LINGUISTIC DIVERSITY AND MULTILINGUAL LANGUAGE ACQUISITION.

Insights from Structural Brain Imaging.

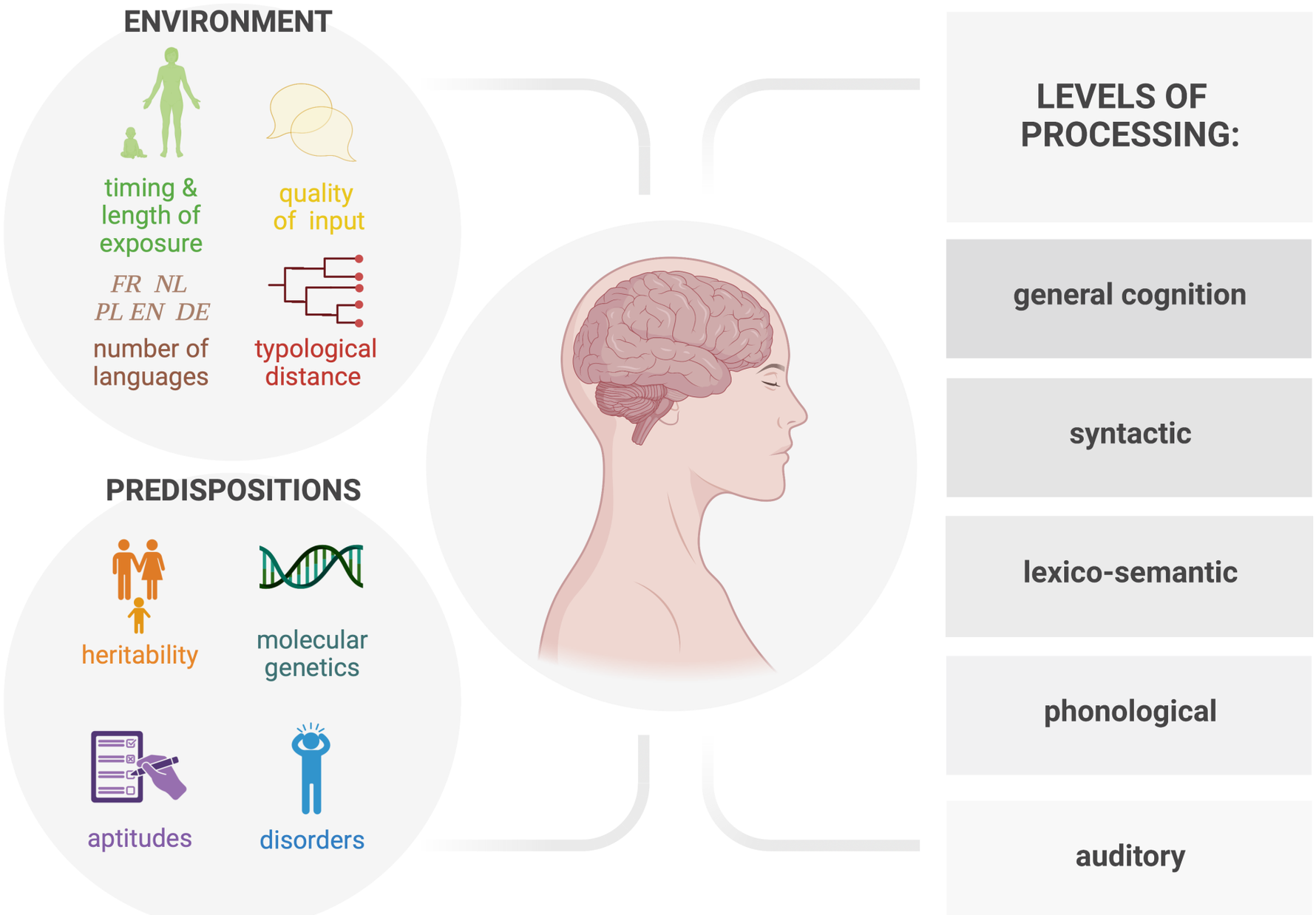
Olga KEPINSKA
Brain and Language Lab
Cognitive Science Hub
University of Vienna

https://olgakepinska.com

Institut de Neurosciences de la Timone
Marseille, December 14th 2023

Individual differences

In (multilingual) language skills



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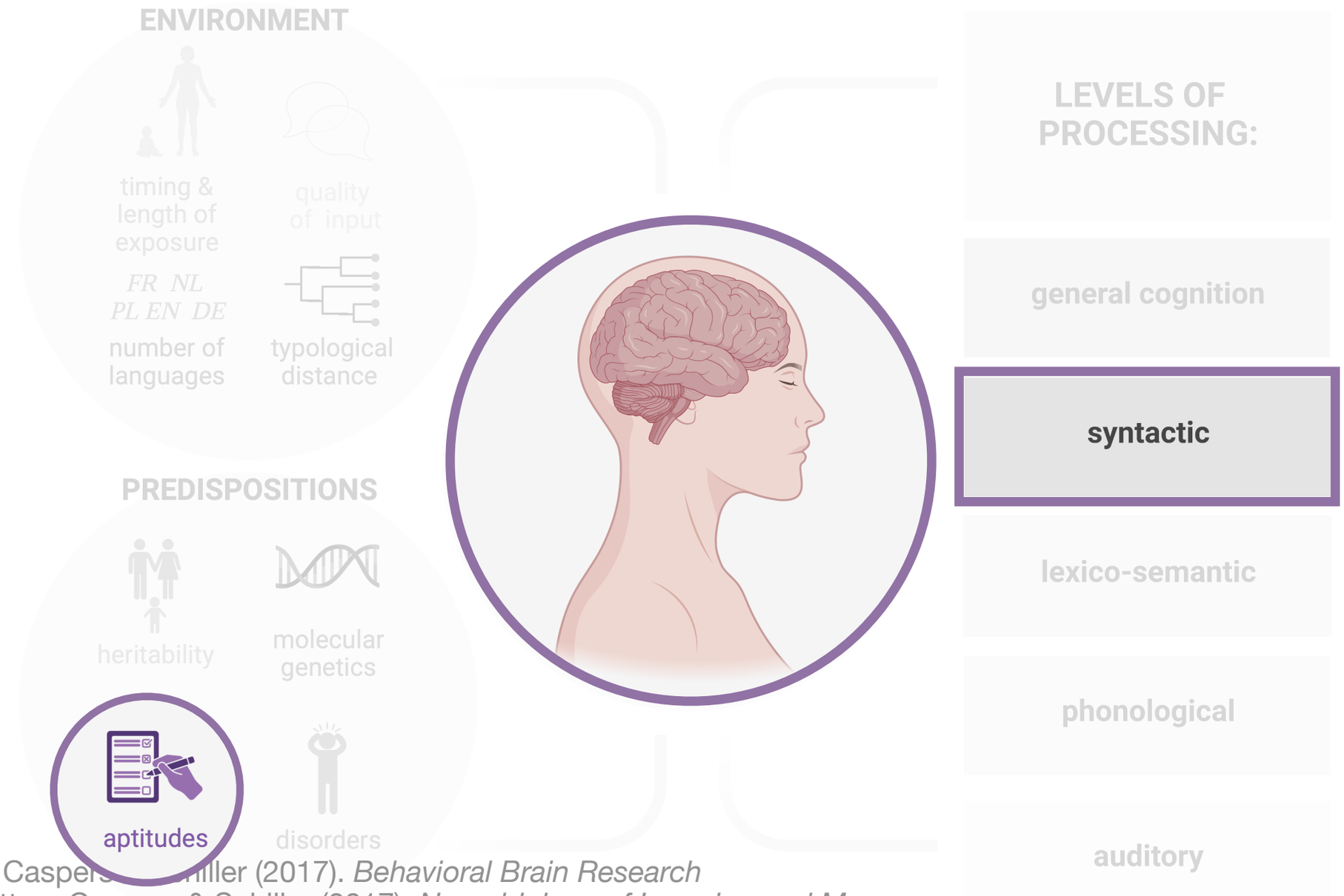

Kepinska, De Rover, Caspers & Schiller (2017). *Behavioral Brain Research*
Kepinska, Lakke, Dutton, Caspers & Schiller (2017). *Neurobiology of Learning and Memory*
Kepinska, Pereda, Caspers & Schiller (2017). *Brain & Language*
Kepinska, De Rover, Caspers & Schiller (2017). *Neuropsychologia*
Kepinska, De Rover, Caspers & Schiller (2018). *NeuroImage*

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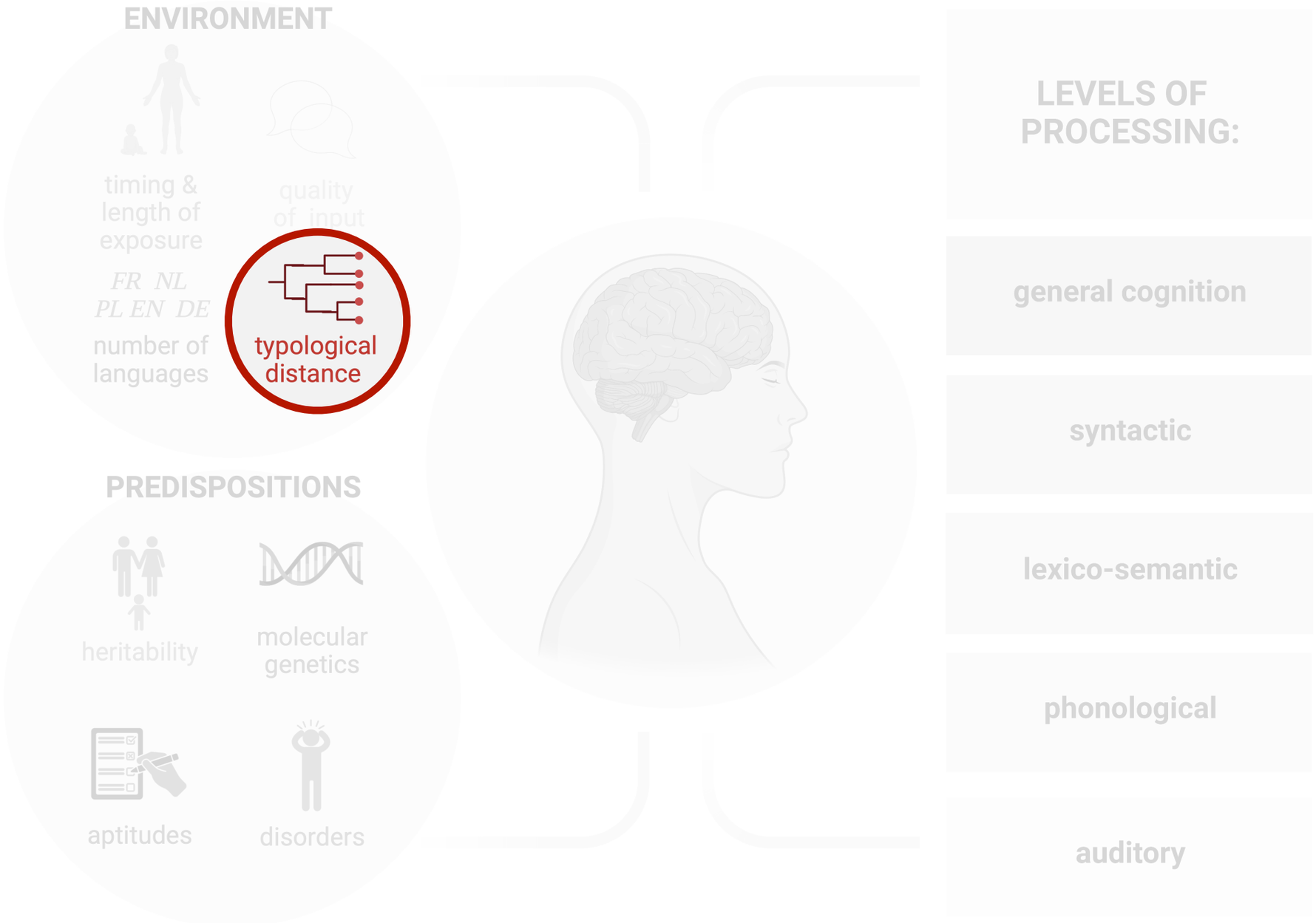
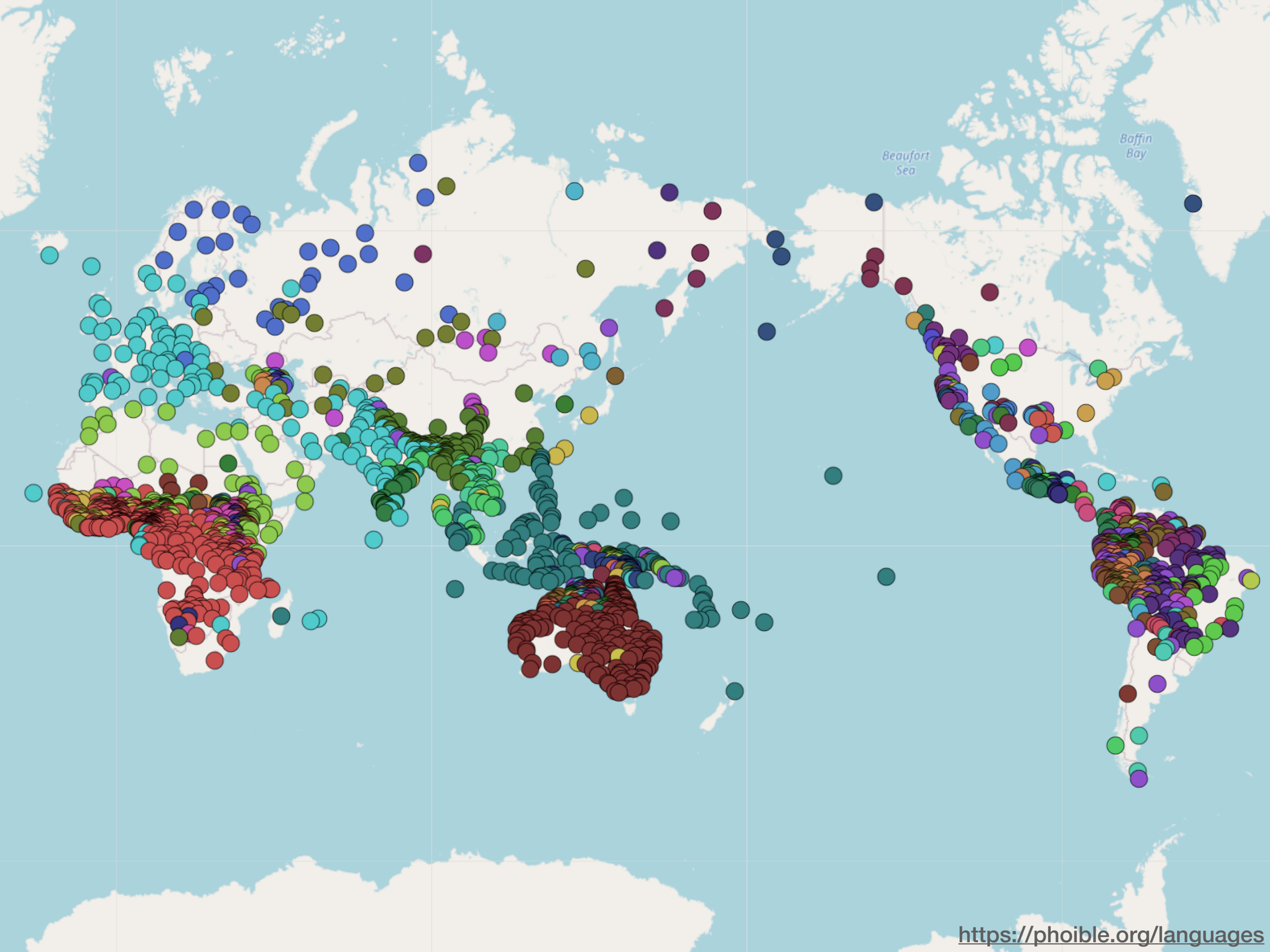


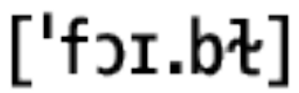

Beaufort Sea
Baffin Bay
https://phoible.org/languages

Typological distances

Available resources

- languages differ in terms of their grammar, phonology and lexicon

- typological features for thousands of languages can be derived from large-scale cross-linguistic databases:

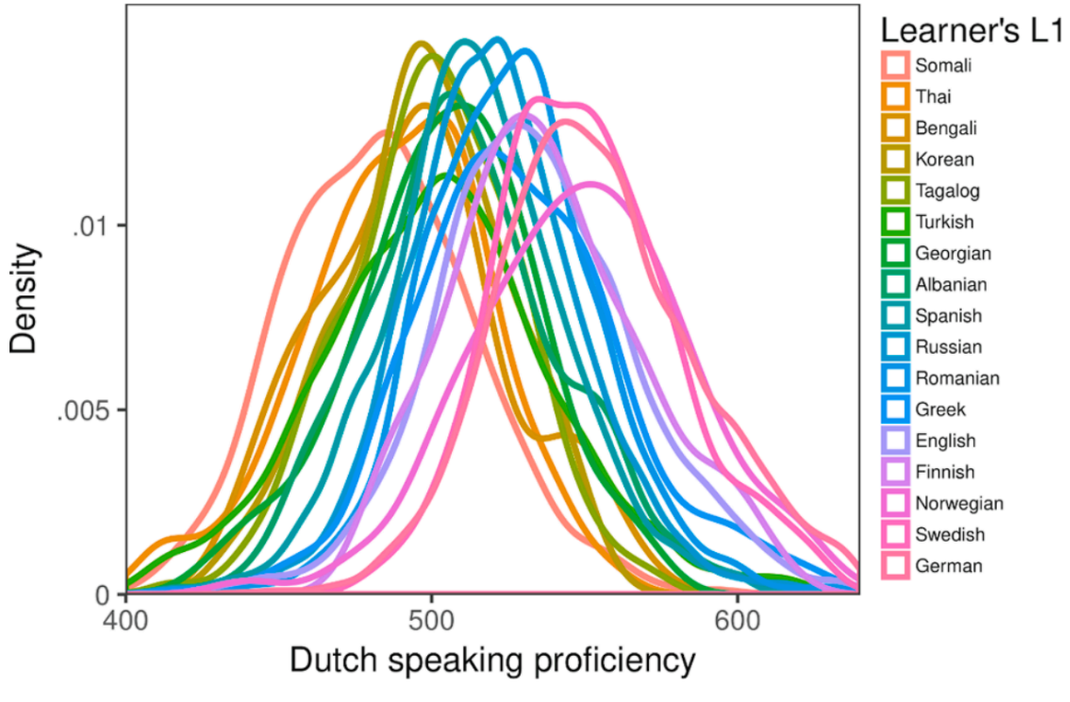
(morpho)syntax		phonology	lexicon
			
Dryer & Haspelmath (2013). https://wals.info/	Skirgård et al. (2022). https://glottobank.org/#grambank	Moran et al. (2019). https://www.phoible.org	Wichmann et al. (2022). http://asjp.clld.org/

- distances can be calculated with e.g., Levenshtein distance, cosine distance, or Jaccard distance.

Language typology

in the context of multilingualism

- the distance (similarity) between one's first and second (and third etc.) language is important for learning outcomes (in adulthood):
  - **It is easier to learn a language that is more similar to your mother tongue**
    - 48,219 learners from 62 L1s
    - L1 background alone accounts for 9-22% of the total variance in L*n* speaking proficiency among adult learners (28-69% of the explained variance).



Measure	Speaking scores
Phonological (dis)similarity	−0.47
Morphological (dis)similarity	−0.59
Lexical (dis)similarity	−0.69

Schepens, Jaeger, van Hout (2020). *Cognition*

Language typology

Outstanding questions

- Does typology also play a role in dominant language (L1) knowledge and processing?

- Do similarities and differences between multilinguals' languages have any neural signatures?

