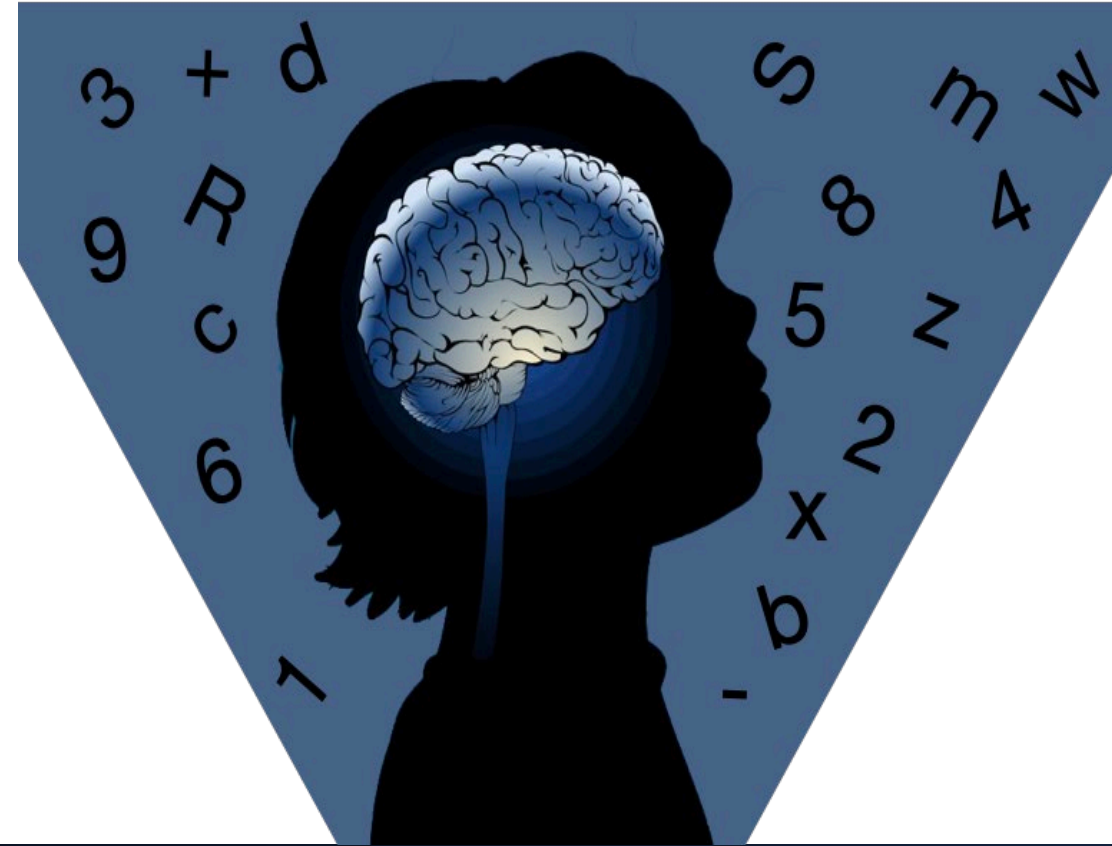


Are grammatical and arithmetic processing related in the brain?

An ALE-meta-analysis



2024 Meeting of the International Mind, Brain and Education Society (IMBES)

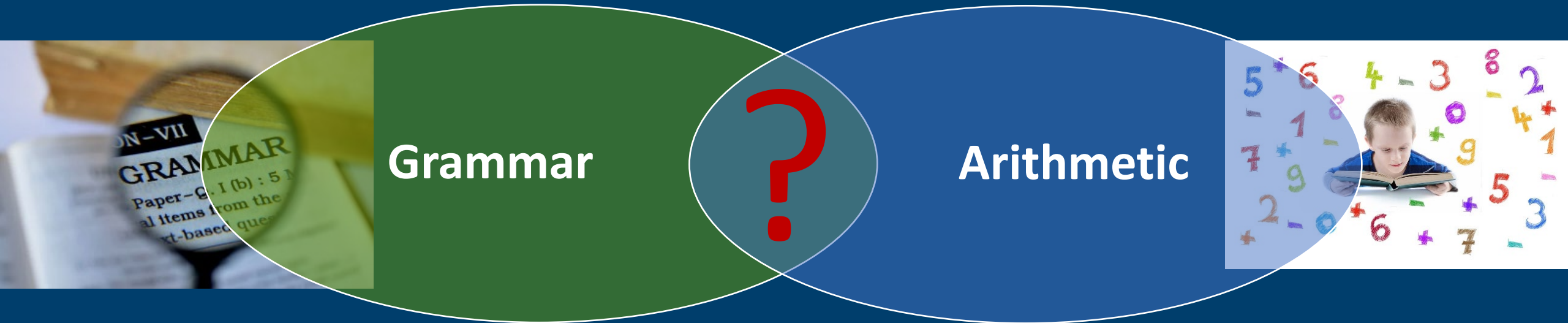
10 – 12 July 2024 in Leuven, Belgium

Nurit Viesel-Nordmeyer^{1,2,3} Johannes C. Ziegler³

& Jérôme Prado⁴



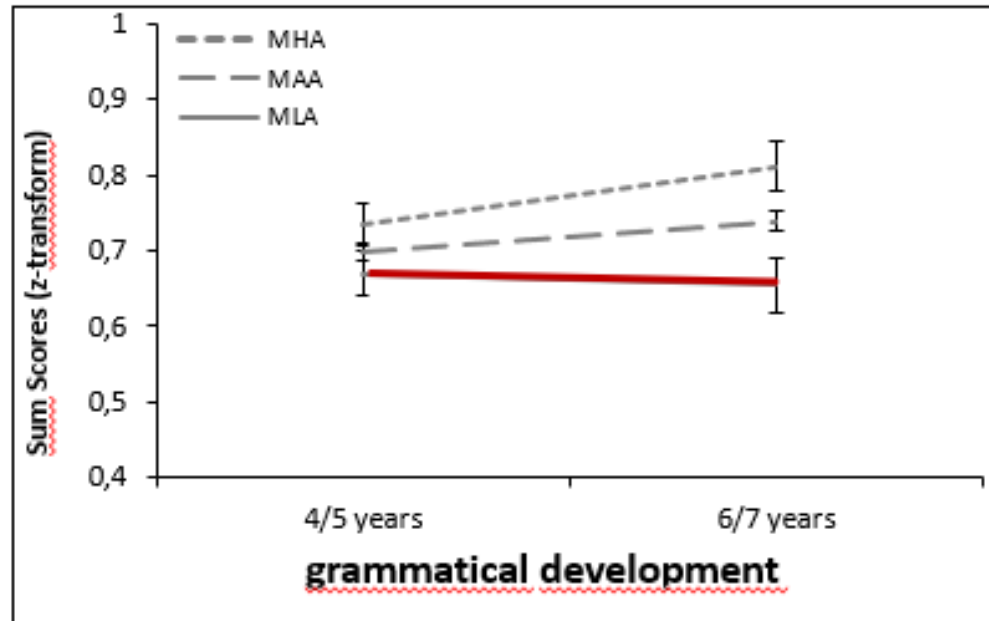
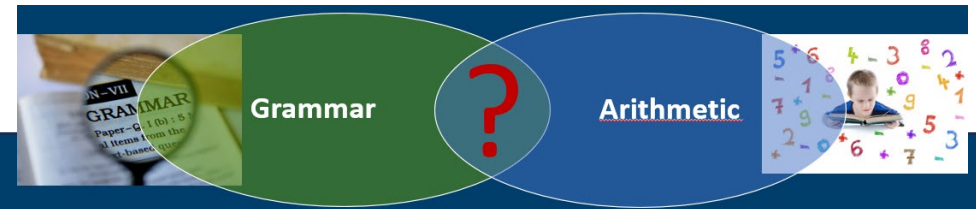
Problem outline



