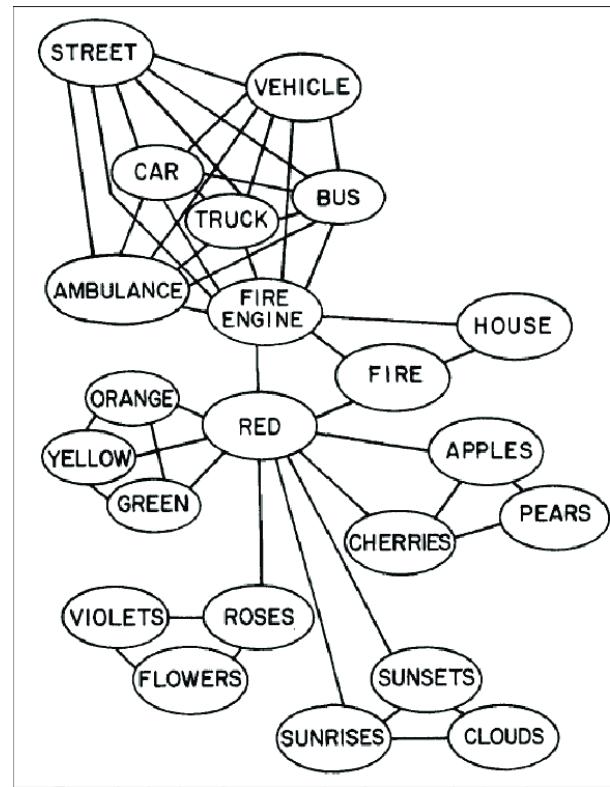


Fig. 2.
English vocabulary scores for monolingually developing children and total vocabulary scores (English+Spanish) for bilingually developing children at 1;10, 2;1 and 2;6. Error bars represent standard errors of the means.

Lexical development

In the adult lexicon, words are stored as a **network**, interconnected by their conceptual or phonological relatedness

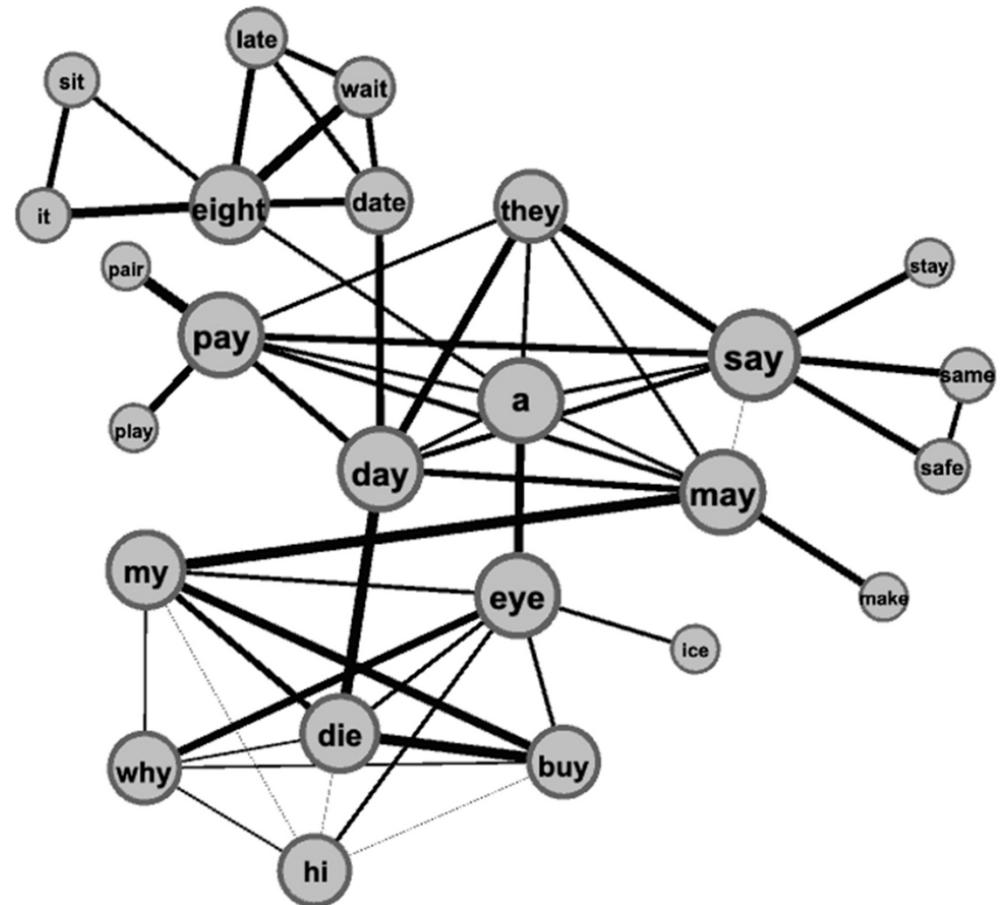
(Collins & Loftus, 1975)