  - functional

  - structural

- effects of typology in **multilinguals**?

in **bilinguals**: overlaps and dissociations in neural activity across L1 and L2:

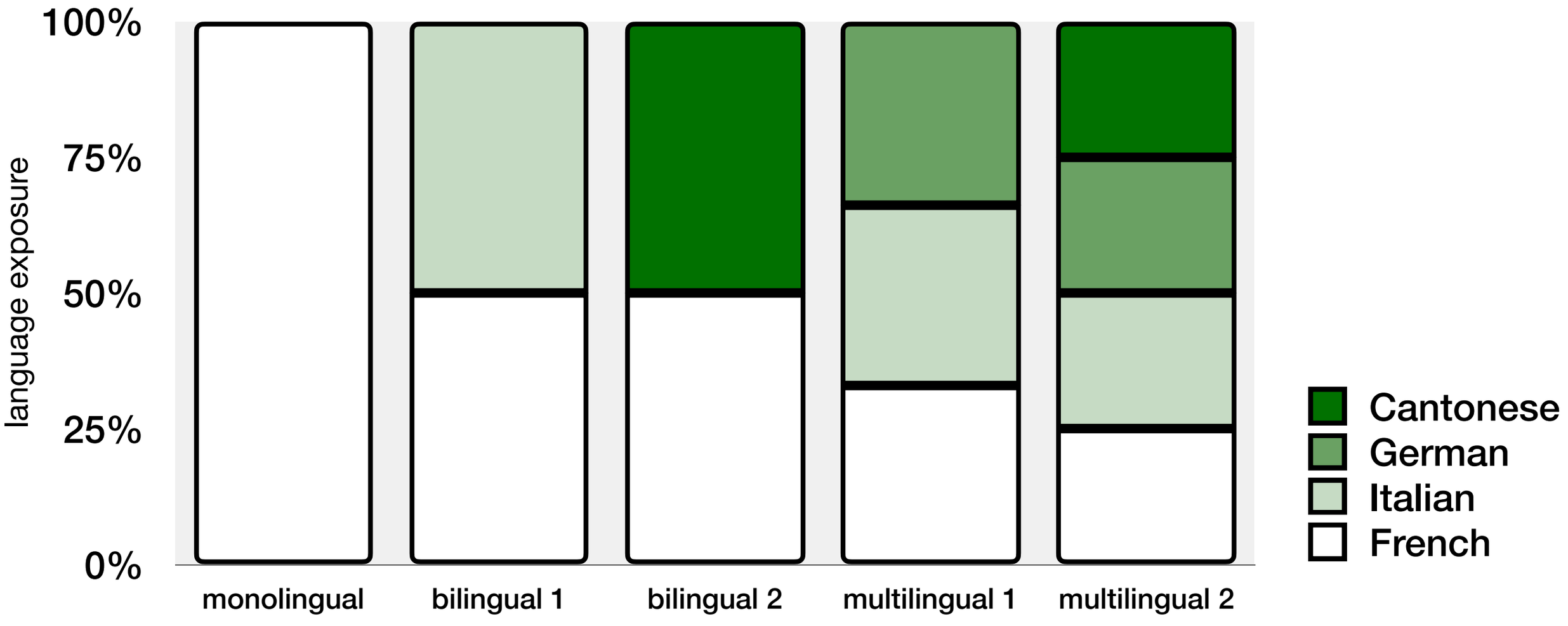
- irrespective of language distance, processing converges on the same neuronal populations (Crinion et al. 2006, *Science*)
- stronger leftward lateralization for L2 auditory processing when L2 is more similar to L1 (D'Anselmo et al. 2013, *Neuropsychologia*)

in **trilinguals**: larger linguistic distance was tied to additional neural resources:

- during reading (Kim et al. 2016, *NeuroImage*)
- syntactic processing (Jeong et al. 2007, *HBM*)

Language typology

How to account for it?



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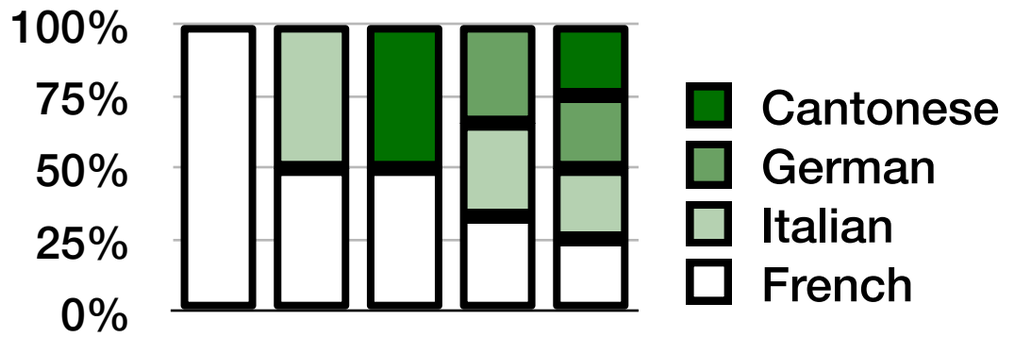
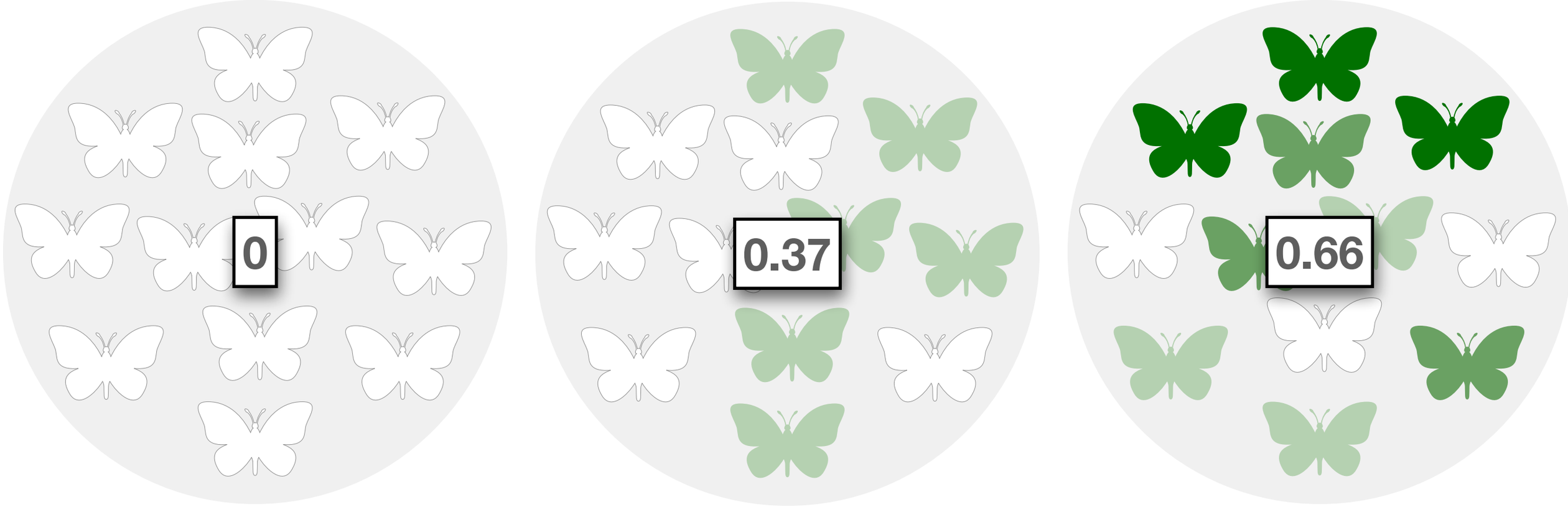


Rao's quadratic entropy *(functional diversity, FD)*

- a measure of diversity of ecological communities (Rao, 1982)
- based on the proportion of the abundance of species present in a community and a measure of dissimilarity among them

$$FD = \sum_{i=1}^{s} \sum_{j=1}^{s} d_{ij} p_i p_j$$



Kondratyeva et al., (2019) *Biological Reviews*

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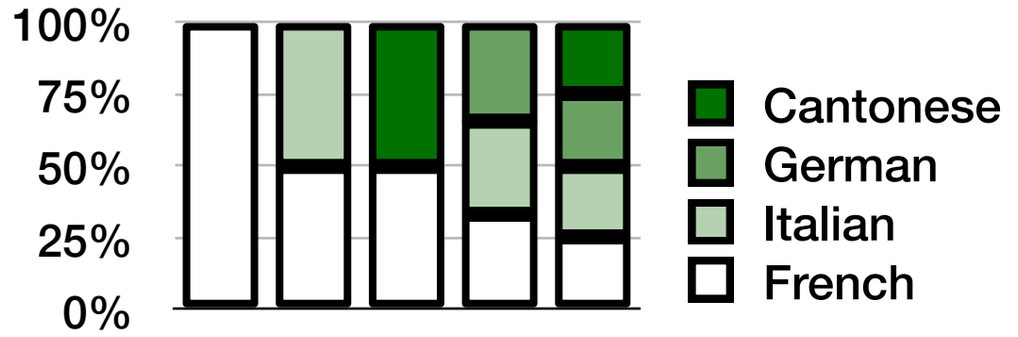

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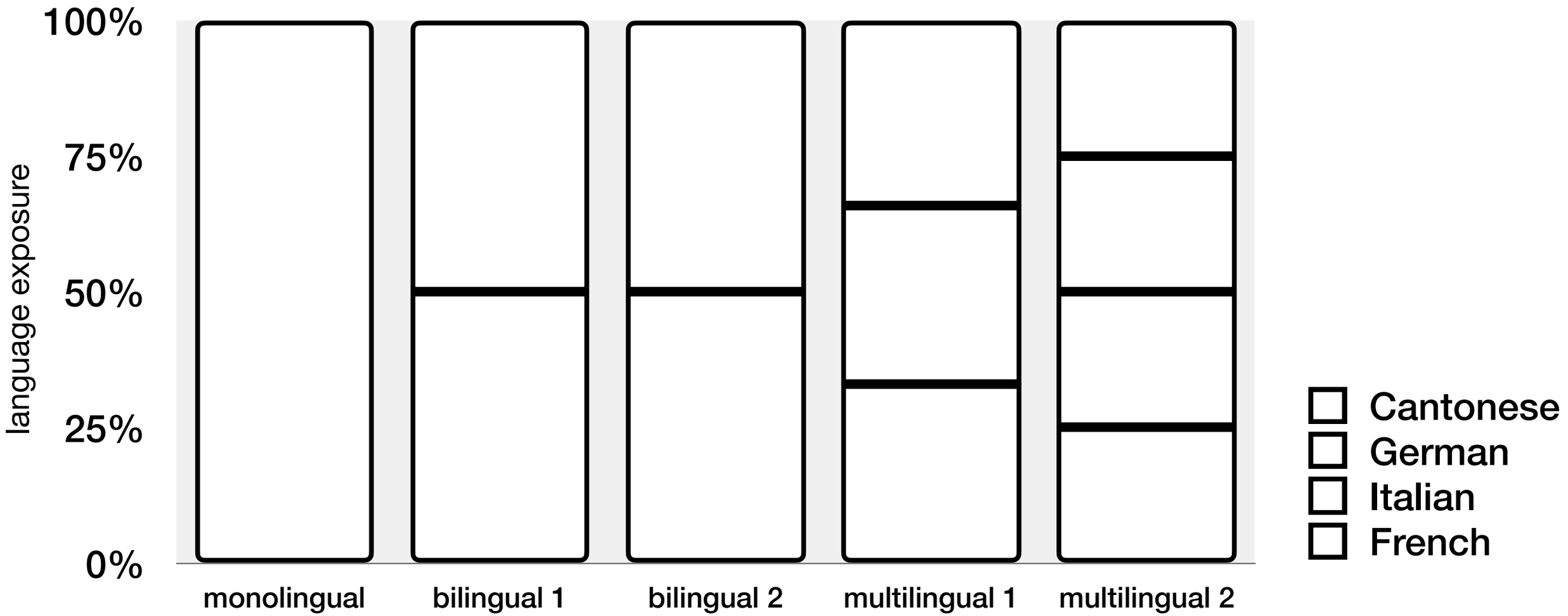

Kepinska et al. (2023). *Scientific Reports*

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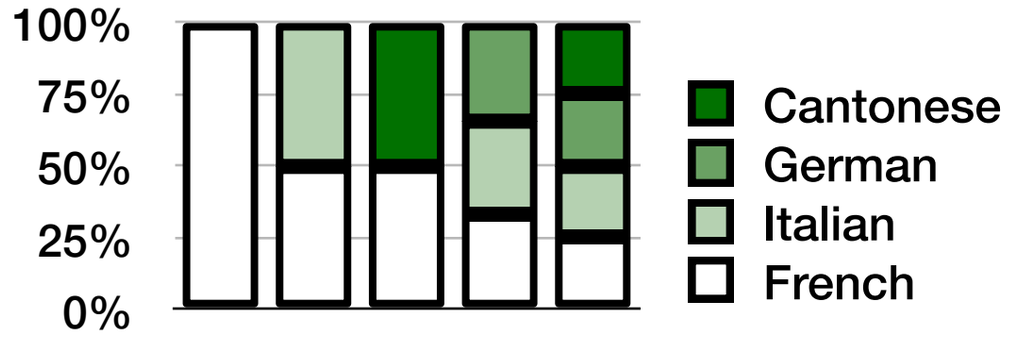

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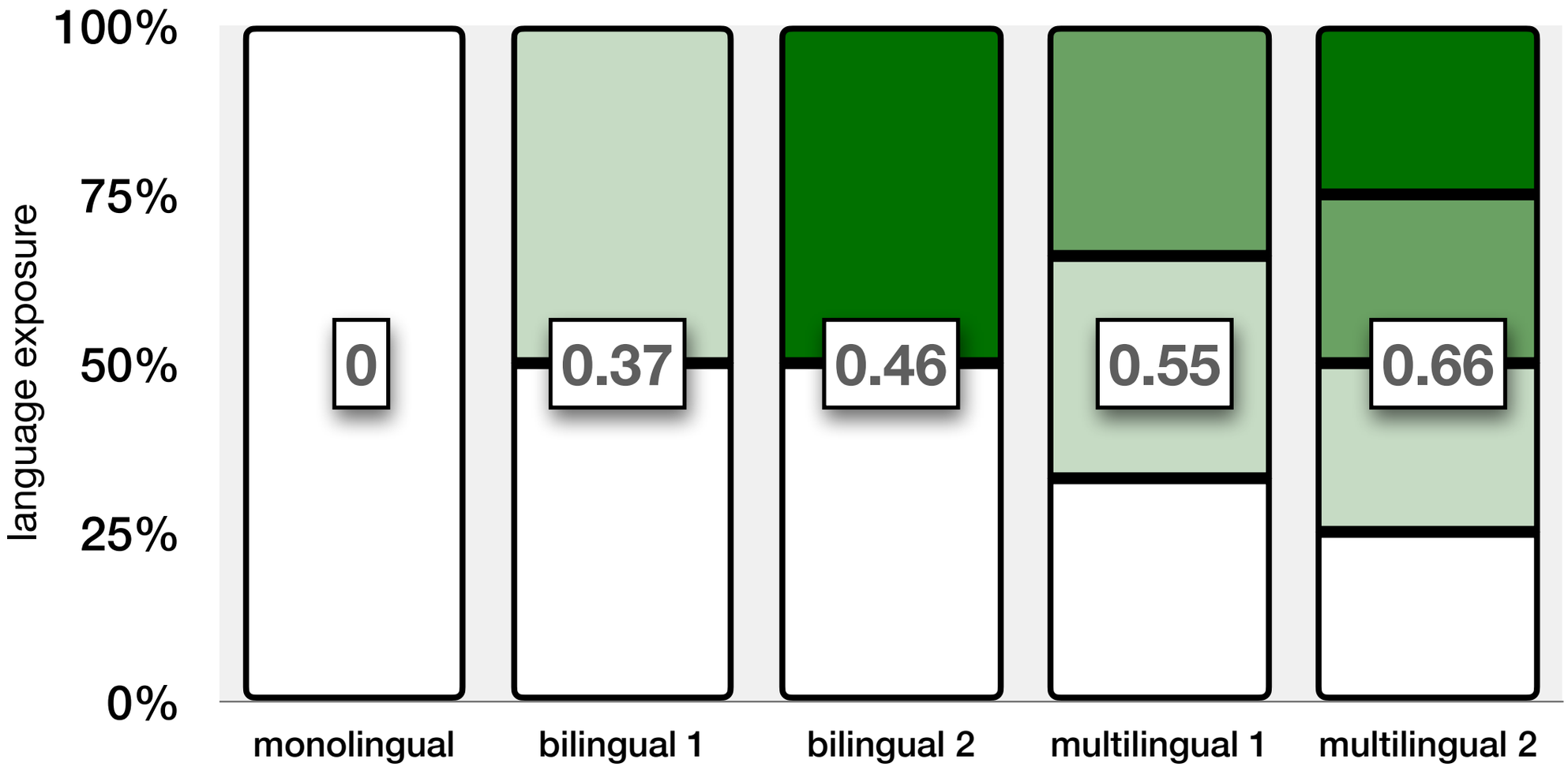

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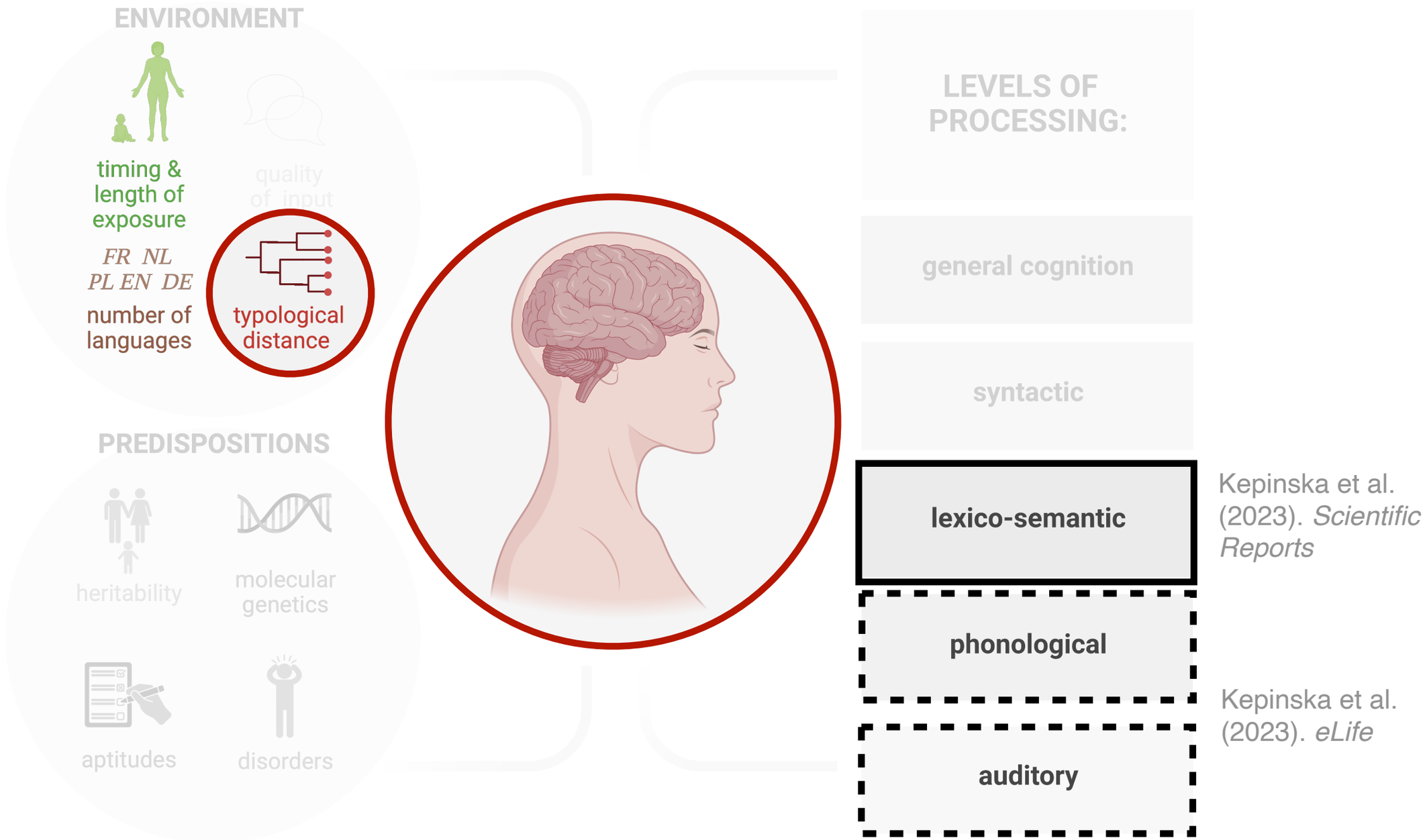