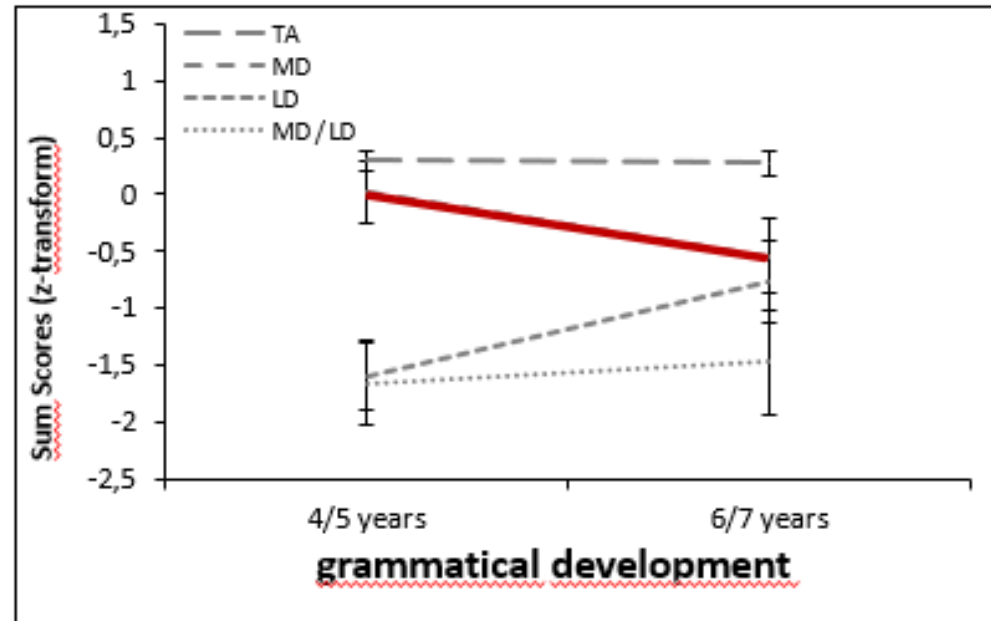
Relation between (impaired) processing

e.g., Chow et al., 2021; Kleemans et al., 2018; Nakai & Okaoya, 2018
Viesel-Nordmeyer et al., 2019; 2021; Wimmer et al., 2024

Problem outline

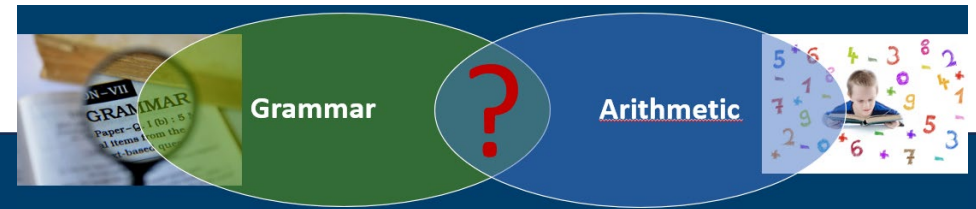


Notes. MLA = mathematical low achievers ($n = 41$); MAA = mathematical average achievers ($n = 225$); MHA = mathematical high achievers ($n = 35$).



Notes. MD/LD = combined learning difficulties ($n = 26$); MD = mathematical learning difficulties ($n = 23$); LD = linguistic learning difficulties ($n = 18$); TA = typical achievers ($n = 234$).

Problem outline

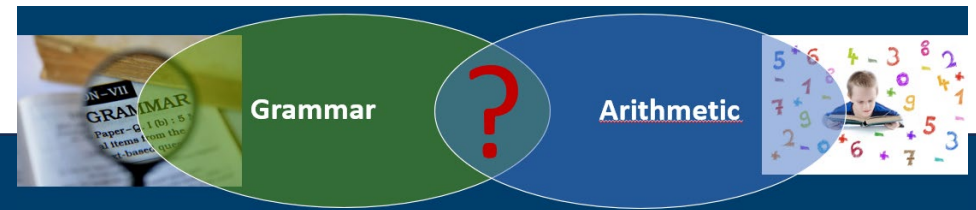


Children with **math impairment**



lower grammar skills than their peers
(e. g., Viesel-Nordmeyer et al., 2021a, 2021b; Wimmer et al., 2023)

Problem outline



Children with **math impairment**



lower grammar skills than their peers

(e. g., Viesel-Nordmeyer et al., 2021a, 2021b; Wimmer et al., 2023)

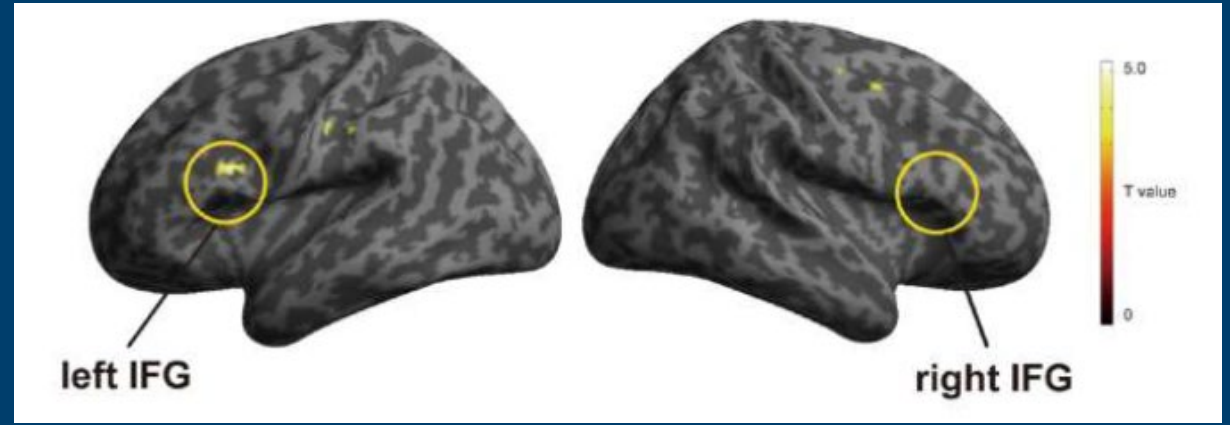
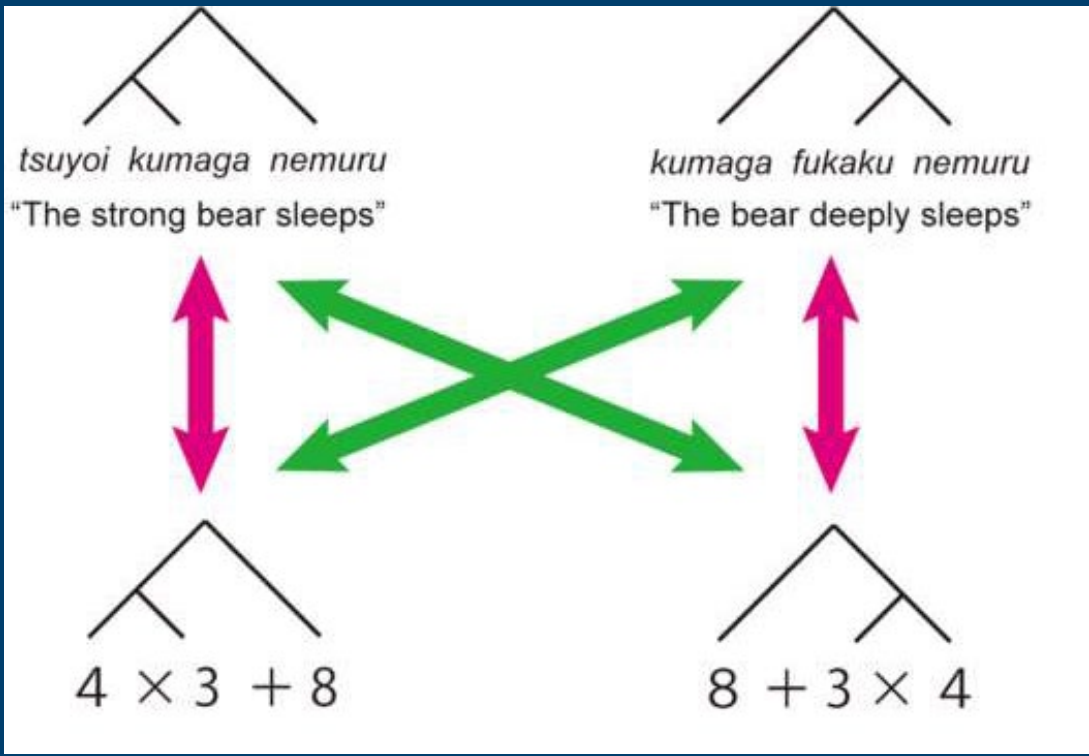
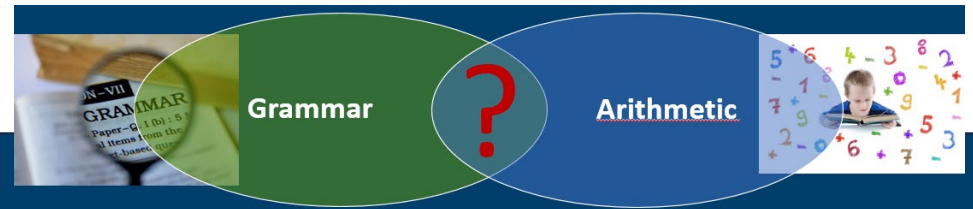
Children with developmental language disorder (DLD) and specifically **grammatical impairment**