Lexical development

In the adult lexicon, words are stored as a **network**, interconnected by their conceptual or phonological relatedness

(Collins & Loftus, 1975)



Lexical development

Lexical decision task: Is the presented word a real word in English?

- Raise your **left** hand if yes
- Raise your **right** hand if no

PLANT

MALDS

TREE

Now you will see a sequence of two words, wait for the second word!

XXXXX

TABLE

NURSE

DOCTOR

XXXXX

BIRD

CAT

PLANE

Lexical development

Responses are faster and more accurate when **prime** and **target** words are **semantically related** (*NURSE-DOCTOR*) compared to when no prime is presented (*XXXX*) or when they are unrelated (*BIRD-CAT*).

Lexical development

Between 18 and 21 months, words start being represented in infants' mental lexicon in association with other phonologically and semantically related word.

Arias-Trejo and Plunkett (2009)

Semantic priming task, auditory word recognition.

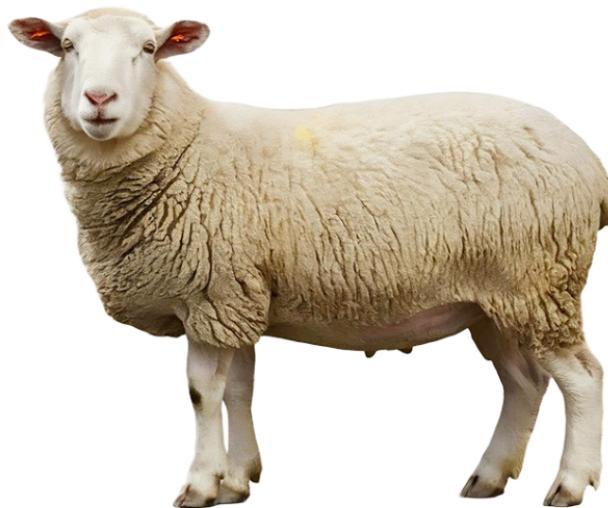
“Look! It’s a swing”



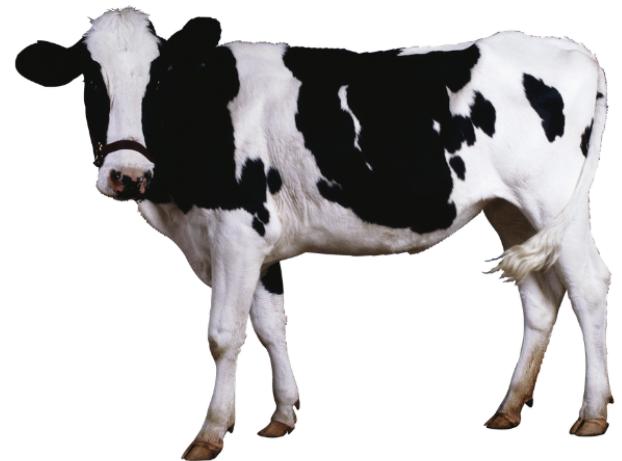
“slide”



“Look! It's a sheep”



“car”



"Look! It's a duck"