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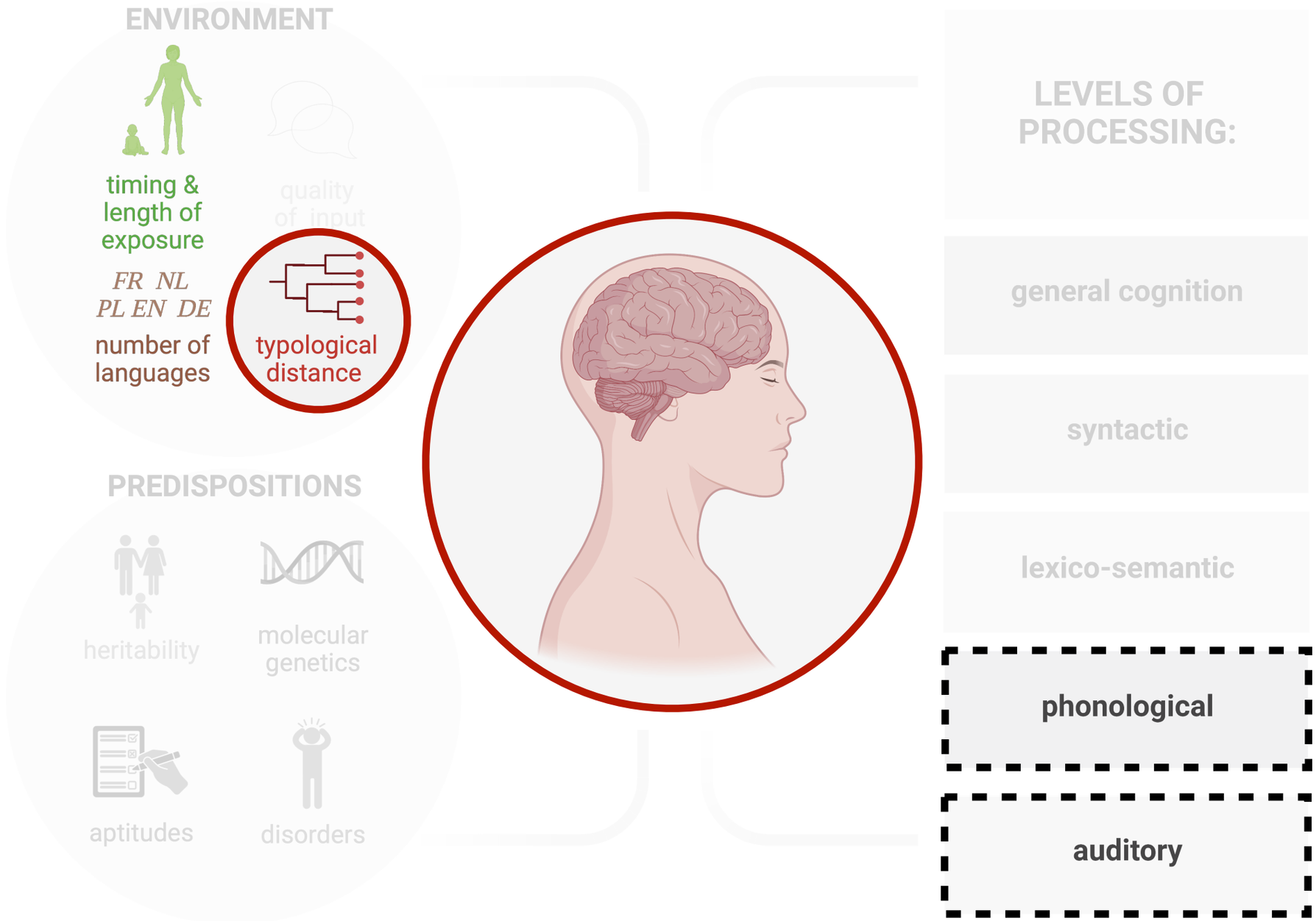
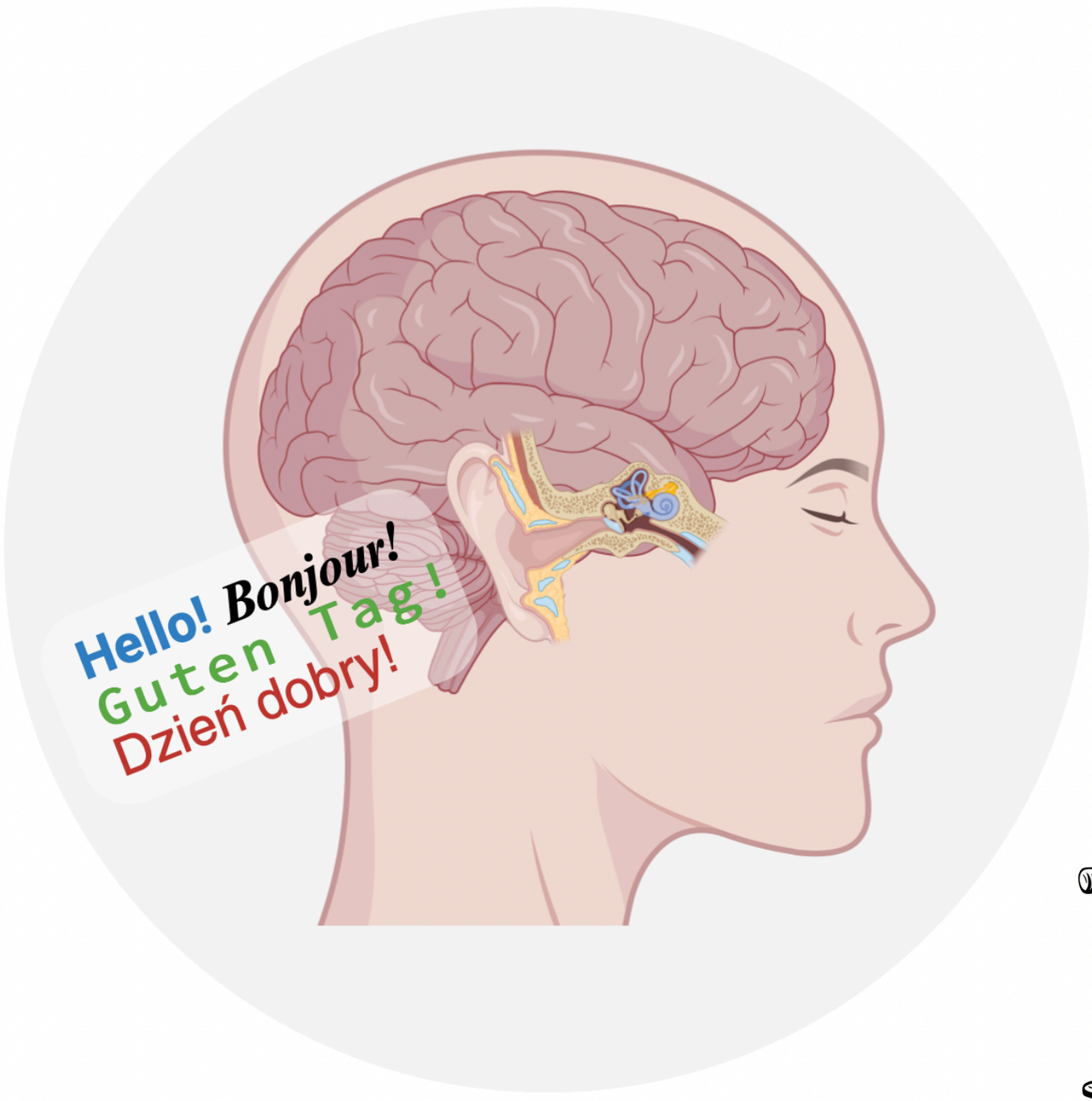
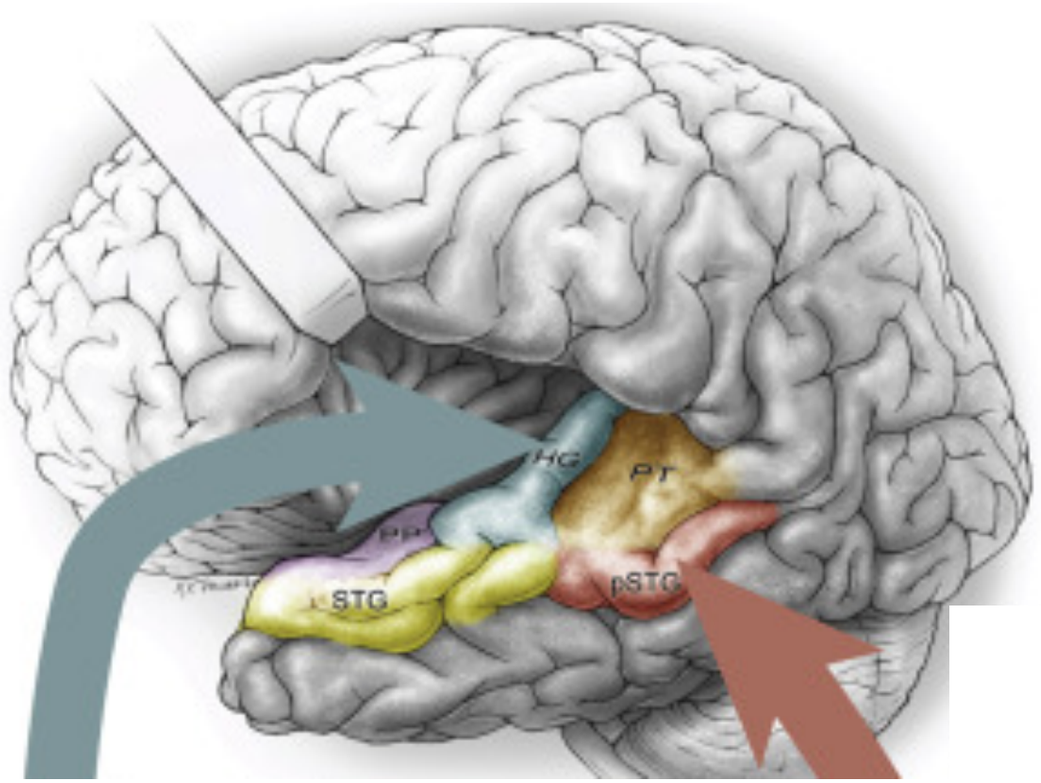


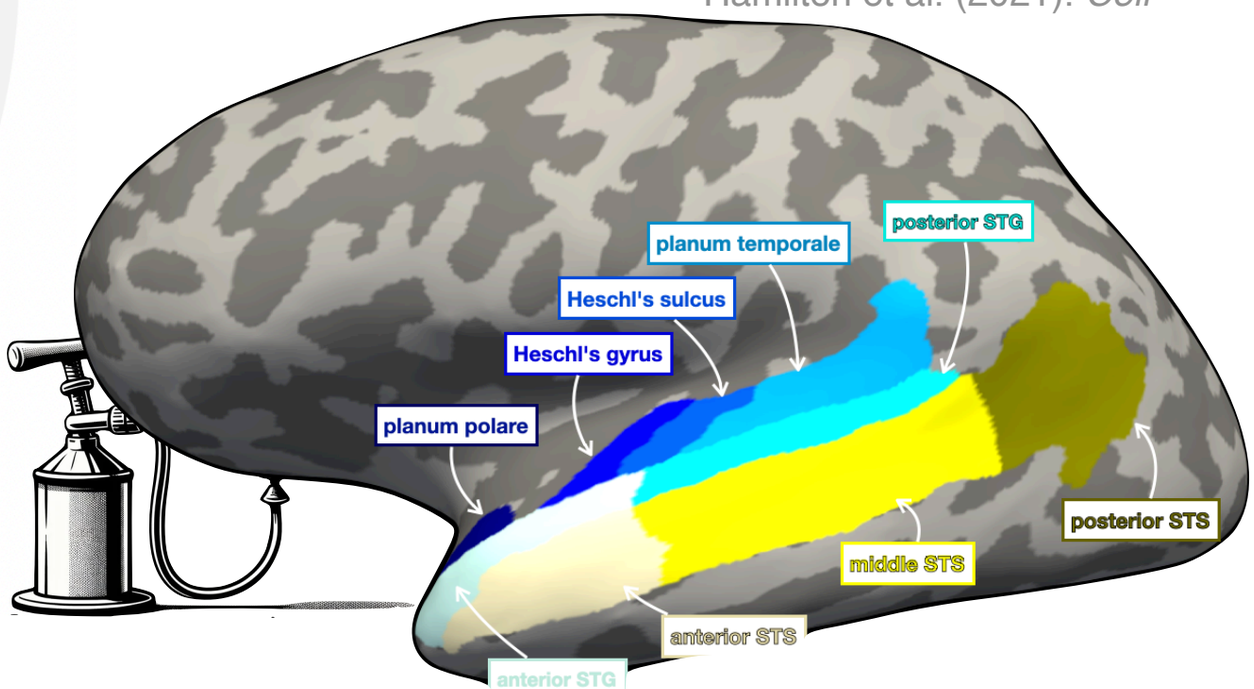
Auditory cortex

Function, structure & development





Hamilton et al. (2021). *Cell*



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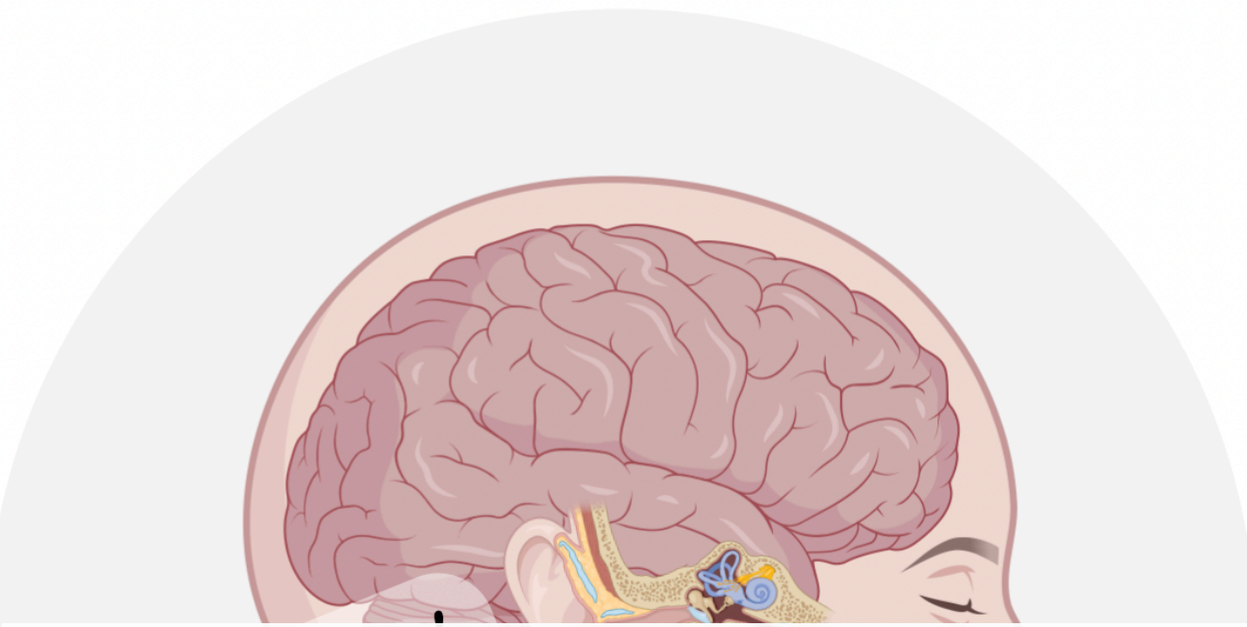
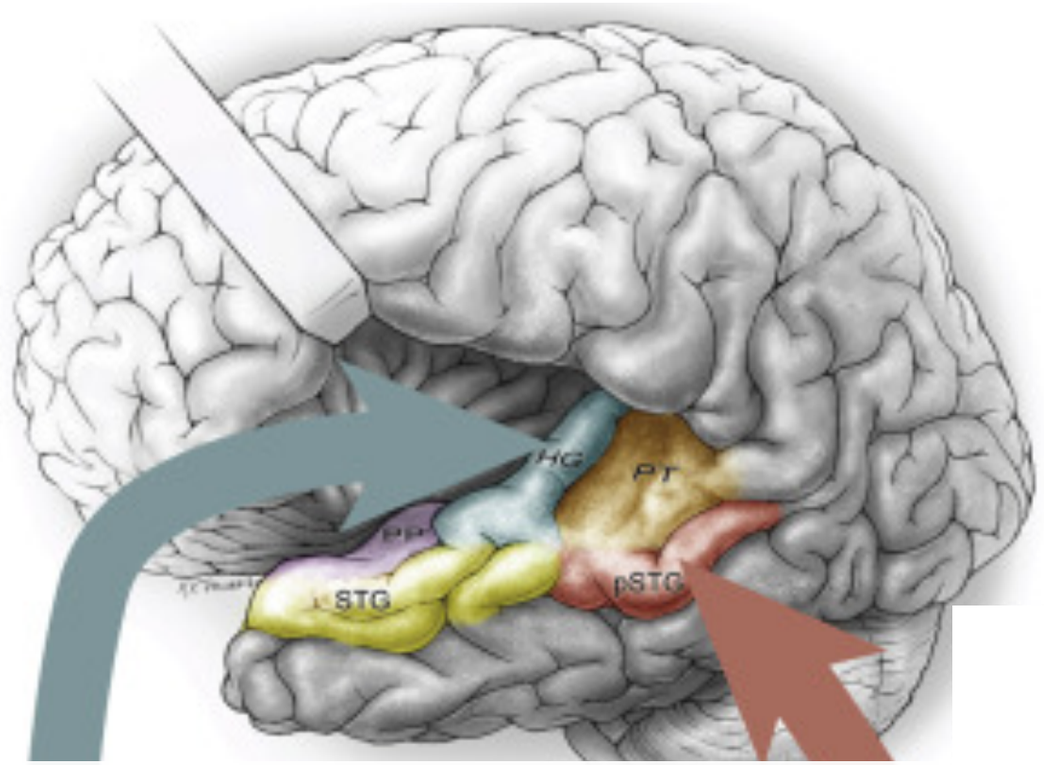
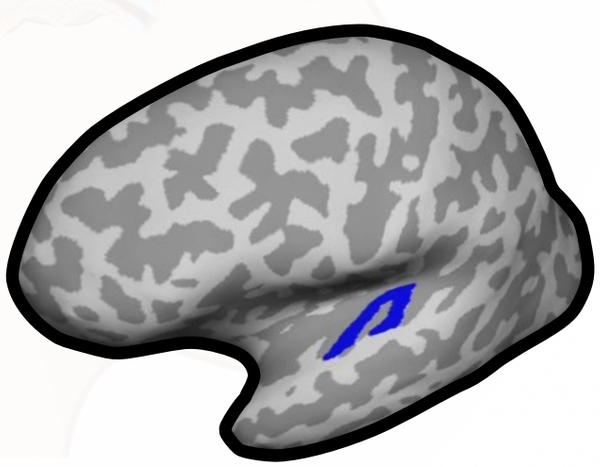




single gyrus



single gyrus
with a common stem duplication

complete duplication

three separate TTGs

Toolbox for the Automated Segmentation of Heschl's gyrus (TASH)
Multivariate Concavity Amplitude Index (MCAI)

Dalboni da Rocha et al. (2020), *Scientific Reports*
Dalboni da Rocha, Kepinska et al. (2023) *NeuroImage*