lower math skills than their peers

(e. g., Kleemans et al., 2018; Schuchardt & Mähler, 2021)

Problem outline



Problem outline

rules?
regularities?

Grammar

Arithmetic

Relation between (impaired) processing

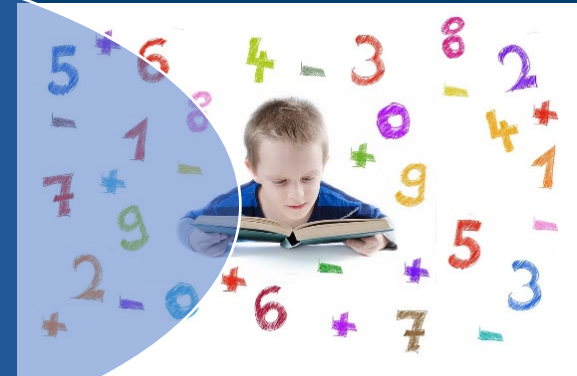
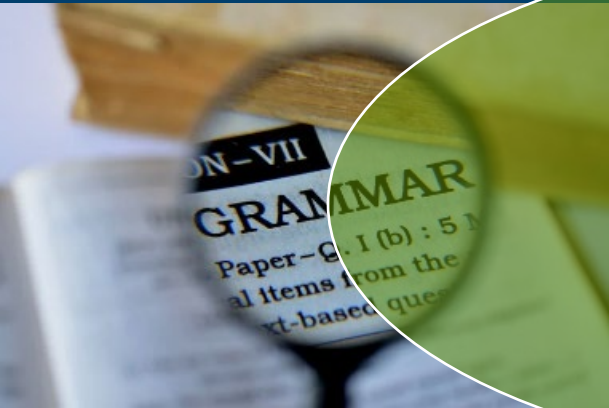
e.g., Chow et al., 2021; Kleemans et al., 2018;
Viesel-Nordmeyer et al., 2019; 2021; Wimmer et al., 2024

Problem outline

rules?
regularities?

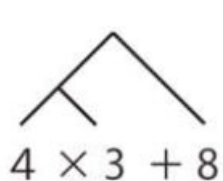
Grammar

Arithmetic



between (impaired) processing

e.g.,



e.g., Chow et al., 2021; Kleemans et al., 2018;
Viesel-Nordmeyer et al., 2019; 2021; Wimmer et al., 2024

Problem outline

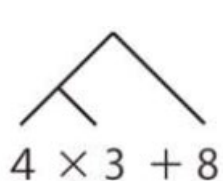
rules?
regularities?

Grammar

Arithmetic

between (impaired) pro

e.g.,

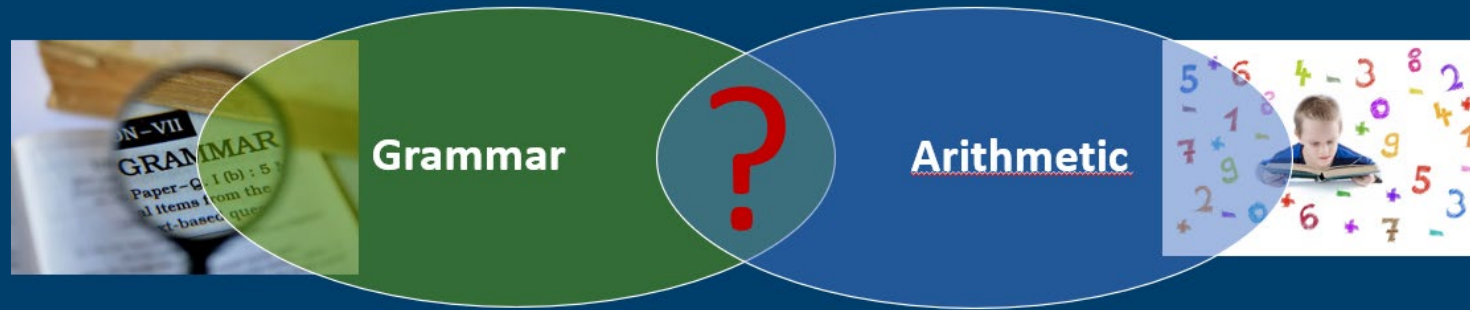


e.g.,

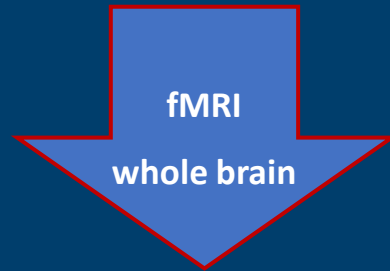
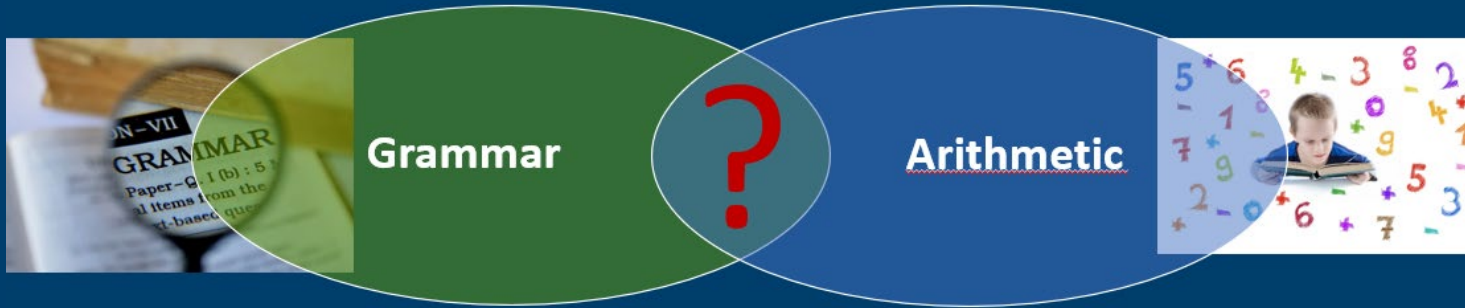
- prepositions
- comparatives
- superlatives

e.g., Chow et al., 2021; Kleemans et al., 2018;
Viesel-Nordmeyer et al., 2019; 2021; Wimmer et al., 2024