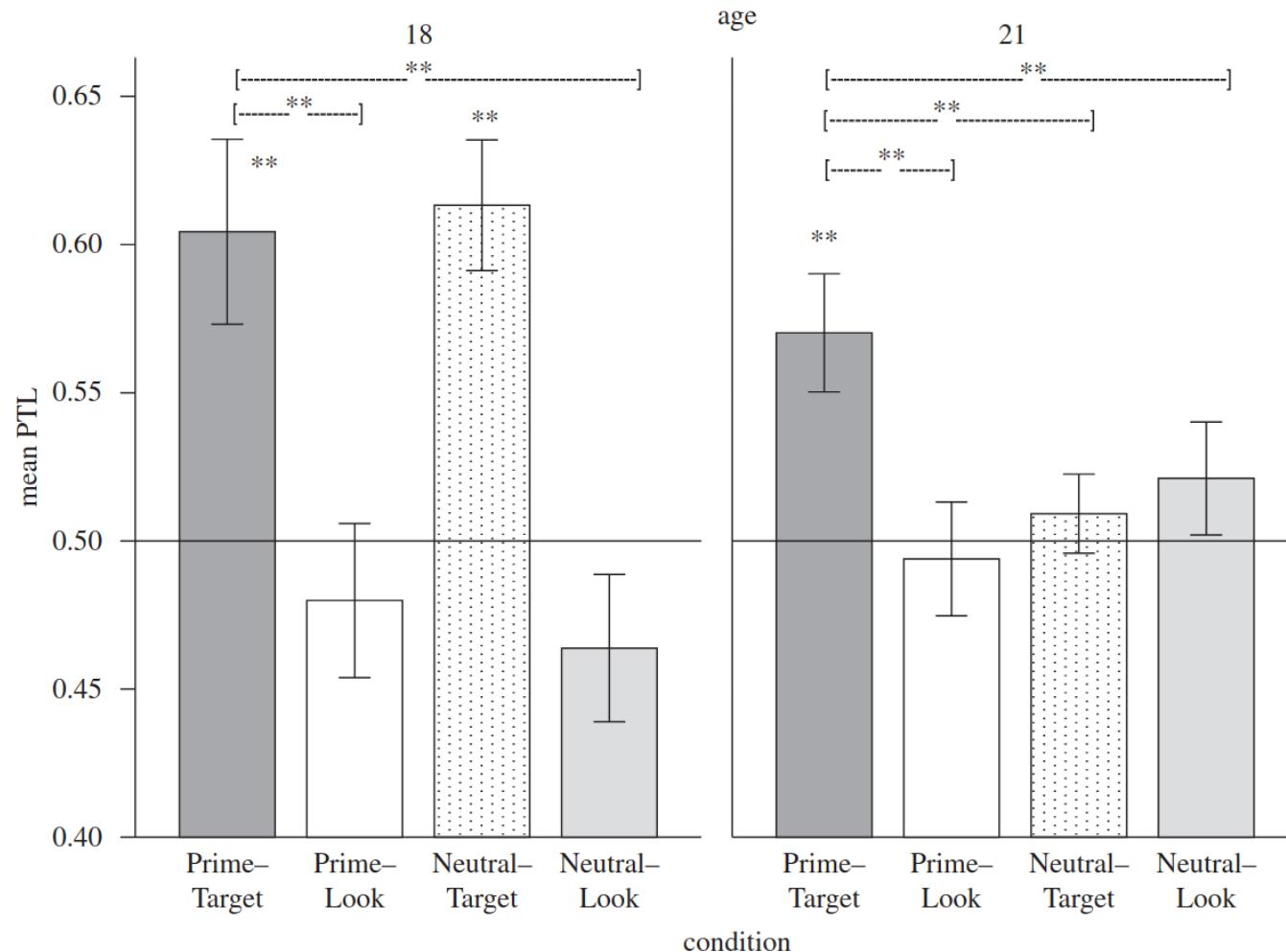


“bowl”



Lexical development

Arias-Trejo and Plunkett (2009)



Questions

Recap

- Can you provide a reasonable definition of language?
- Can you describe the main linguistic units?
- What features of language are fetuses familiarized with?
- Can newborns discriminate between different languages at birth? If so, how?
- Around what ages do we specialize in the phonology of our native language? Do bilinguals follow the same path as monolinguals?
- When do we learn our first words?
- Do we learn words at a linear rate across ages?
- Does bilingualism slow down vocabulary growth?
- Around what ages does the early lexicon start sharing its core features with the adult lexicon?

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