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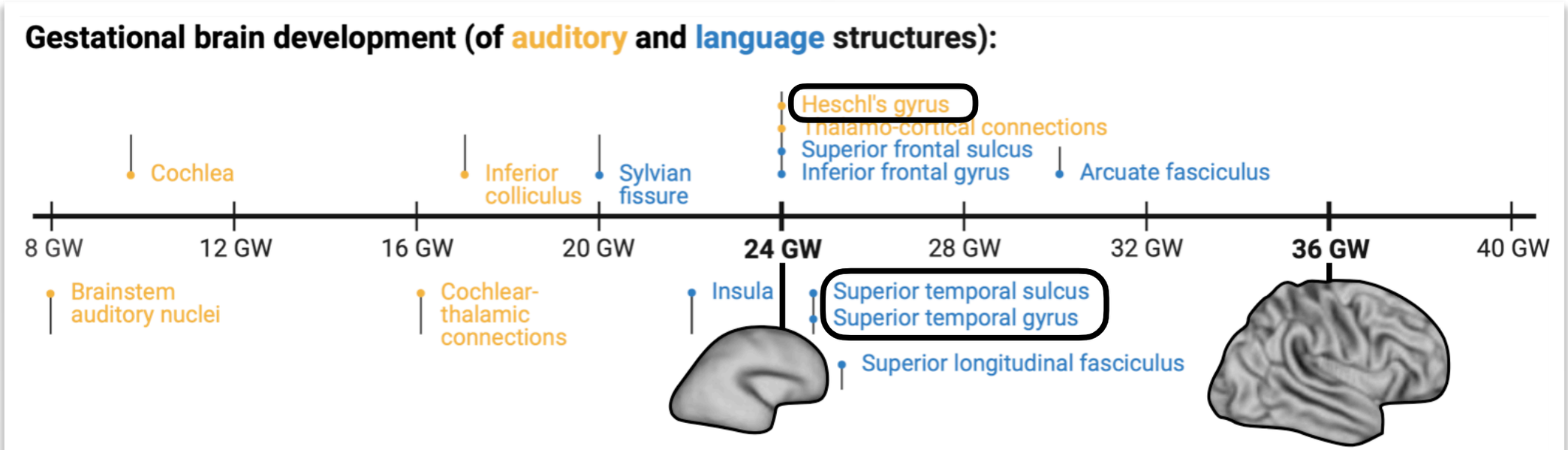
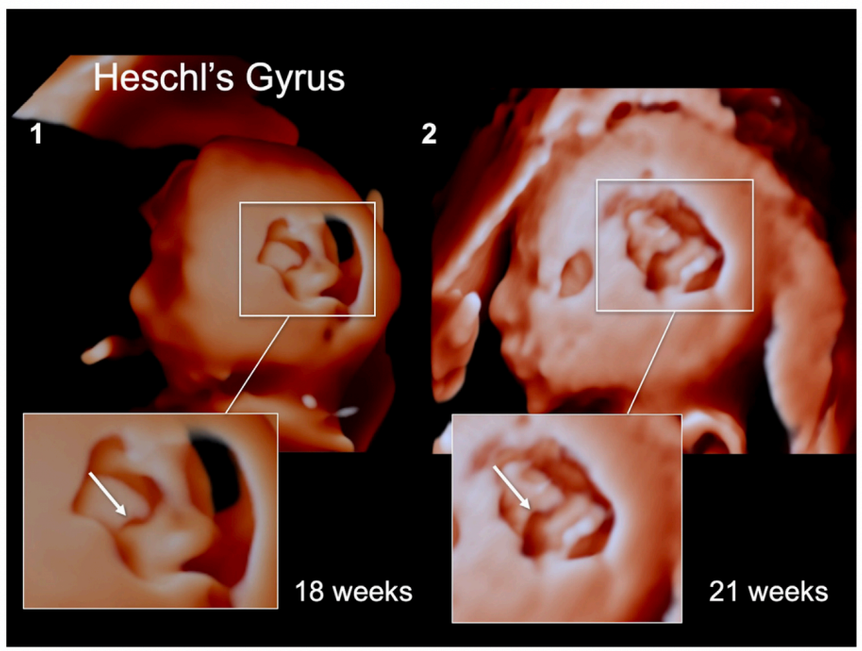
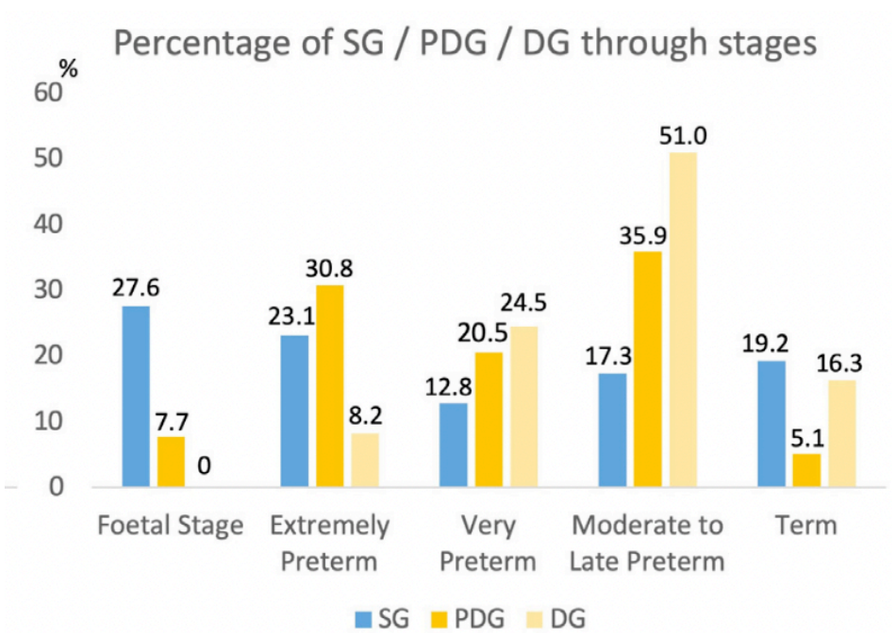


based on: Ghio et al. 2021 *Neuroscience and Biobehavioral Reviews;* Karolis et al. 2023 *OHBM*

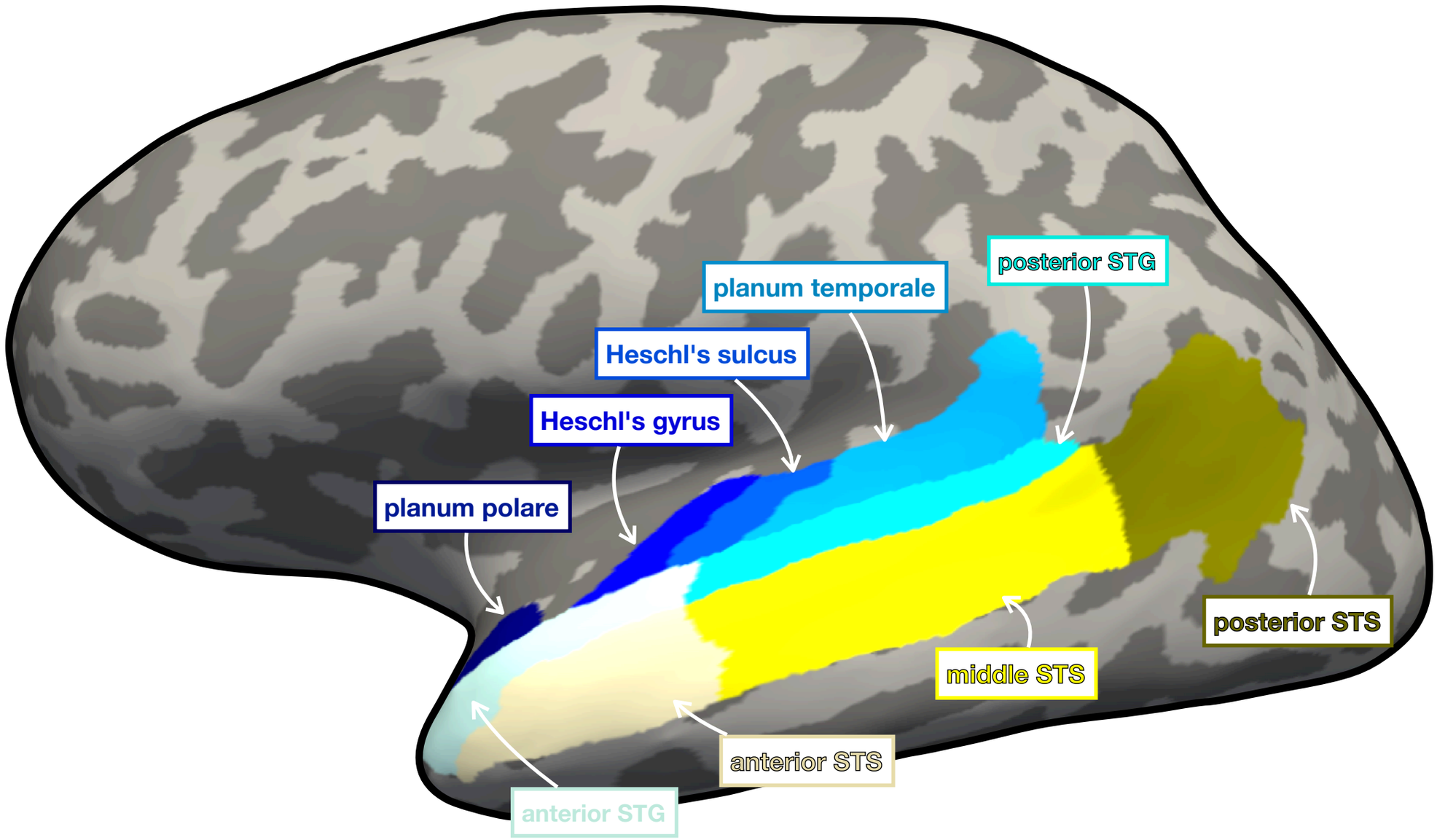




López Ramón y Cajal 2019 *Medical Hypotheses*

Auditory cortex

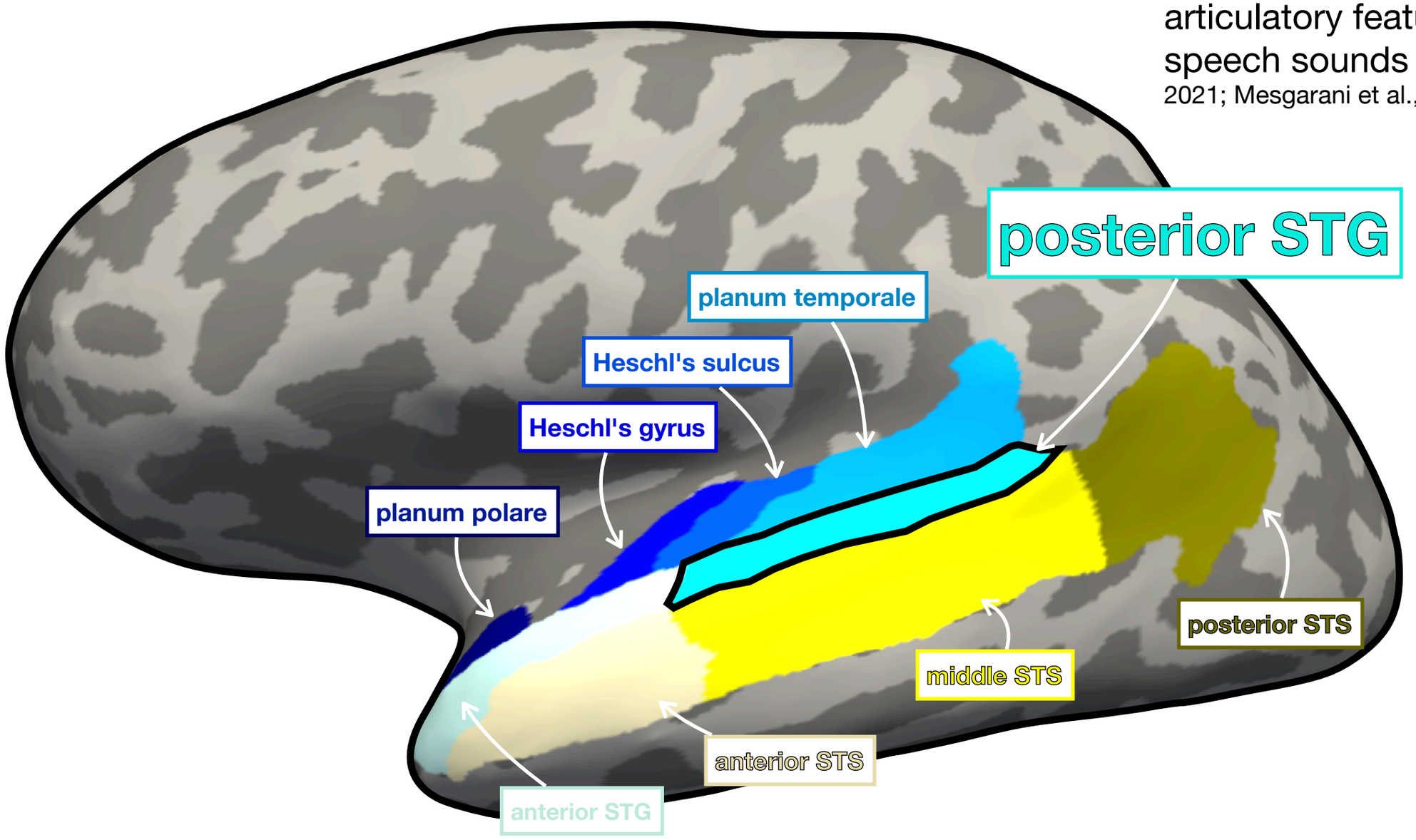
Function, structure & development



Auditory cortex

Function, structure & development

- crucial & essential locus for language and phonological processing (Bhaya-Grossman & Chang, 2022; Hillis et al., 2017)
- encodes acoustic-articulatory features of speech sounds (Lakertz et al., 2021; Mesgarani et al., 2014)



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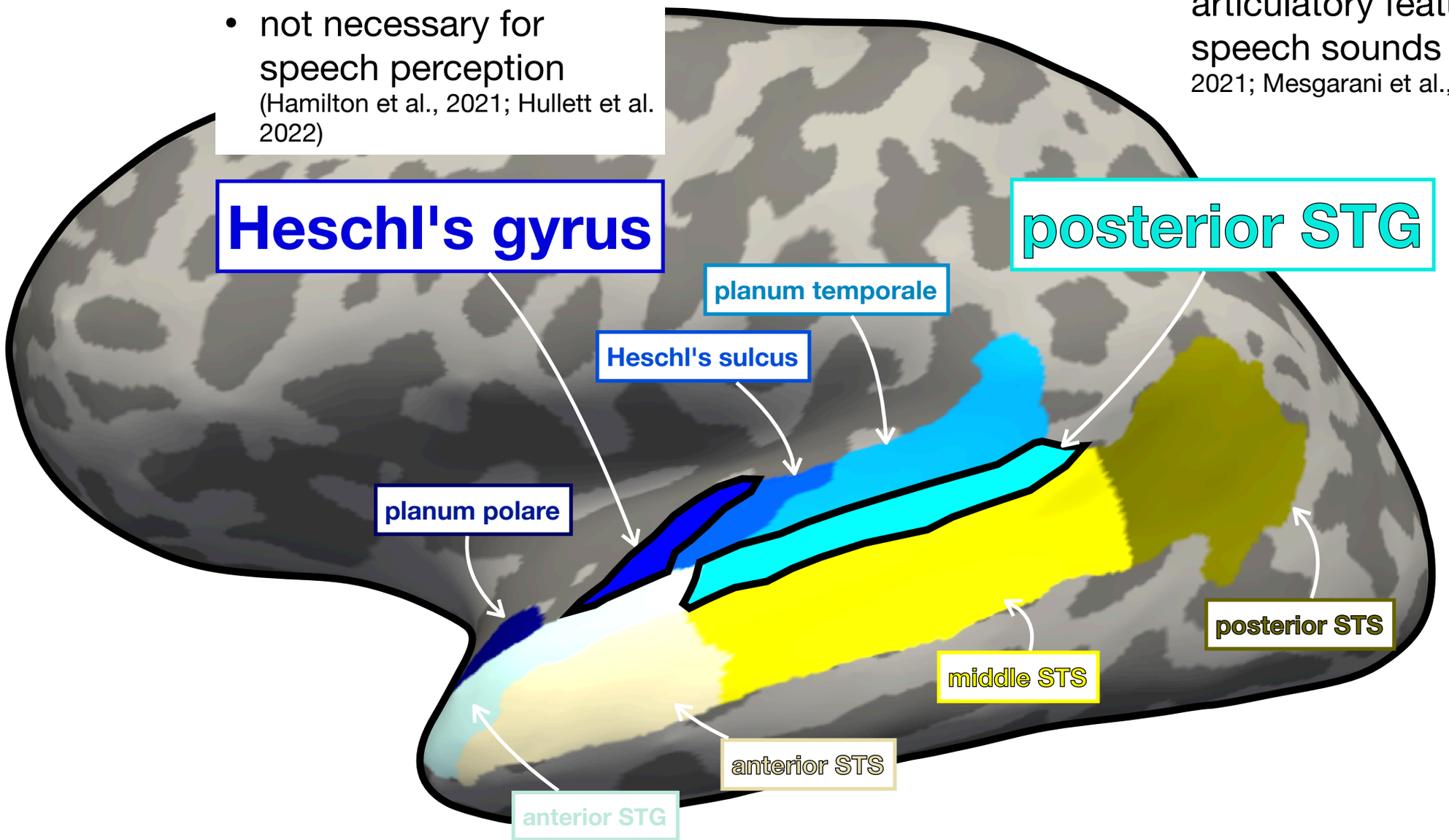
- not necessary for speech perception (Hamilton et al., 2021; Hullett et al. 2022)