Method



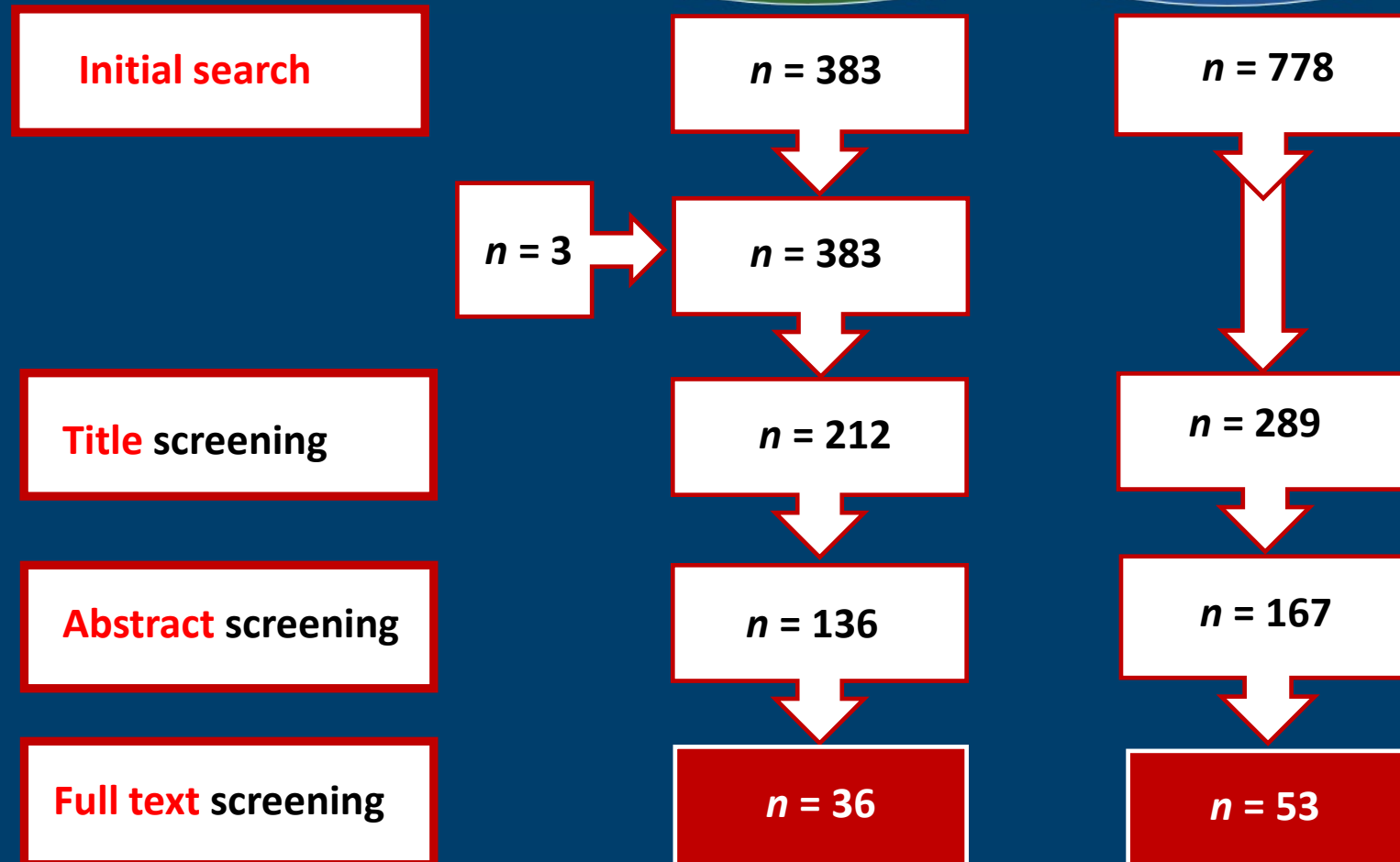
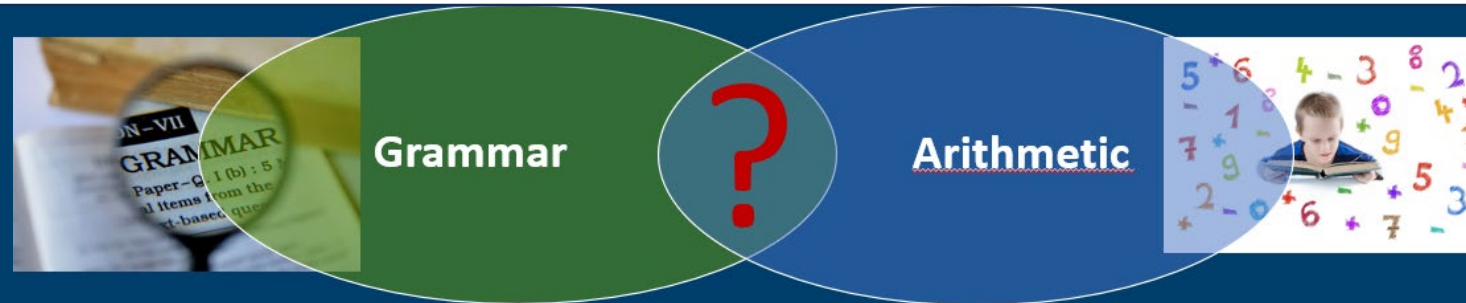
Method



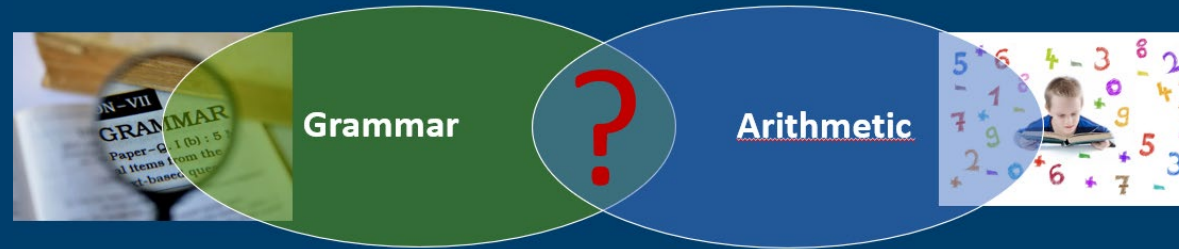
ALE
Meta-Analysis

e.g., Eickhoff et al., 2012

Method



Method

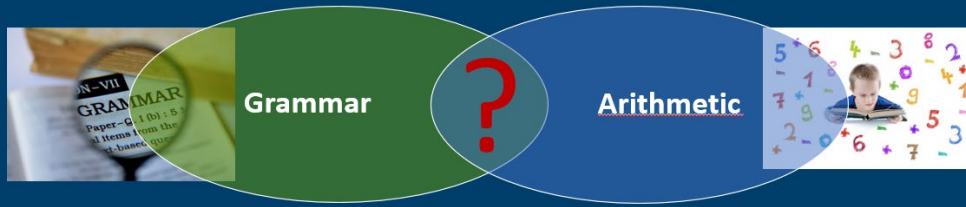


	Studies	Foci	Participants
Arithmetic	53	1049	1358
Grammar	36	393	653
pooled	89	1442	2011



	Studies	Foci	Participants
Arithmetic	13	14	356
Grammar	8	10	141
pooled	21	24	497

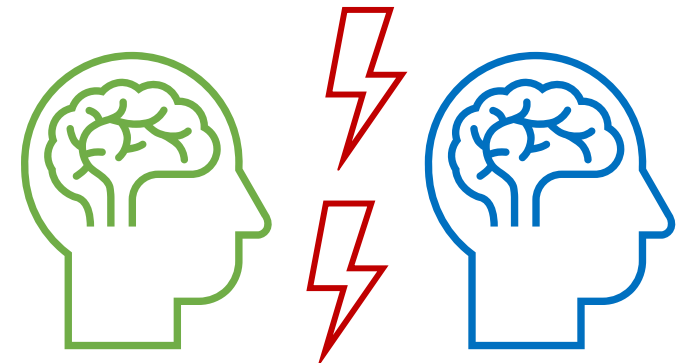
Results



Overlapping brain areas



Different brain areas



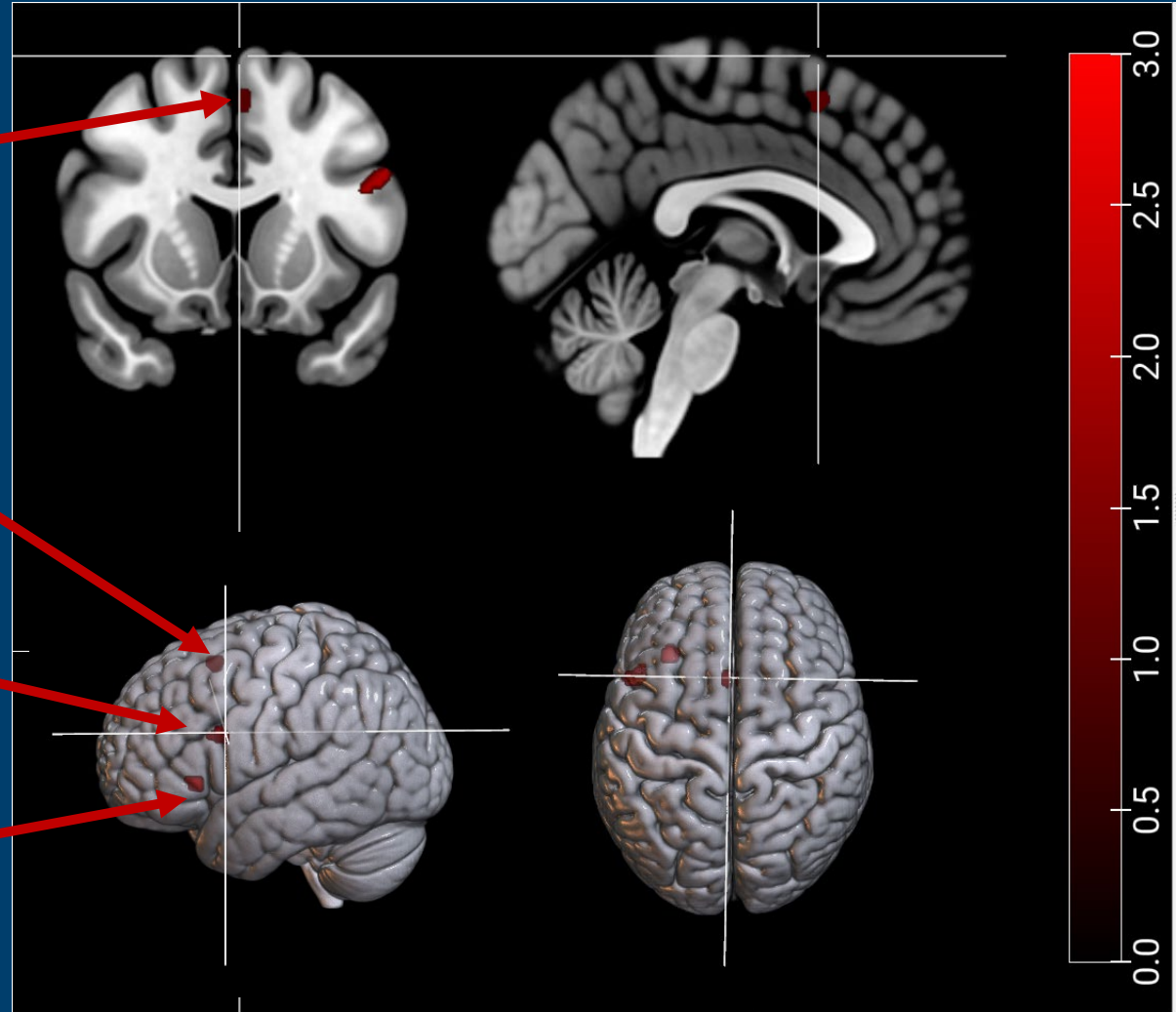


Results: Overlap between grammar and arithmetic processing

1. Left Supplementary Motor Area (BA6)

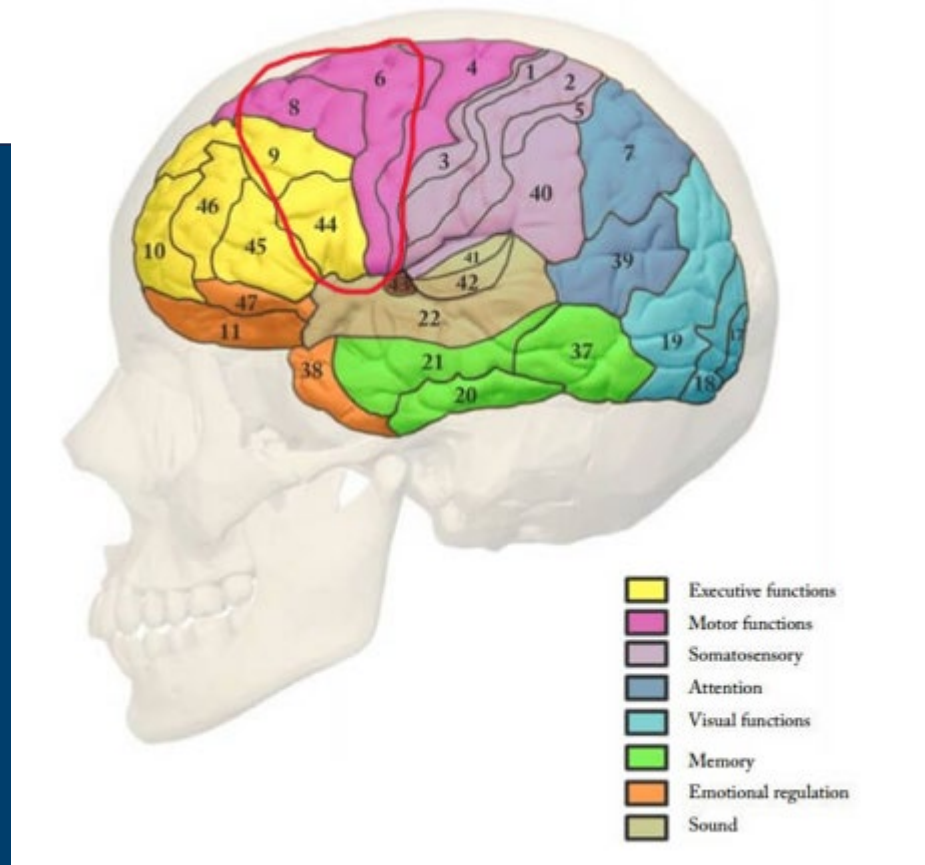
2. Left Dorsal Inferior Frontal Gyrus (BA9)