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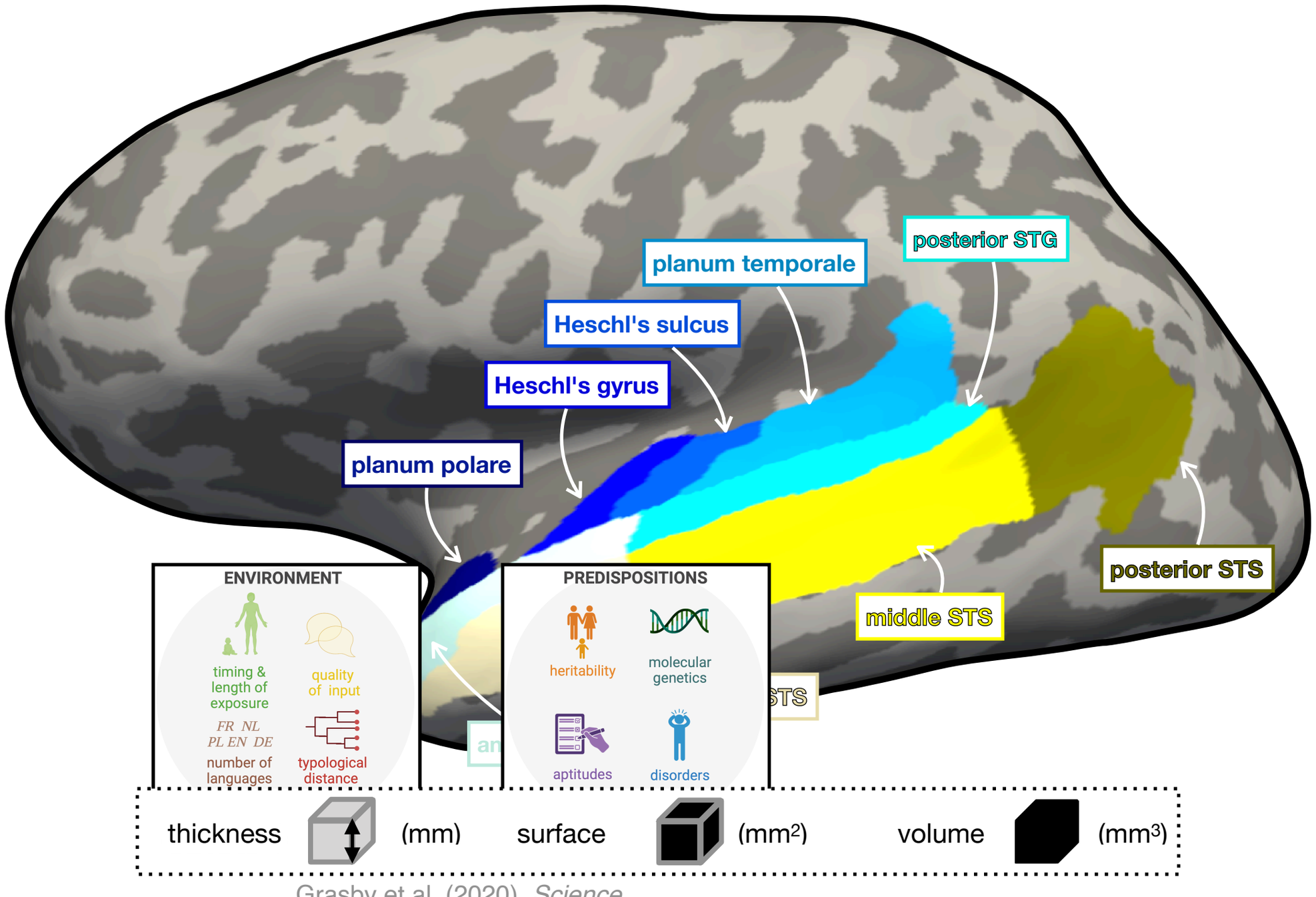
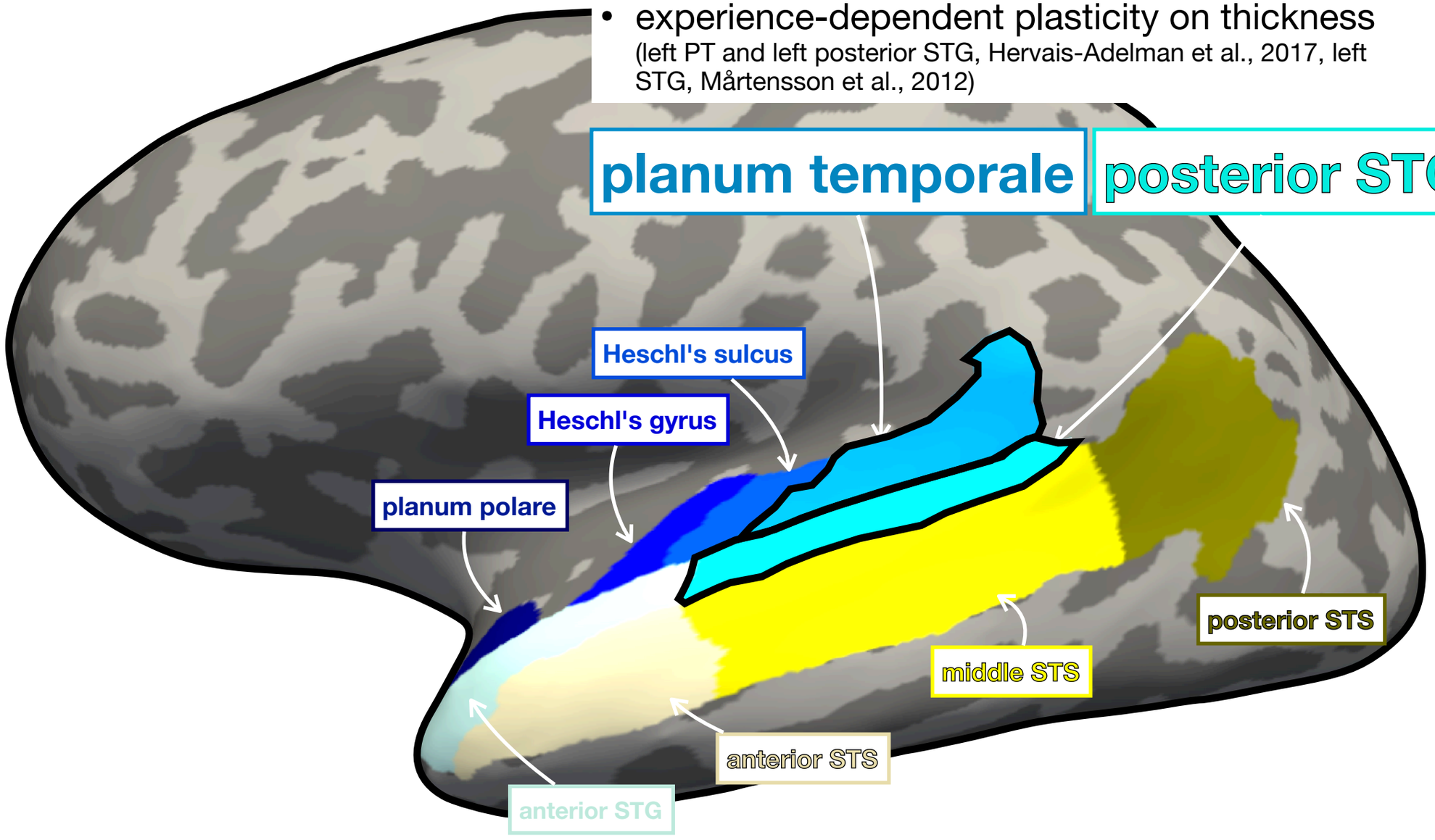


Grasby et al. (2020), *Science*

Auditory cortex

Function, structure & development

- experience-dependent plasticity on thickness
  (left PT and left posterior STG, Hervais-Adelman et al., 2017, left STG, Mårtensson et al., 2012)



Auditory cortex

Function, structure & development

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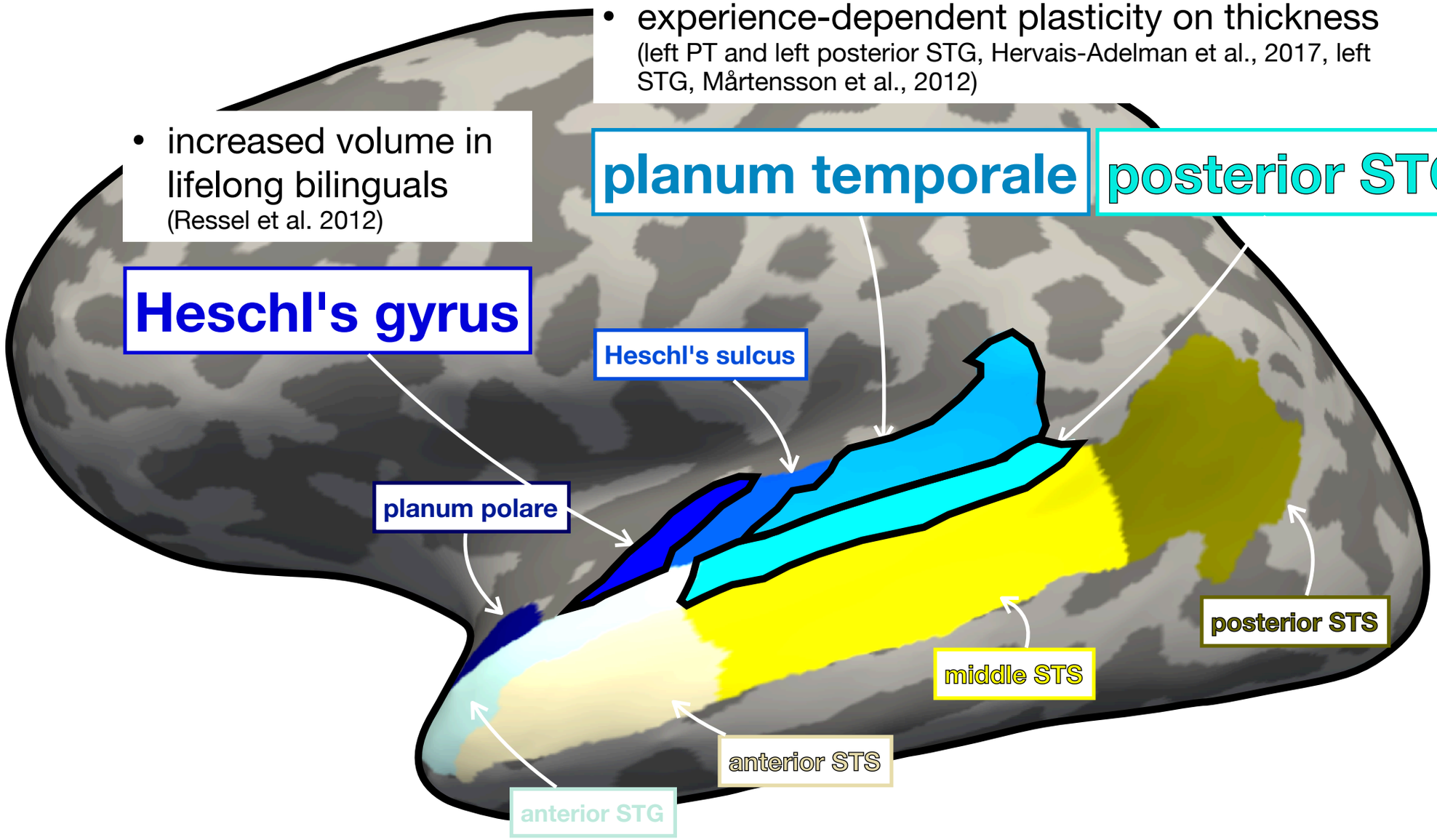
- increased volume in lifelong bilinguals
  (Ressel et al. 2012)



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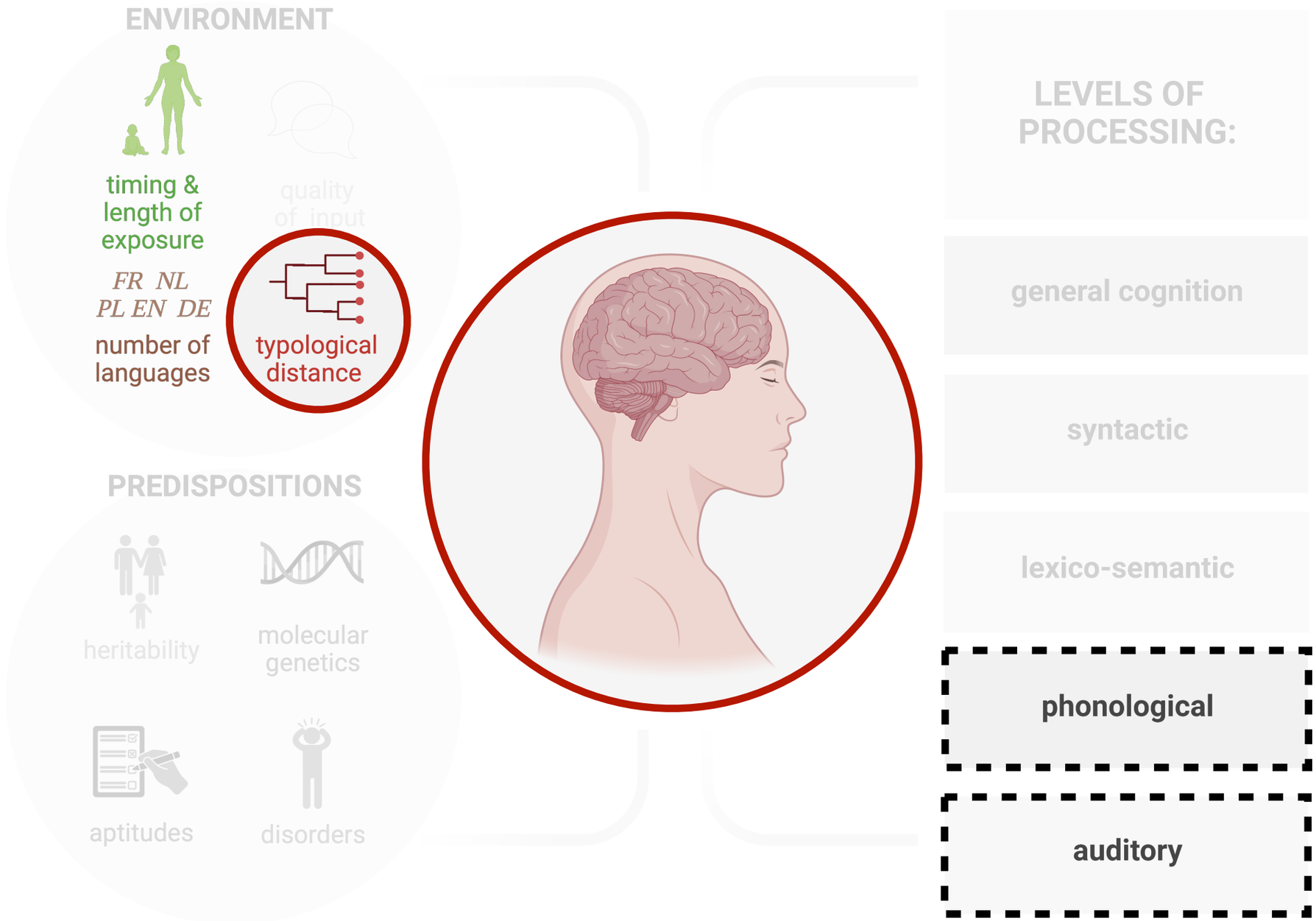
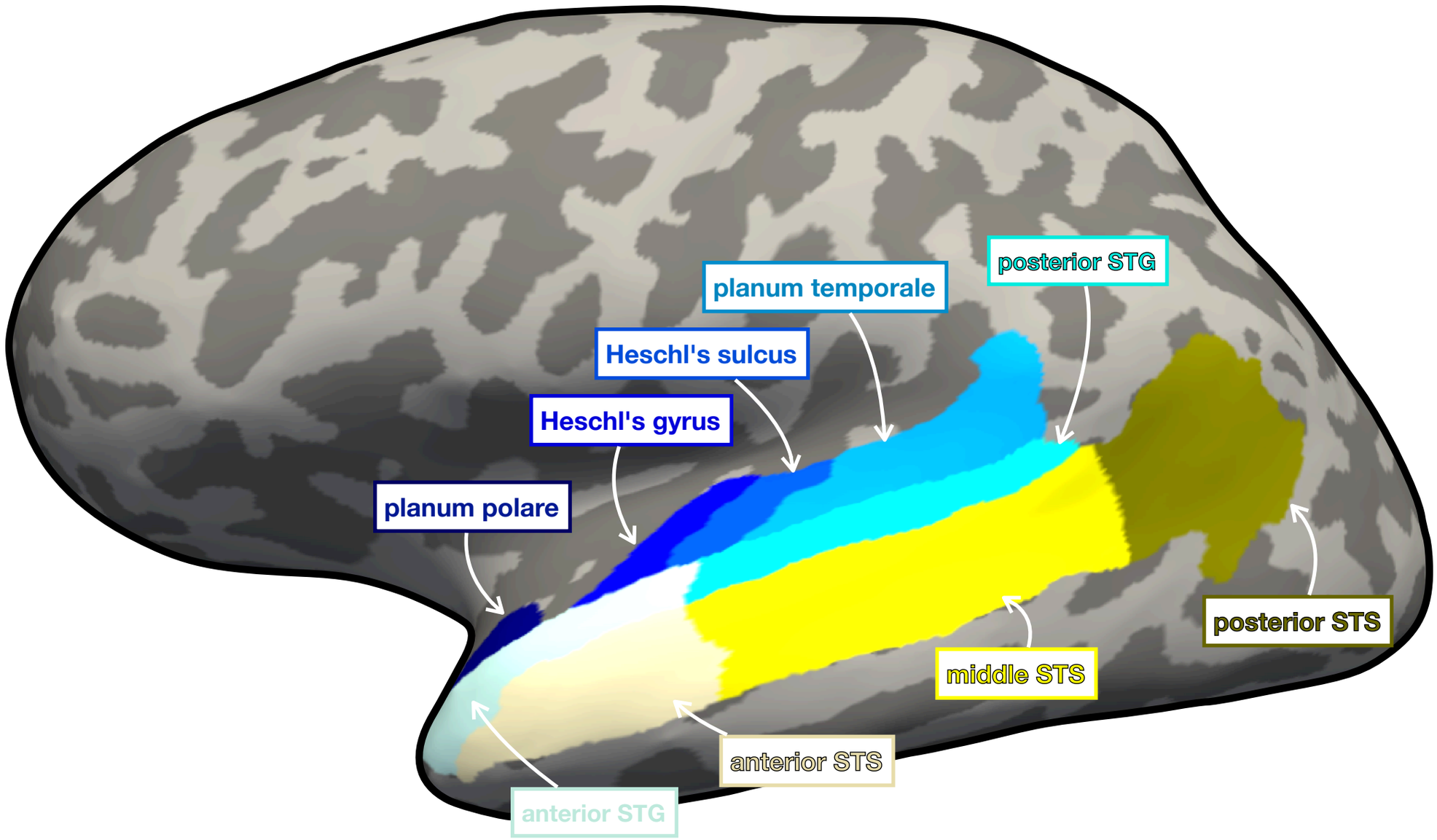


Anatomy of the auditory cortex:

T1w 1.5T MRI + FreeSurfer's brain structural pipeline (Fischl et al. 2004) + Destrieux (2010) parcellation refined with automatic segmentation of TTG (TASH, Dalboni da Rocha et al., 2020):

thickness (mm) surface (mm^2) volume (mm^3)



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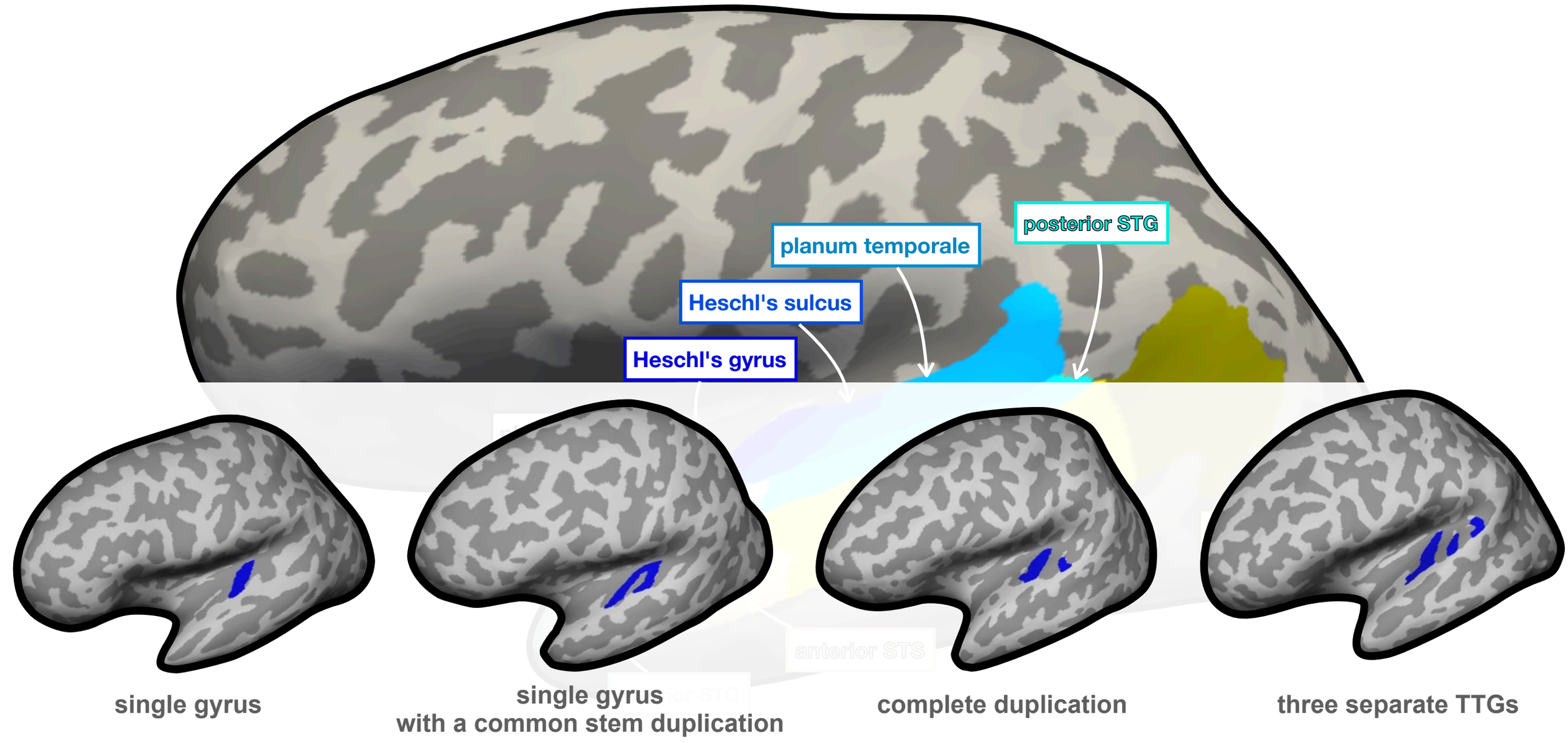

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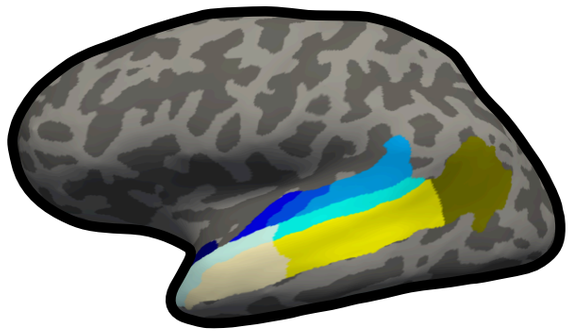

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Multilingualism:

multilinguals — trilinguals — bilinguals — monolinguals

n = 136; M_{age} = 35.79, *SD* = 15.77; 85 females; exposed to 1 to 7 languages (31 monolinguals)

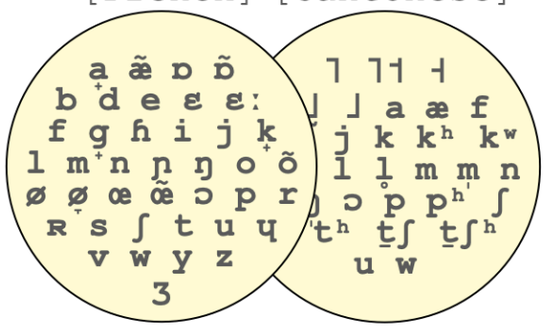
UCL

Rao's entropy

Language typology (phonological distances):

(1) Segments (phonemes)

[French] [Cantonese]



PHOIBLE 2.0 (Moran et al. 2019. https://www.phoible.org)

(2) (Articulatory) features

	[French]	[Cantonese]
tone	0	1
short	0	0
long	1	0
nasal	1	1
labial	1	1
...	...	...