3. Left Insula (BA13)



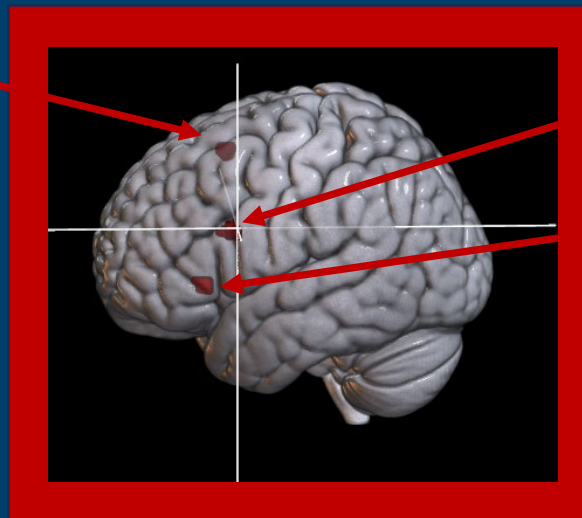
Notes. Conjunction analysis of arithmetic and grammar processing including 21 studies (Arithmetic: N = 13; Grammar: N = 8); Voxel-level FWE of 0.05, 1000 Permutations, and 200mm³ volume

Results



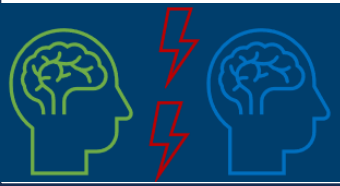
Left SMA

Grammar
&
Arithmetic



Left IFG

Left Insula



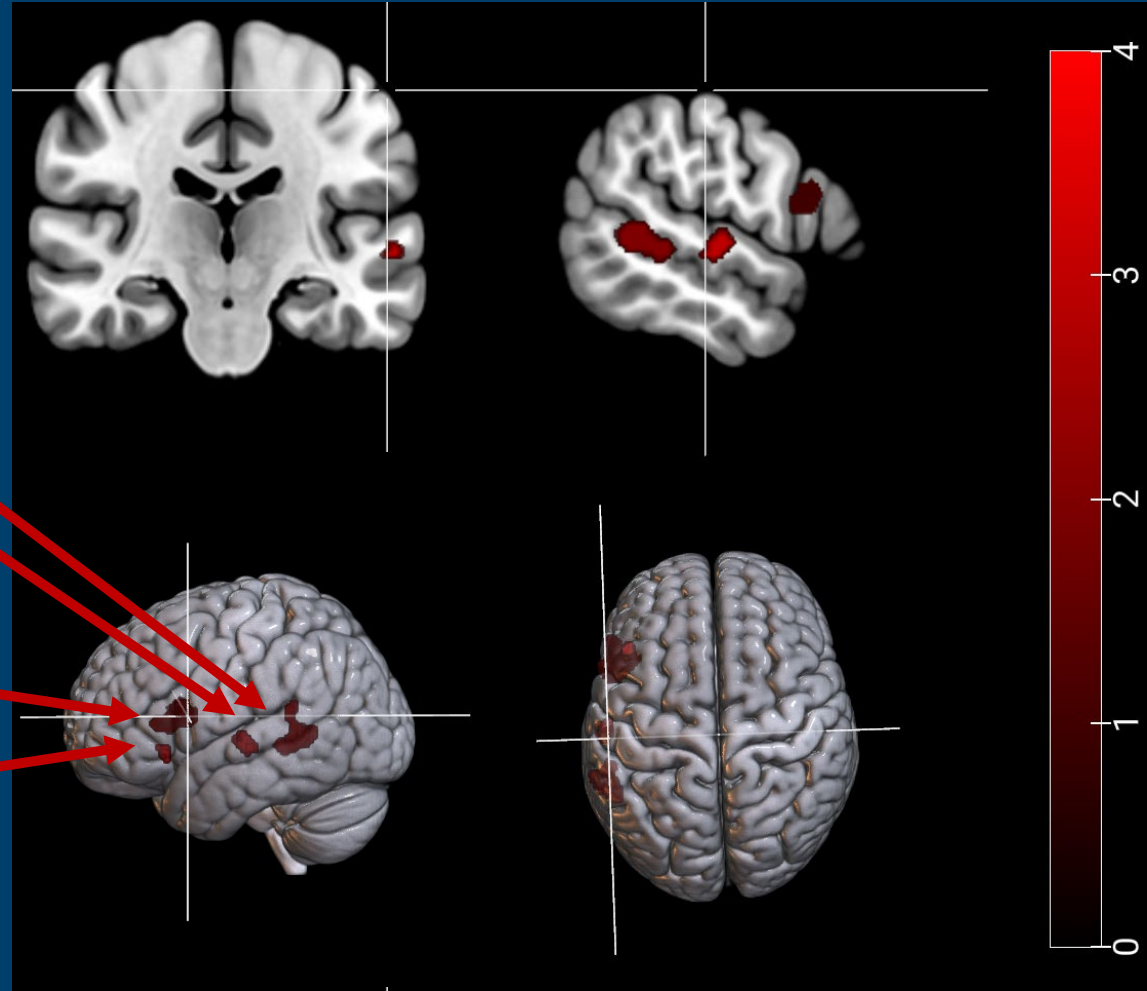
Results: Grammar processing vs. Arithmetic processing

2. Left Middle/Superior Temporal Gyrus (BA22,BA21)

3. Left Superior Temporal Gyrus (BA22)

1. Left Inferior Frontal Gyrus (BA44,BA45)

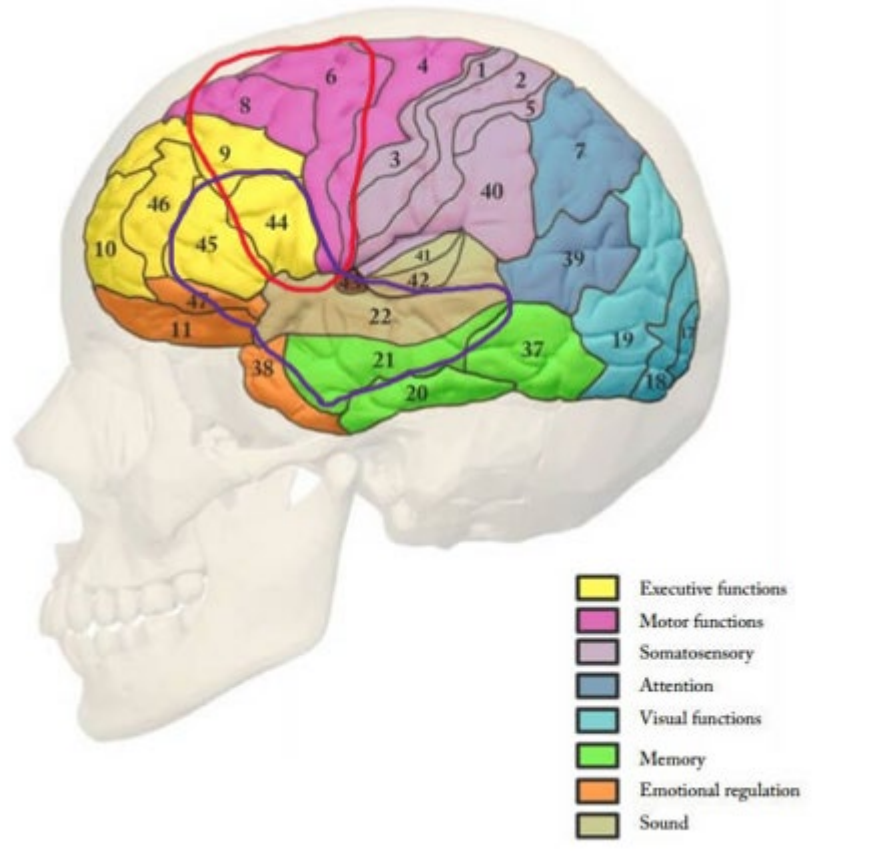
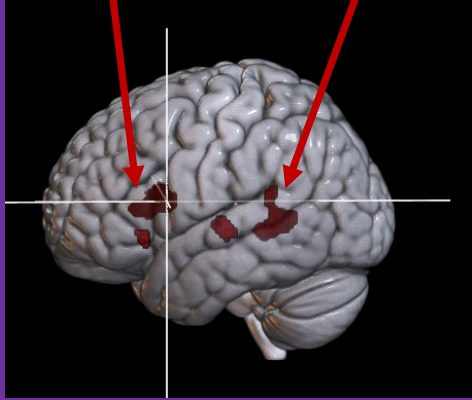
4. Left Inferior Frontal Gyrus (BA47)