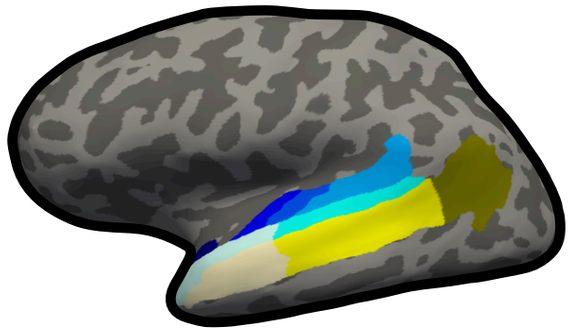
(3) Counts of phonological classes

	[French]	[Cantonese]
segments	40	27
vowels	17	5
long vowels	1	0
nasal vowels	4	0
consonants	23	22
...	...	...

Dediu & Moisik (2016)

Kepinska et al. (2023). *eLife*

Anatomy of the auditory cortex:



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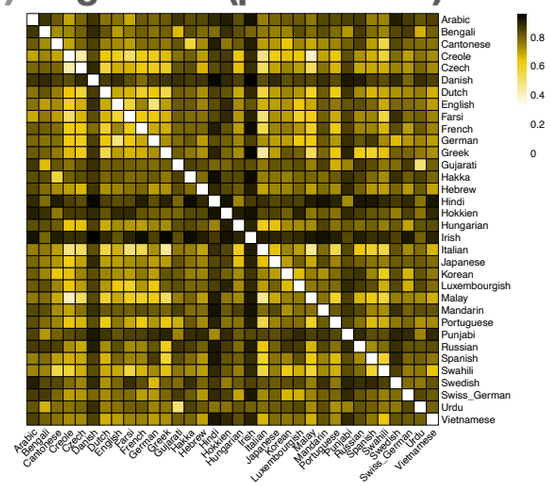

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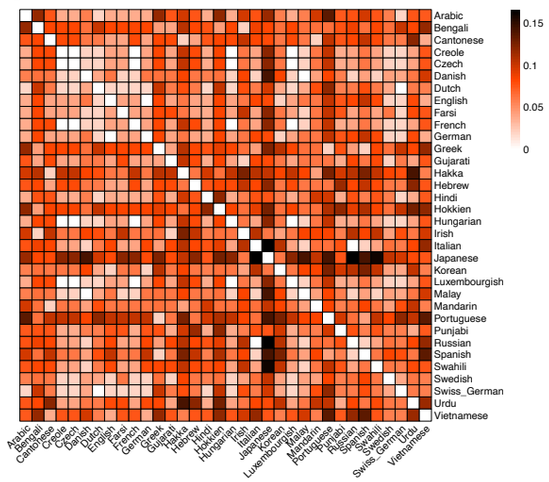

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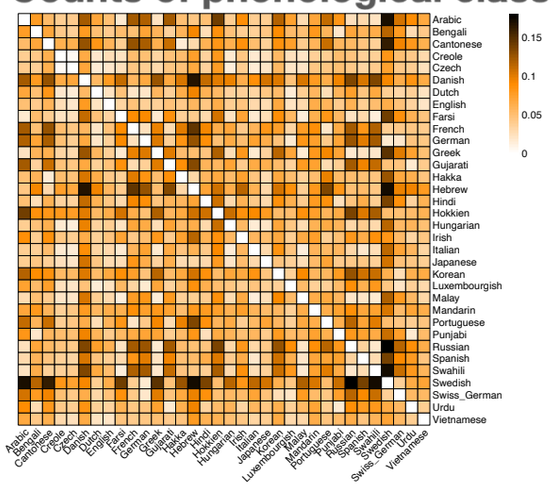


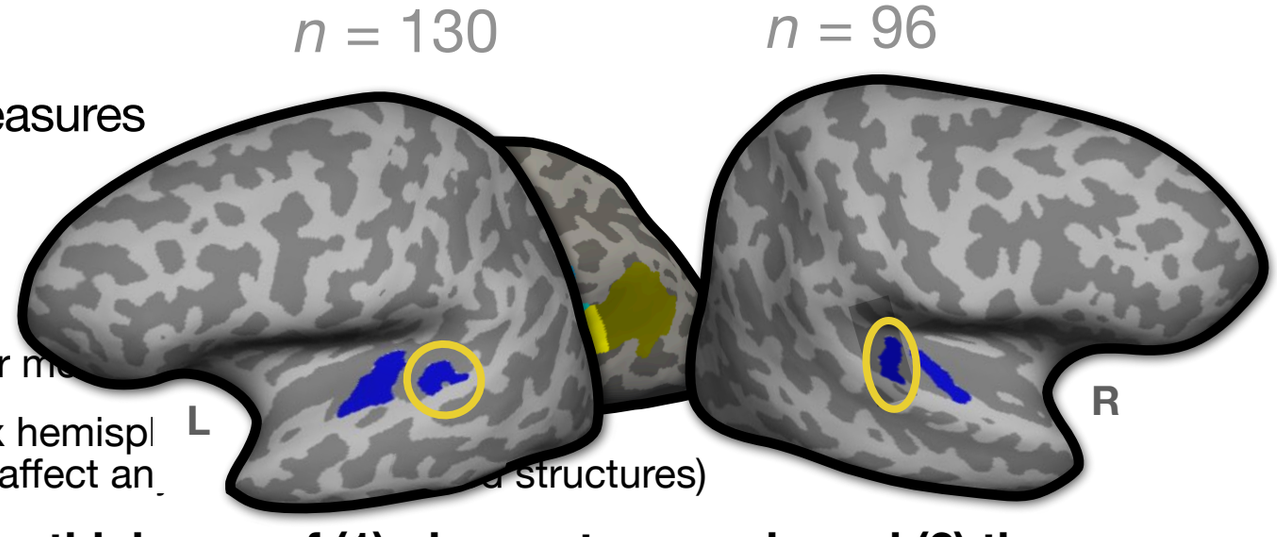
Kepinska et al. (2023). *eLife*

Does the morphology of the auditory cortex reflect language experience?

Exploratory analysis

linear mixed models fit to the extracted anatomical measures (volume, surface area, average thickness):

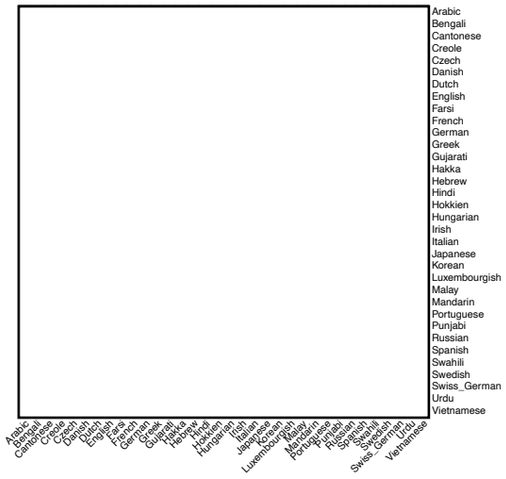
- random effects: participants
- fixed effects language experience, gyrus/sulcus
- covariates: age, gender and whole-brain volume, area, or m
- interaction terms: language experience x **gyrus/sulcus** x hemispl
  (to determine if language experience would differentially affect an structures)



- Out of all investigated cortical measures, only **average thickness of (1) planum temporale and (2) the second TTG (bilaterally)** was related to participants' Language Experience at $p < .01$

Does accounting for typology explain more variance in the neuroanatomical indices?

(0) baseline



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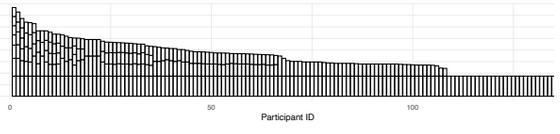
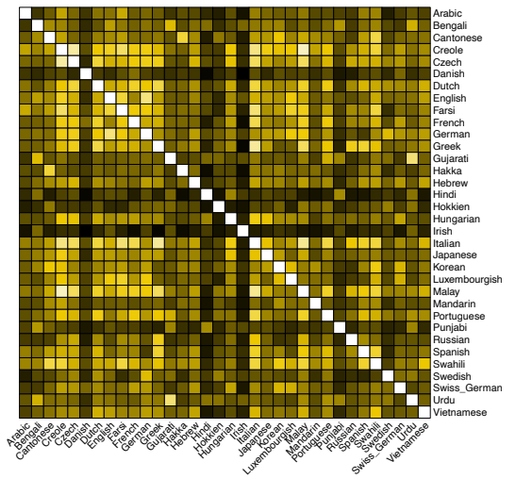


(1) phonemes



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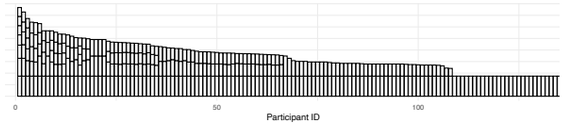
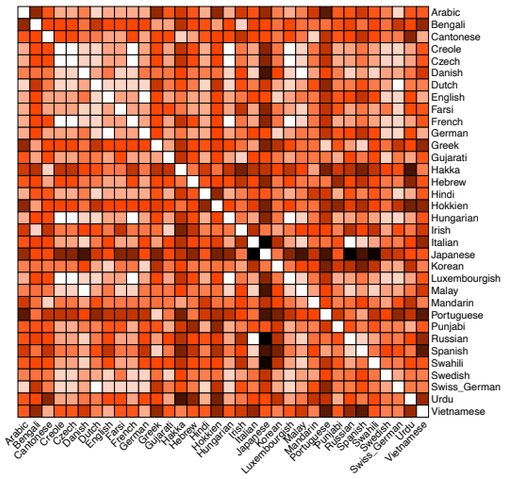


(2) features



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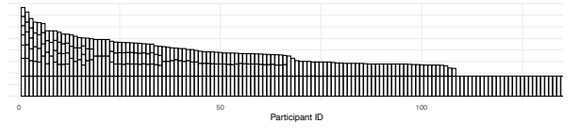
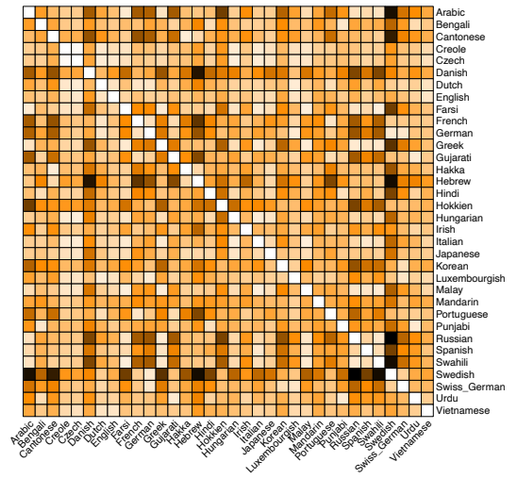


(3) phonological classes



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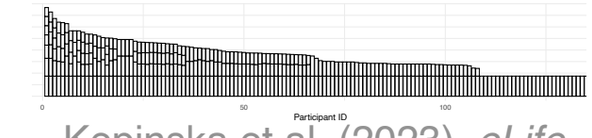


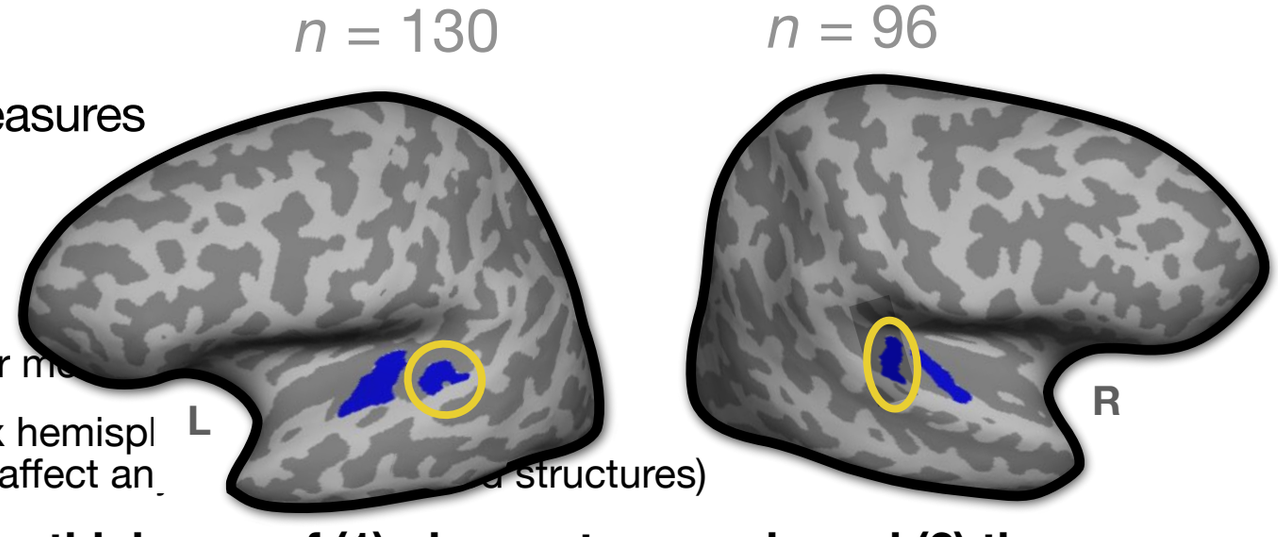
Kepinska et al. (2023). *eLife*

Does the morphology of the auditory cortex reflect language experience?

Exploratory analysis

linear mixed models fit to the extracted anatomical measures (volume, surface area, average thickness):

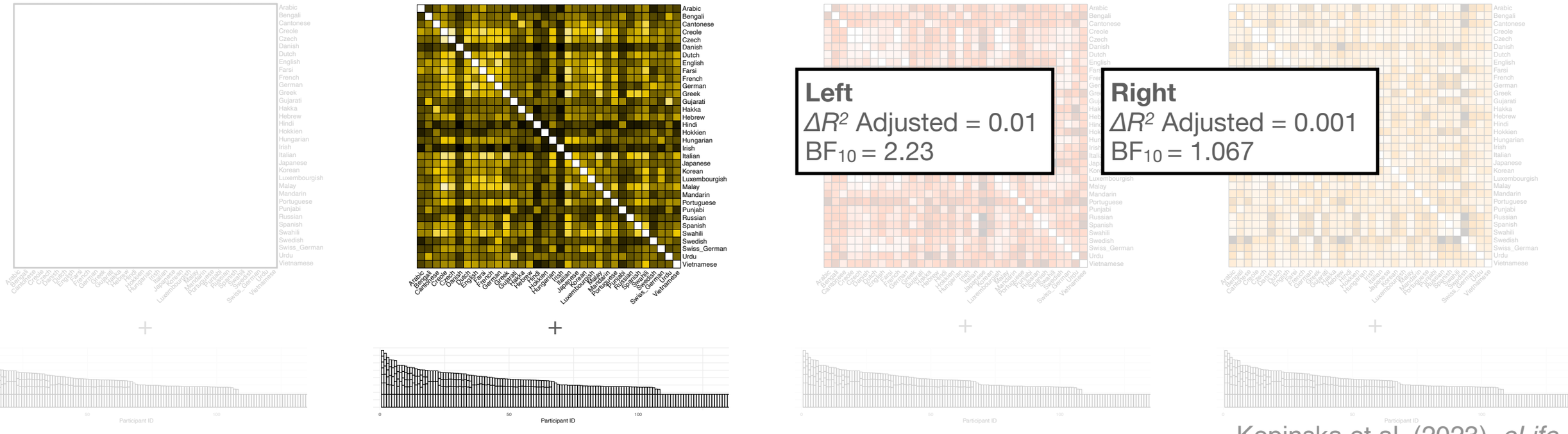
- random effects: participants
- fixed effects language experience, gyrus/sulcus
- covariates: age, gender and whole-brain volume, area, or me
- interaction terms: language experience x **gyrus/sulcus** x hemispl
  (to determine if language experience would differentially affect an structures)



- Out of all investigated cortical measures, only **average thickness of (1) planum temporale and (2) the second TTG (bilaterally)** was related to participants' Language Experience at $p < .01$

Does accounting for typology explain more variance in the neuroanatomical indices?

(0) baseline (1) phonemes (2) features (3) phonological classes



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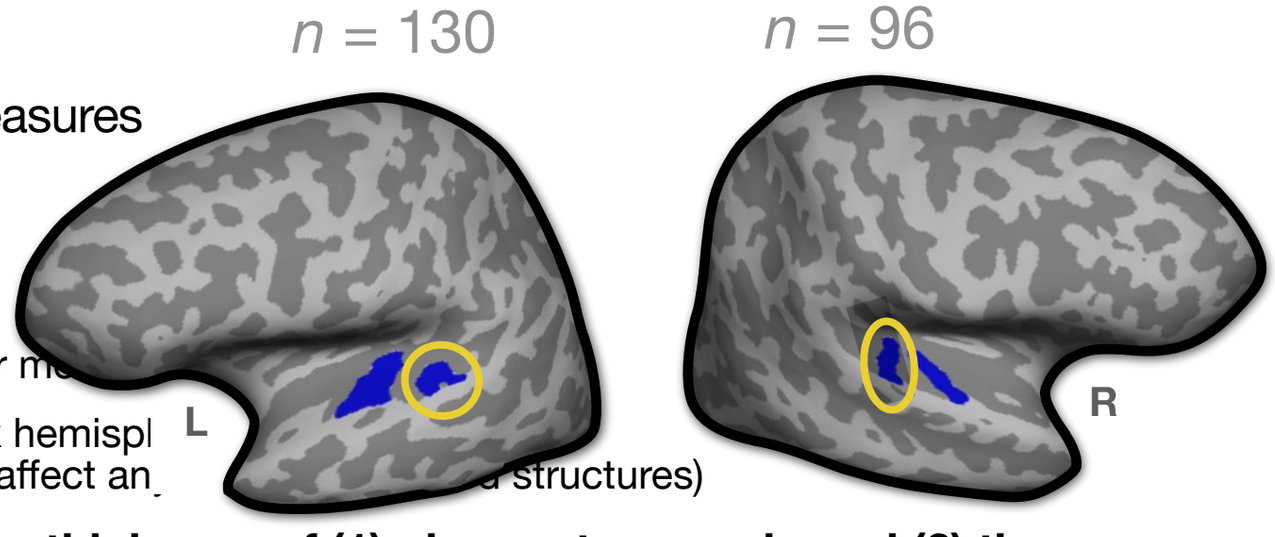

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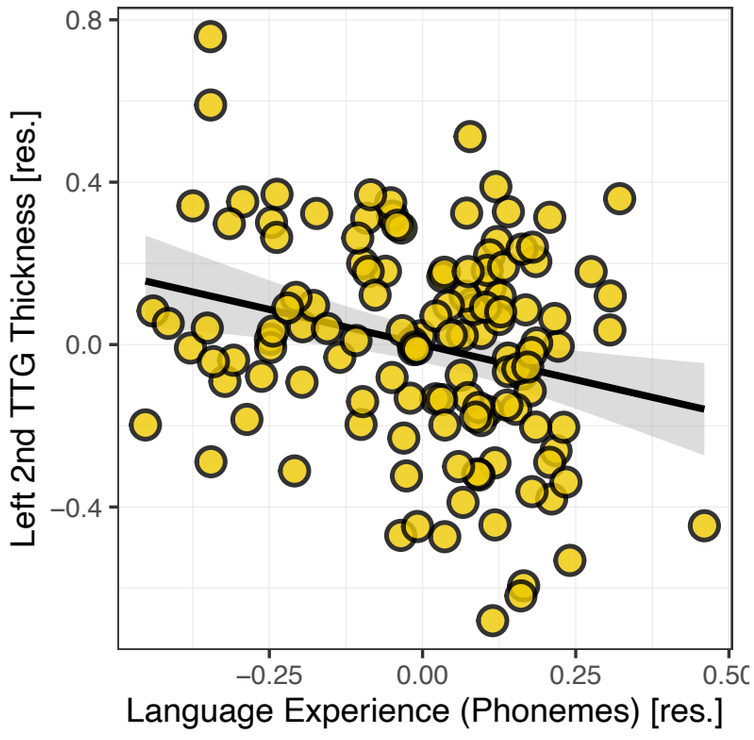

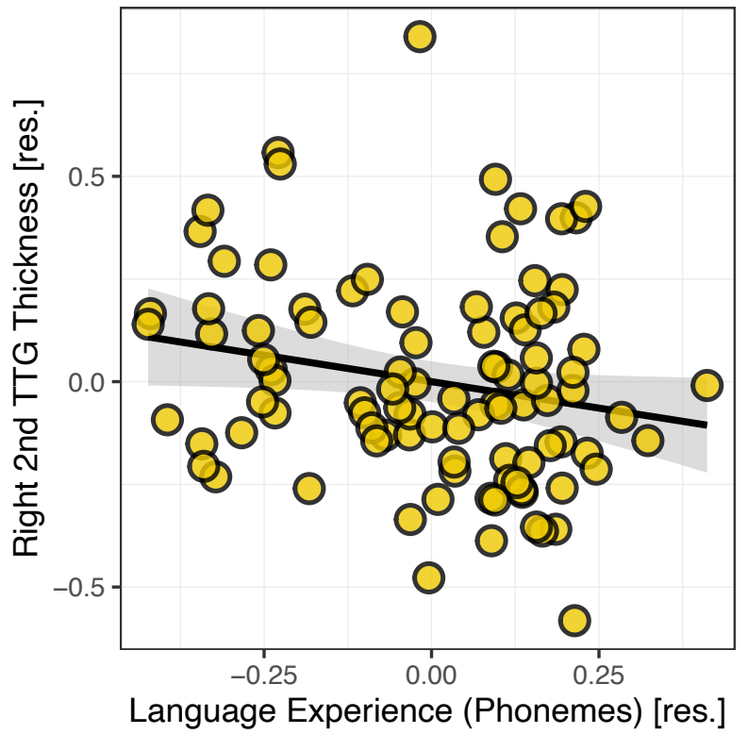

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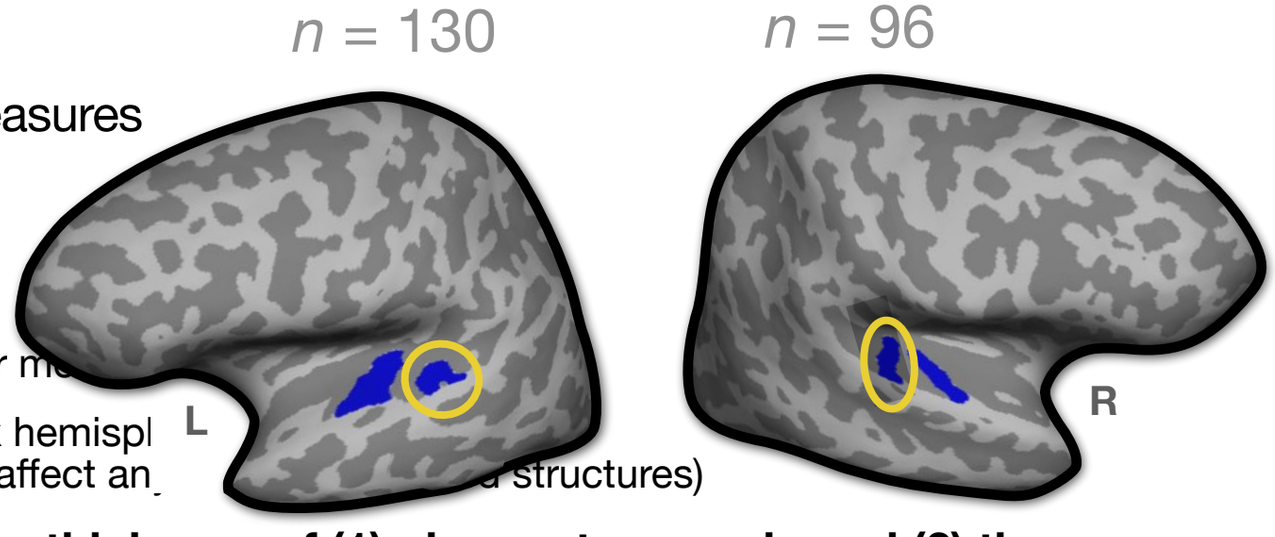

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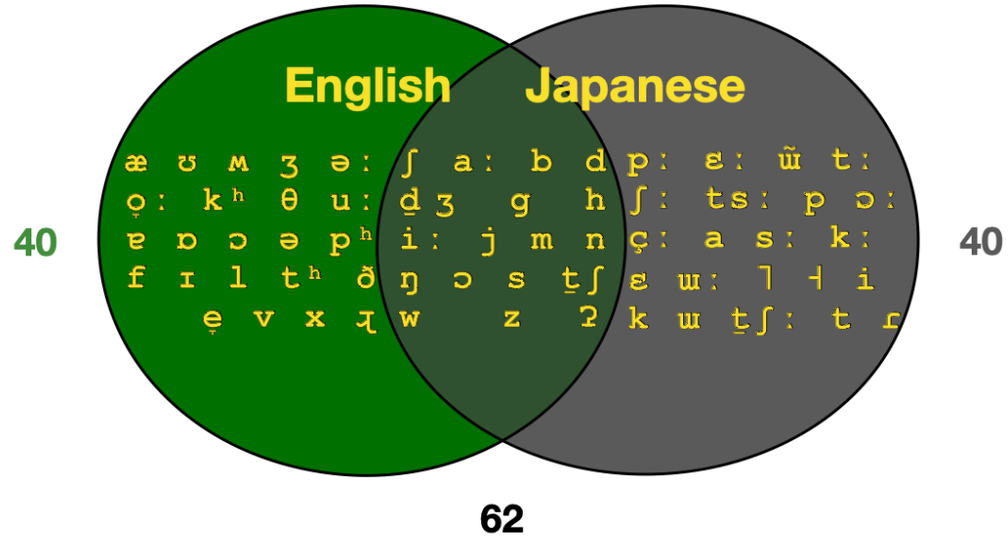
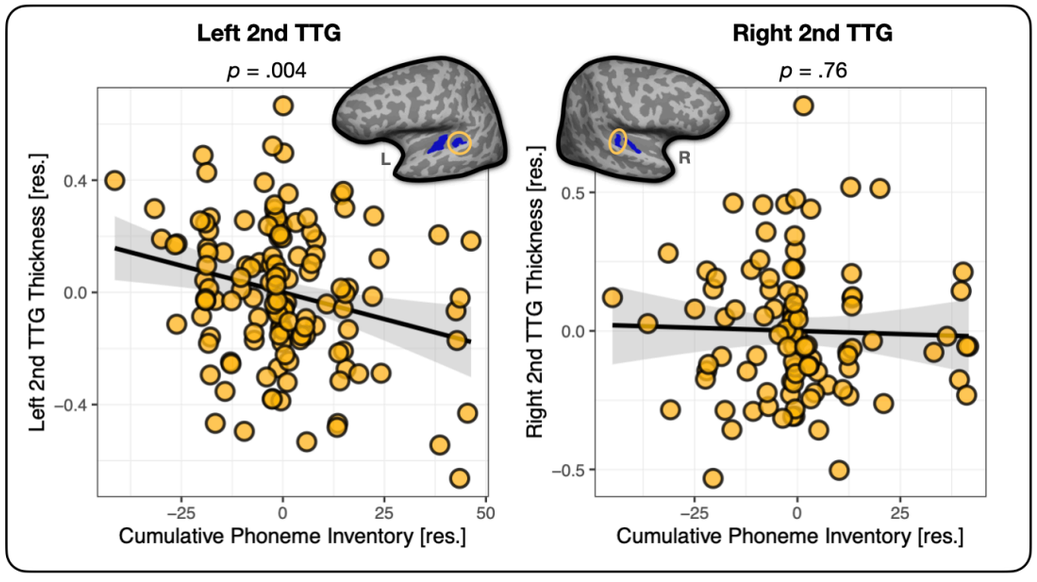
Does accounting for typology explain more variance in the neuroanatomical indices?

'Cumulative phoneme inventory'

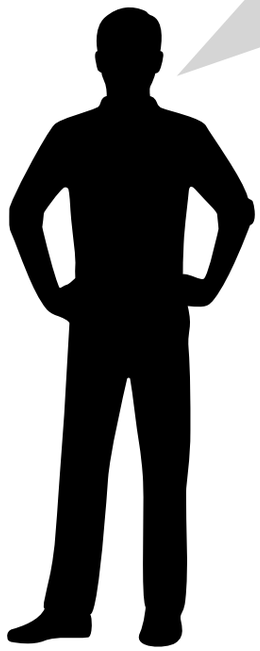
sum of unique number of phonemes across languages per participant:

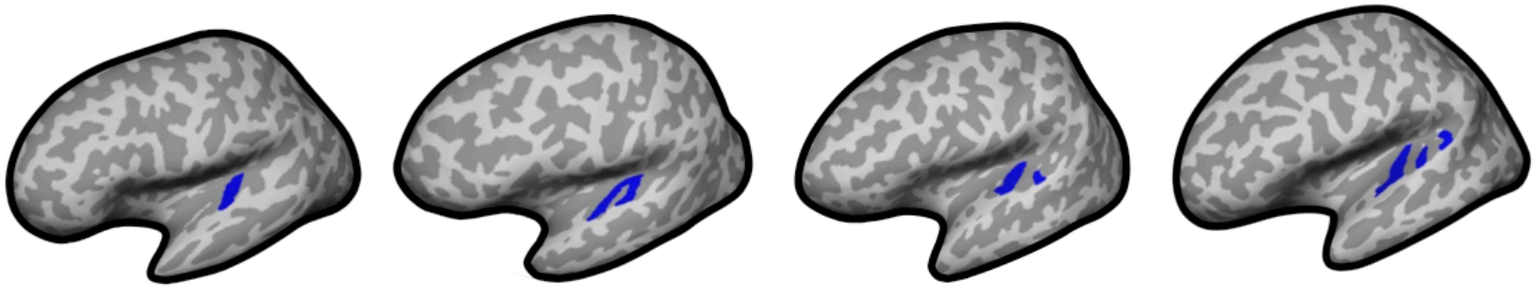


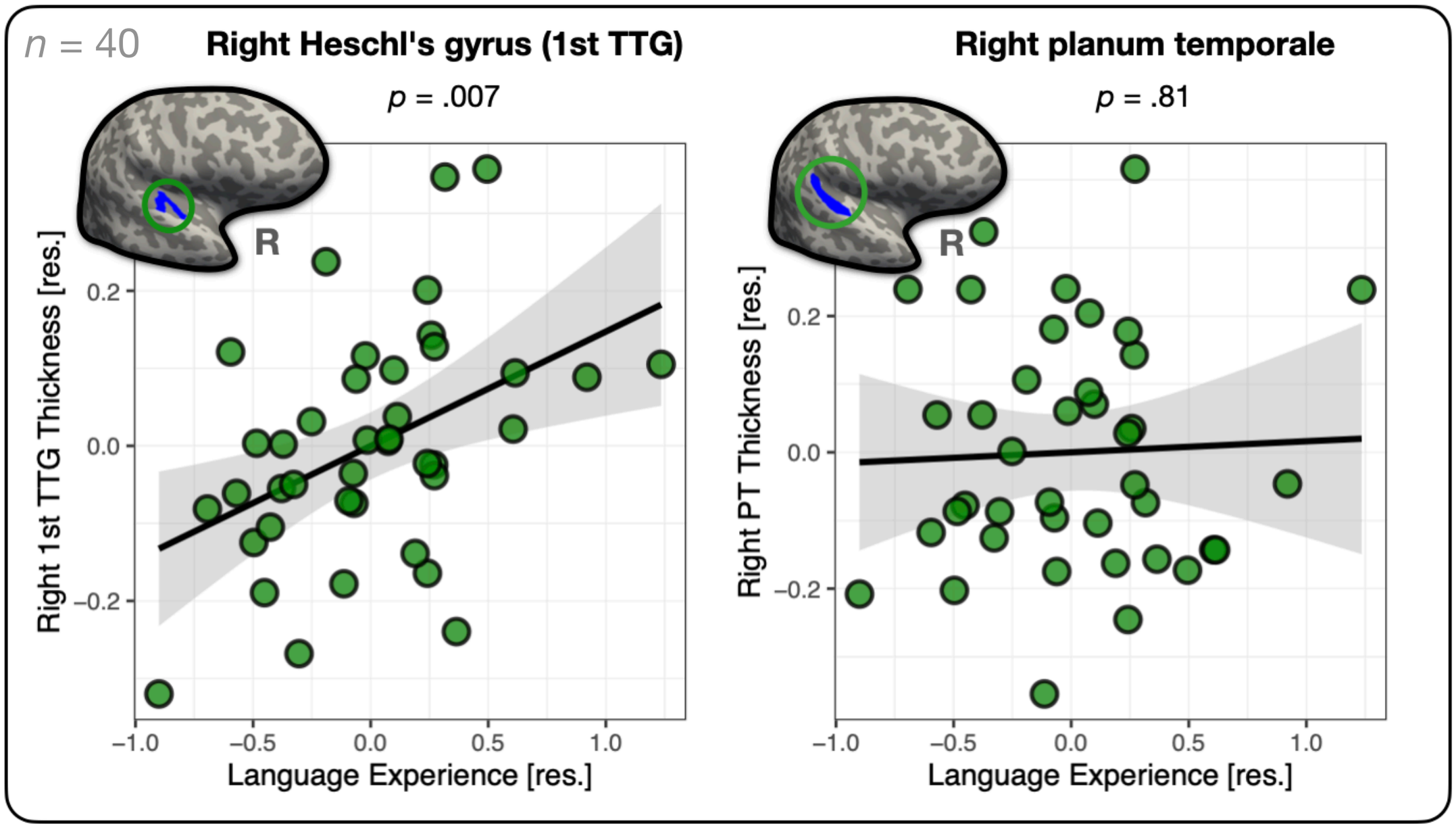


Kepinska et al. (2023). *eLife*

How about individuals who don't have multiple gyri, Olga?



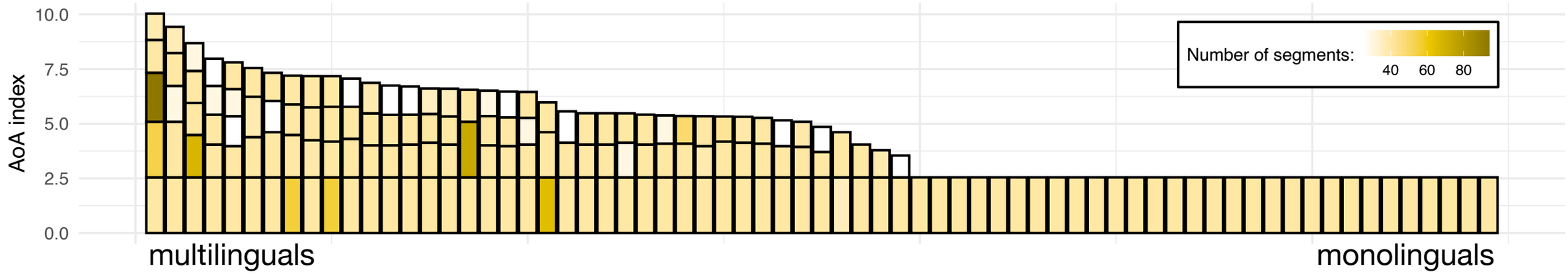




Kepinska et al. (2023). *eLife*

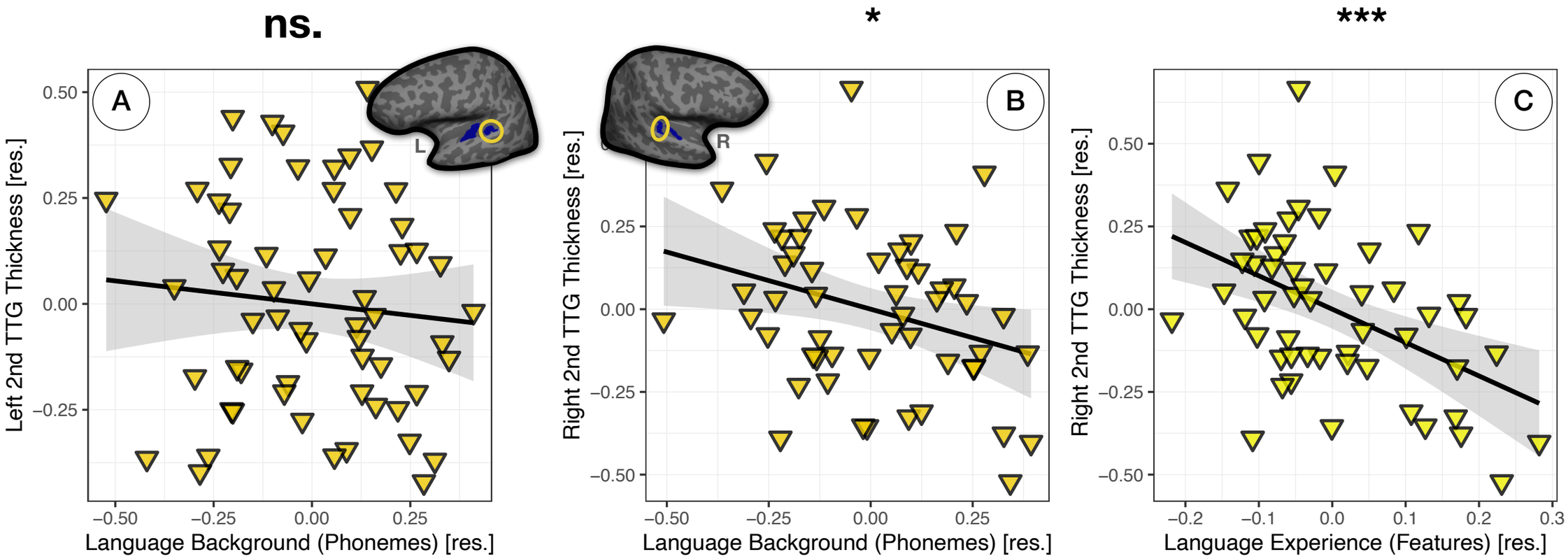
Replication

in an independent sample



T1w 3T MRI;

n = 68; M_{age} = 32.004, *SD* = 11.68; 38 females; exposed to 1 to 5 languages (29 monolinguals)



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Replication

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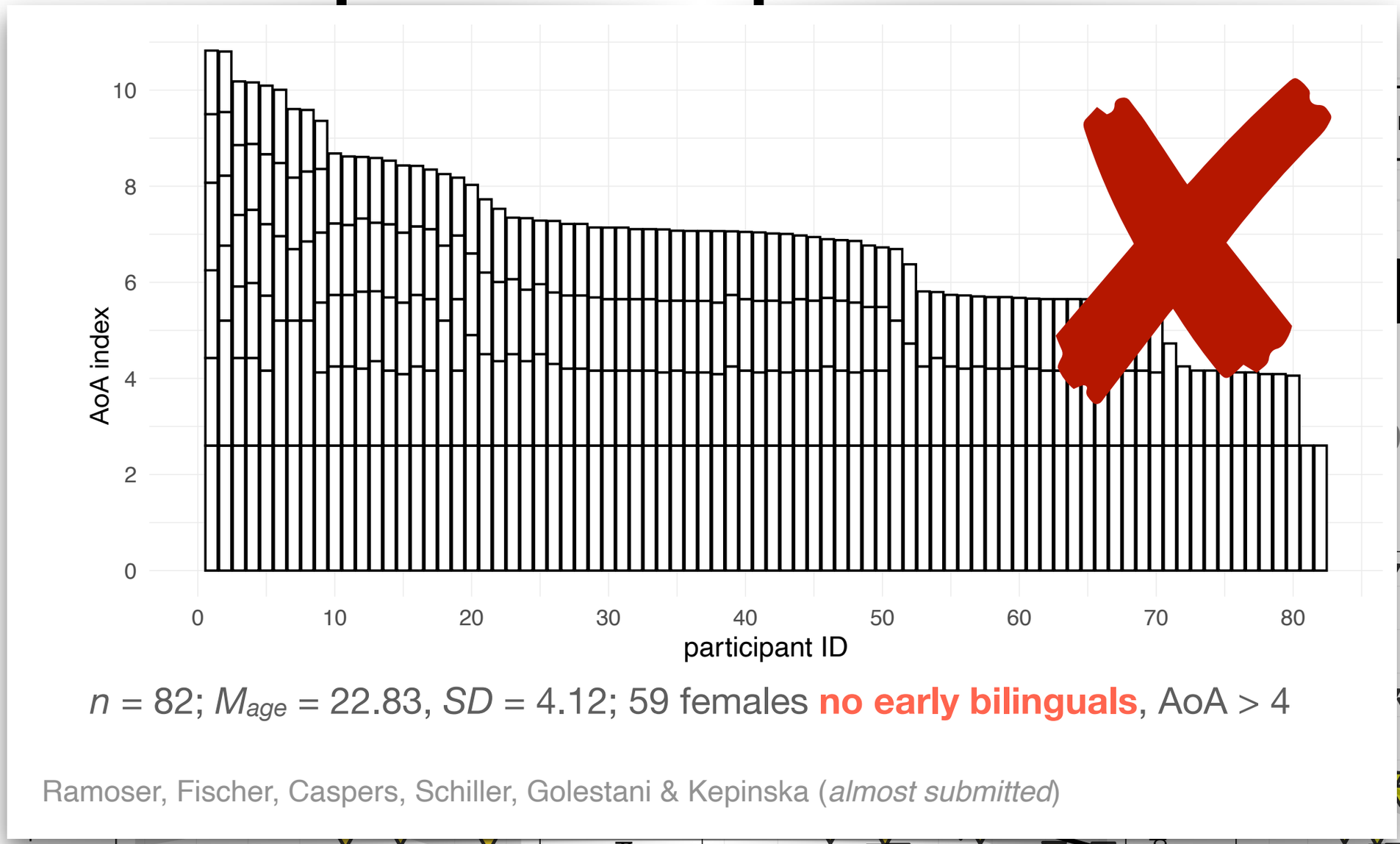
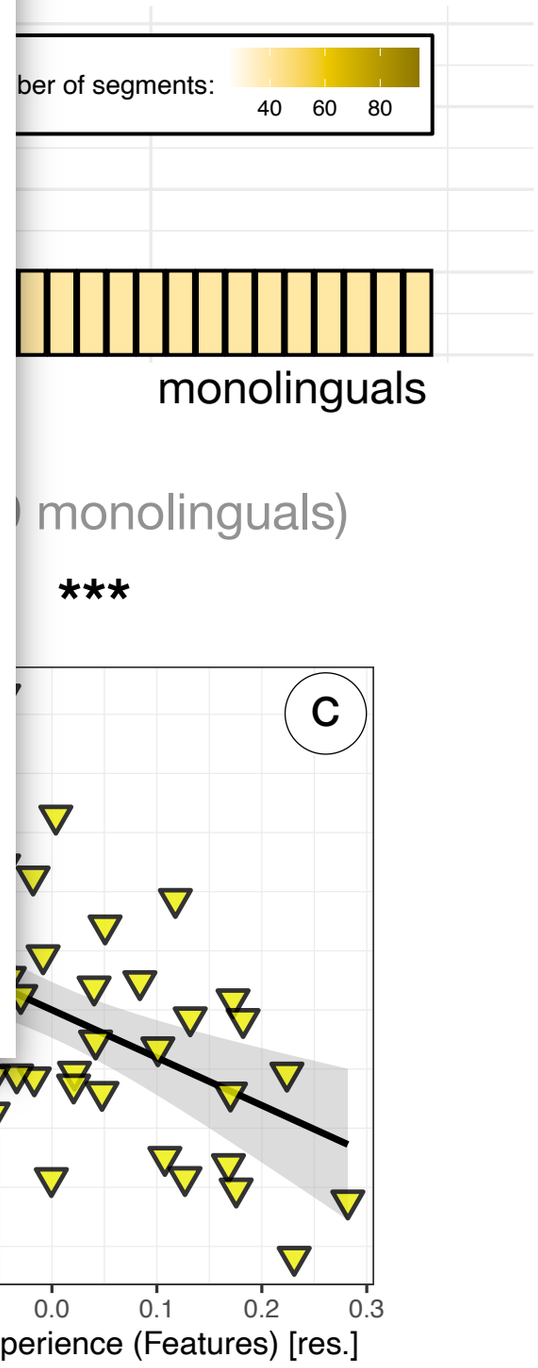


n = 82; M_{age} = 22.83, SD = 4.12; 59 females **no early bilinguals**, AoA > 4

Ramoser, Fischer, Caspers, Schiller, Golestani & Kepinska (*almost submitted*)



Kepinska et al. (2023). *eLife*

Does the morphology of the auditory cortex reflect language experience?

YES:

- Language experience is related to the thickness of the TTG
- Effects of language experience on the auditory cortex are specific to the **second** TTG

Does accounting for typology explain more variance in the neuroanatomical indices?

YES:

- The more extensive one's language experience and more varied at the **segmental** level one's languages are, the thinner the second TTG.
- reflection of experience-driven pruning and neural efficiency?
- Differences in structural characteristics of the auditory cortex (single *versus* multiple gyri) may be related to differences in how multilingual language experience is accommodated in primary *versus* secondary auditory regions.

Kepinska et al. (2023). *eLife*

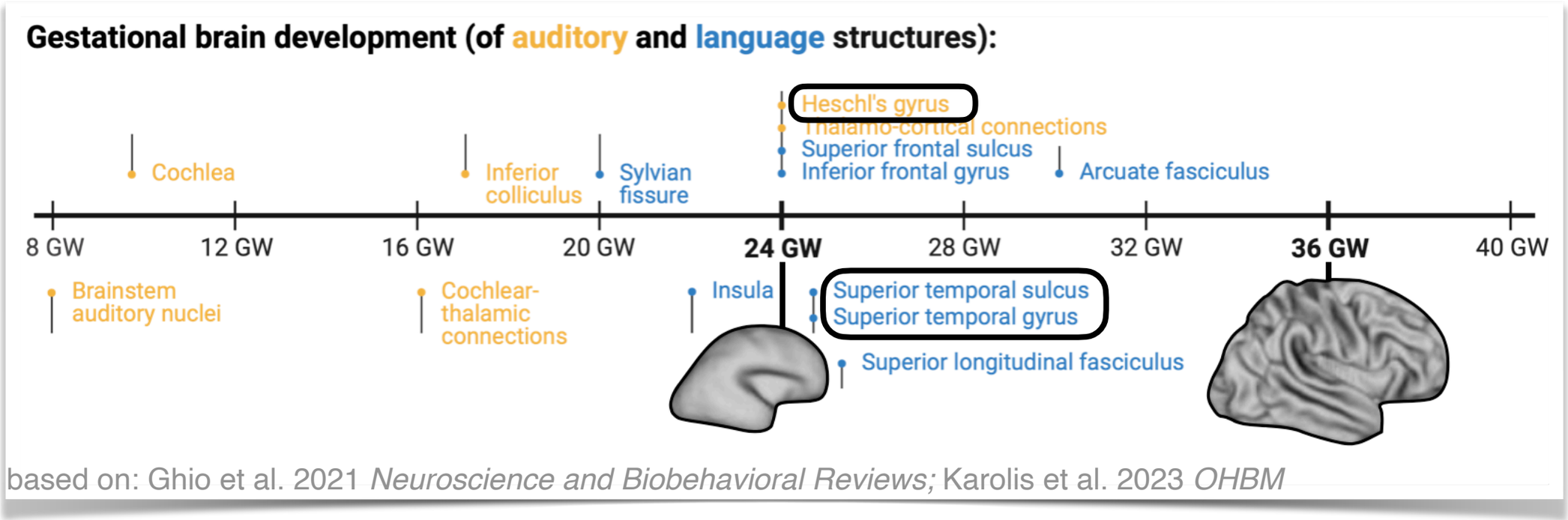
General discussion

Describing the continuum of multilingual language experience and accounting for typology of <u>all</u> languages a person has been exposed to during their life

- an ecologically valid approach potentially contributing to **a broader inclusiveness of experimental cohorts**

- shows that the **typology of multilinguals' languages is related to specific neural signatures**

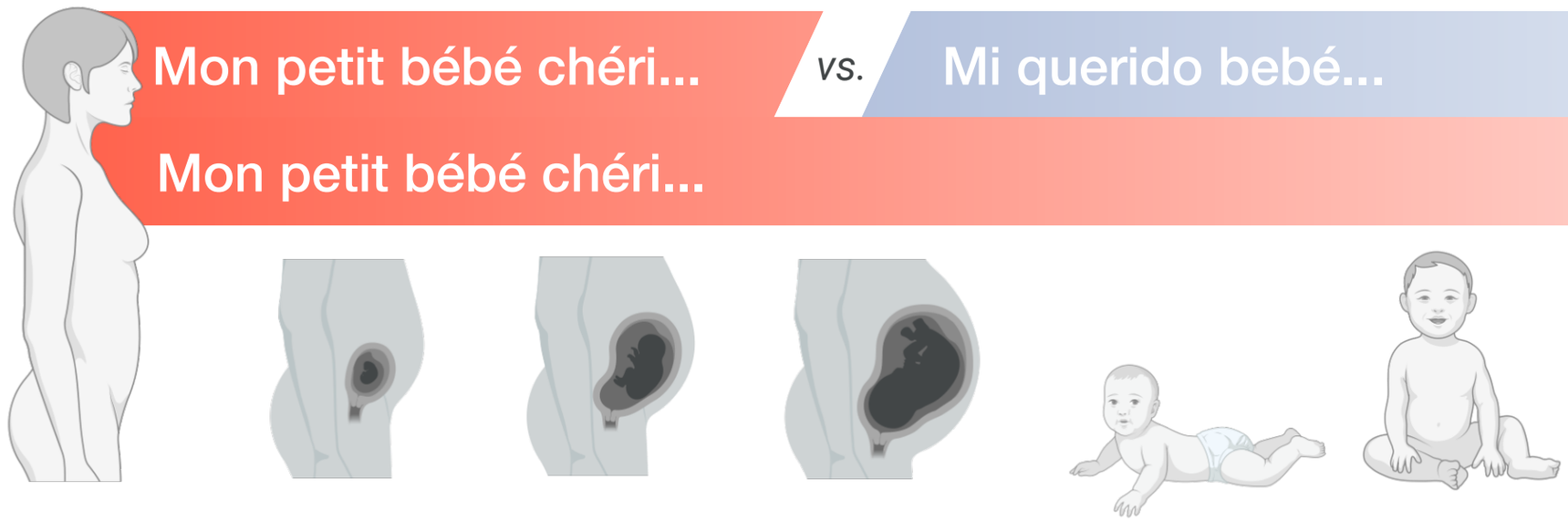
- *<u>but</u>*: we observe it only in cohorts with multilinguals who have been exposed to their different languages **from very early on**

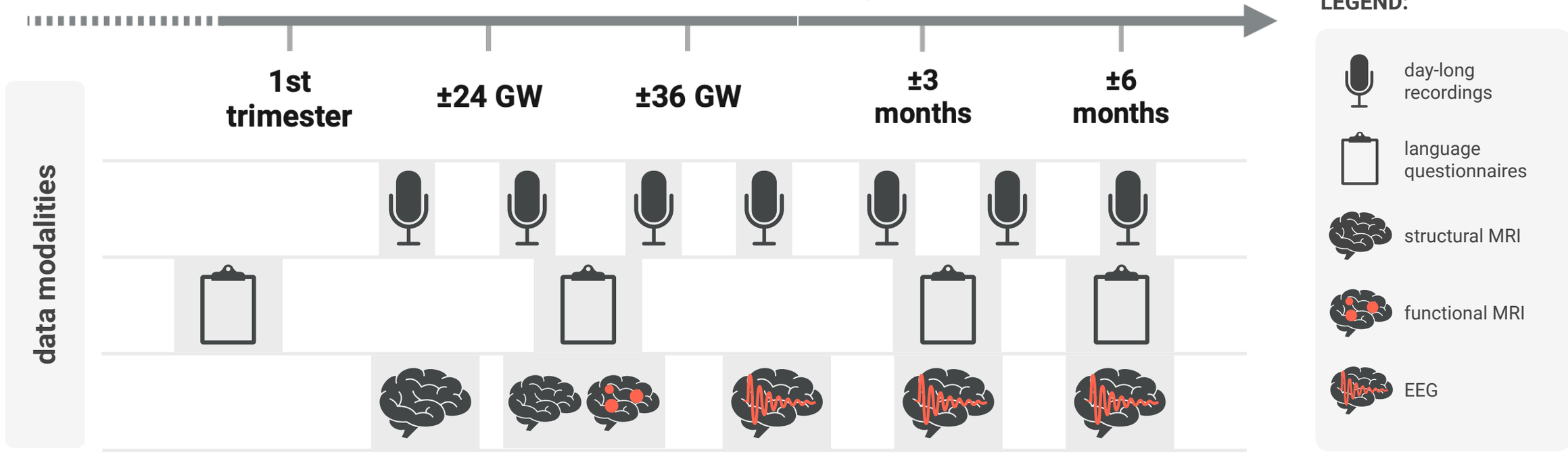


based on: Ghio et al. 2021 *Neuroscience and Biobehavioral Reviews;* Karolis et al. 2023 *OHBM*

ERC Starting Grant 2024 **proposal**:

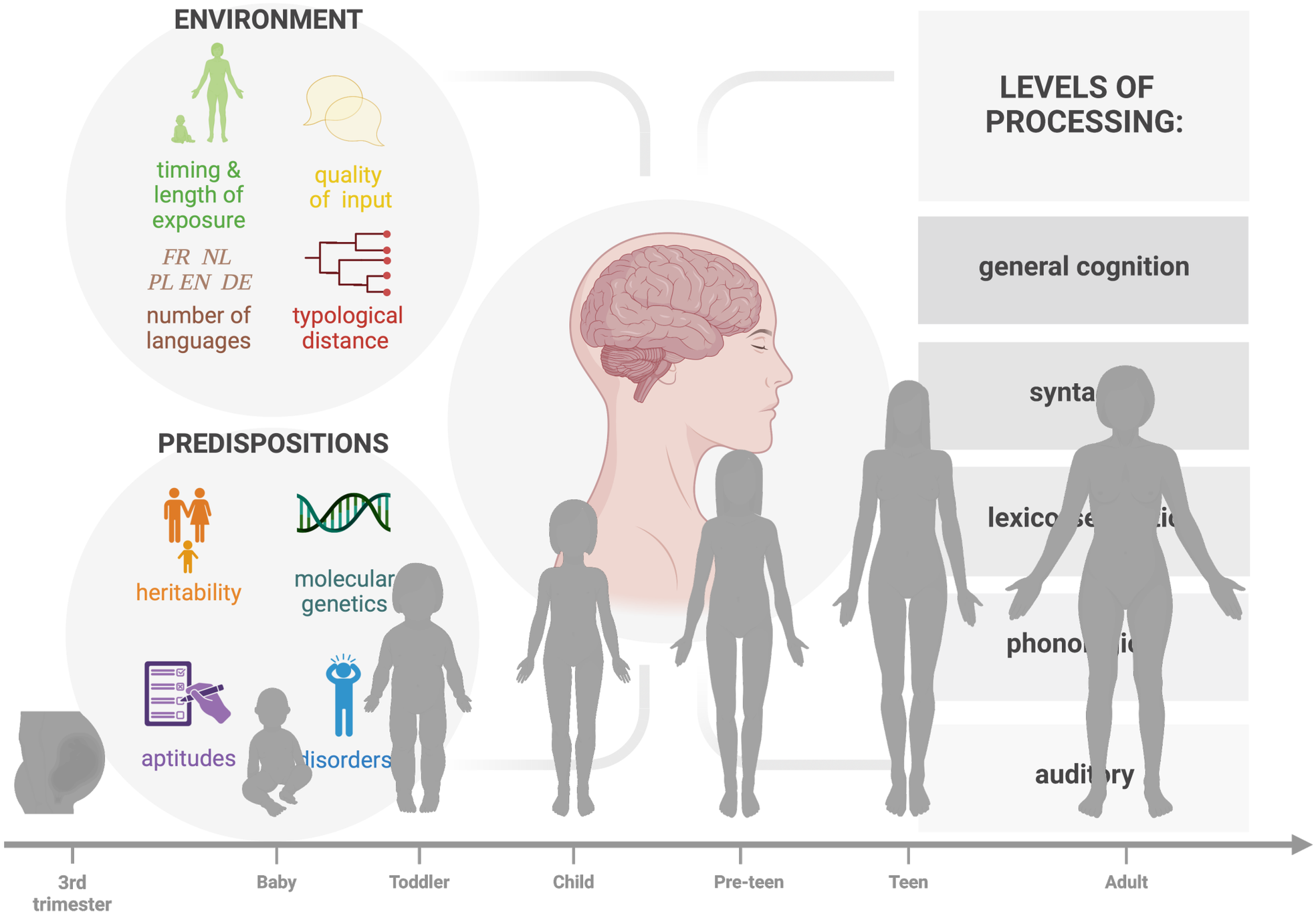
Diverse Sounds: How Prenatal Experience with Phonological Diversity Shapes Fetal Brain Development and Later Language Learning





Individual differences

In (multilingual) language skills



Fumiko Hoeft
Nikola Vukovic
Jocelyn Caballero
Leo Zekelman
Stephanie Haft
Rebecca Marks
Austin Jewison
Safiyyah Bachar
Myriam Oliver
Cheng Wang
Julia St John
Stephanie Gee
Søren Wichmann

Narly Golestani
Cathy Price
David Green
Josue Dalboni da Rocha
Carola Tuerk
Alexis Hervais-Adelman
Florence Bouhali

Thank you!

olga.kepinska@gmail.com
@olgakepinska.bsky.social

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