Results

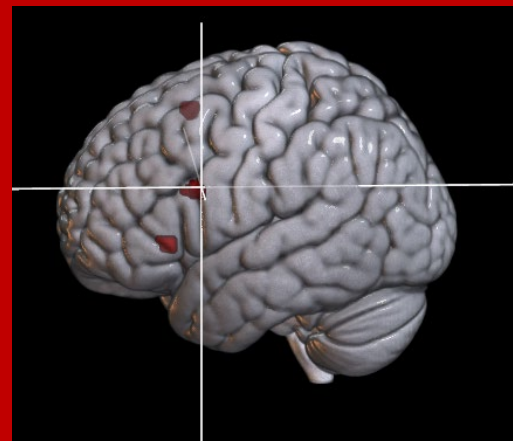
Left IFG

Left MTG



Grammar vs. Arithmetic

Grammar
&
Arithmetic

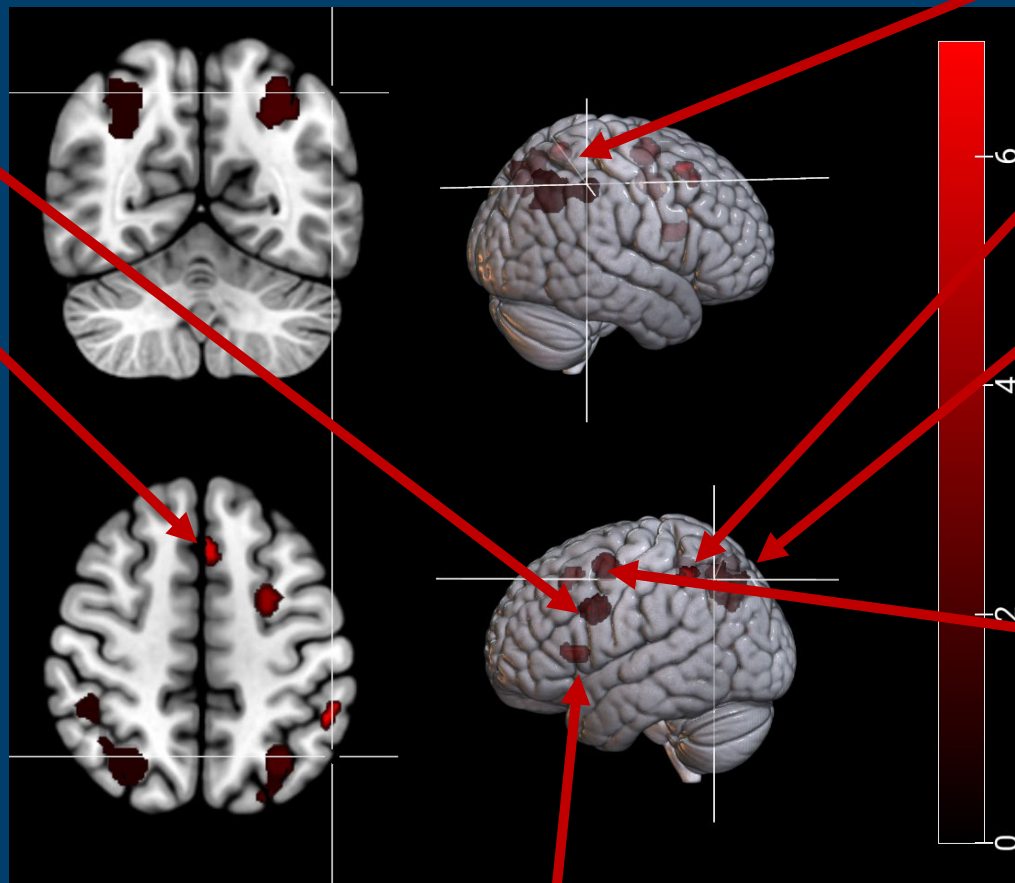




Results: Arithmetic processing vs. Grammar processing

3. Left Dorsal Inferior Frontal Gyrus/
Precentral Gyrus
(BA6; BA9)

6. Left Supplementary Motor Area (BA6)



1. Right IPS (BA7; BA40)

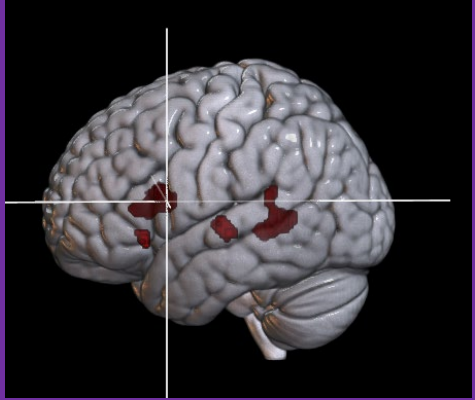
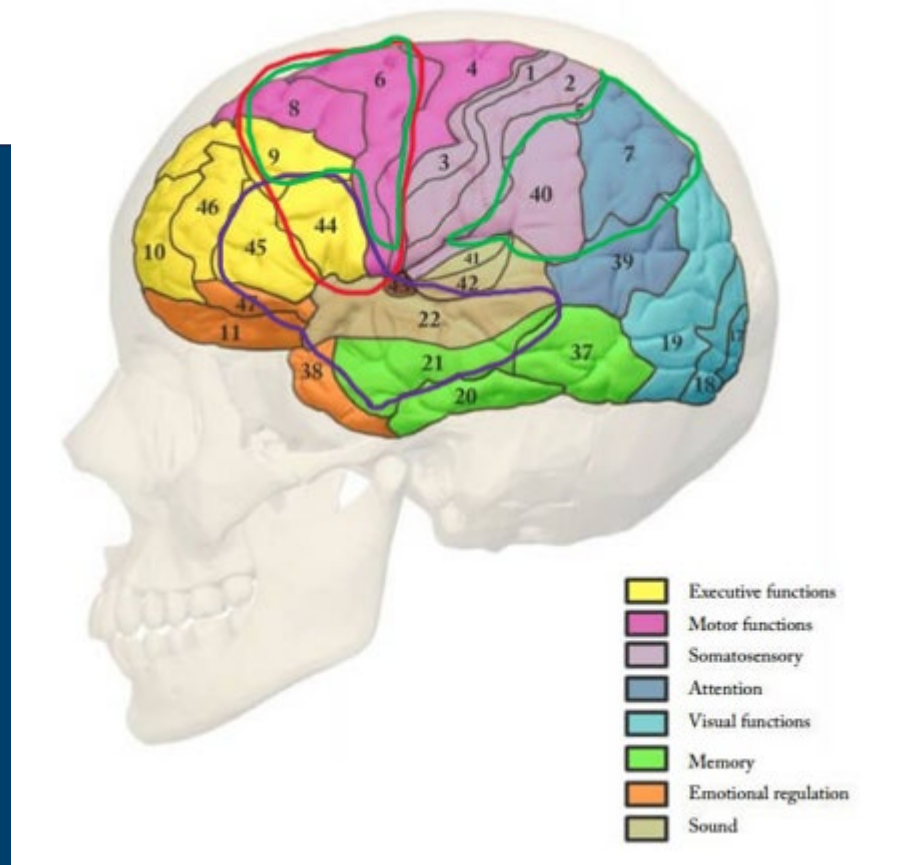
7. Left IPS (BA6; BA40)

2. Left IPS (BA7; BA31)

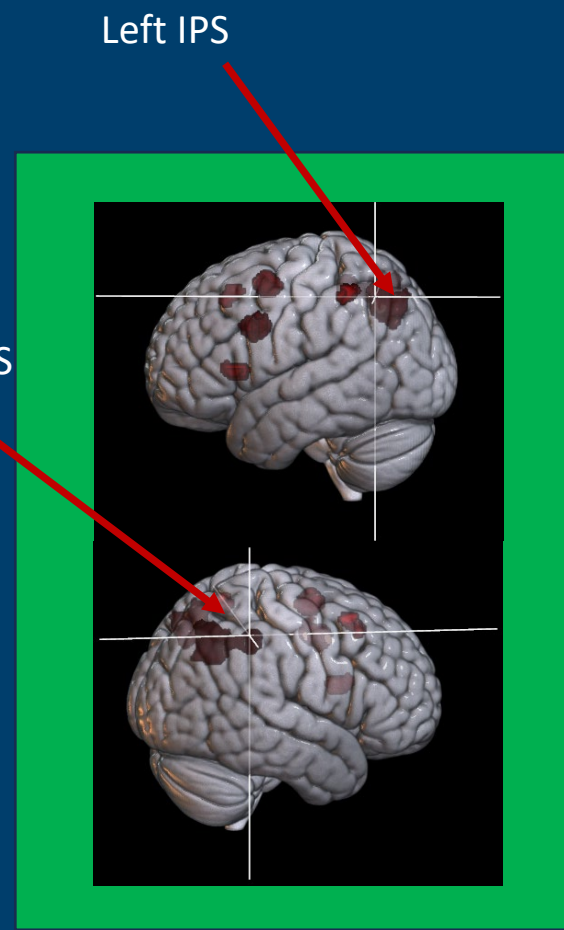
4. Left Middle Frontal Gyrus
(BA6)

5. Left Insula (BA13)

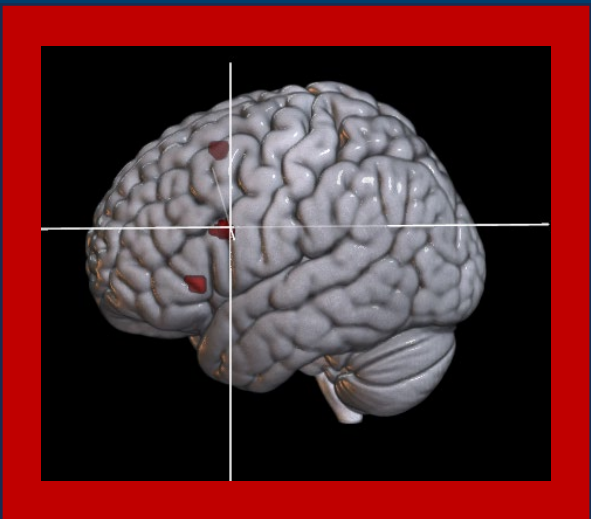
Results



Grammar vs. Arithmetic



Arithmetic vs. Grammar



Grammar & Arithmetic

Discussion – Overlap between grammar and arithmetic

Overlap

- **Multiple demand network** (e.g., review: Fedorenko et al., 2024)
- **Executive demand** (e.g., meta-analysis: Nee et al., 2012)
- “hierarchical dependencies, regardless of modality and use”
(e.g., Fadiga et al., 2009)
- “grammar center” (Sakai et al., 2005)

+ evidence of **domain separate mechanisms** for arithmetic and grammar processing

Discussion – Overlap grammar and arithmetic

Overlap

→ **Multiple demand network** (e.g., review: Fedorenko et al., 2024)

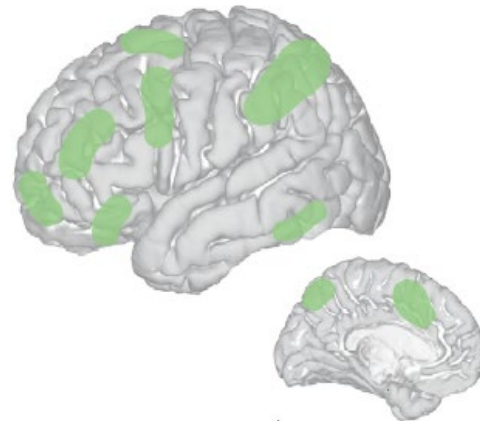
→ **Executive control network** (e.g., Nee et al., 2014)

→ “hierarchical dependencies”
(e.g., Fadiga et al., 2009)

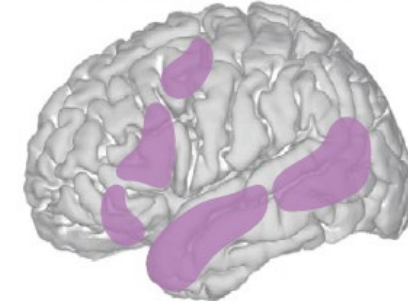
→ “grammar center” (Sakai et al., 2009)

+ evidence of **domain separate mechanisms**

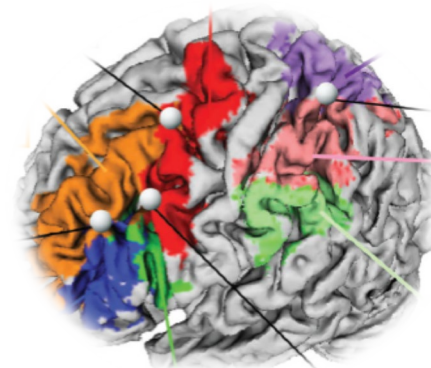
Multiple demand network



Language network



Review language network: Fedorenko et al., 2024



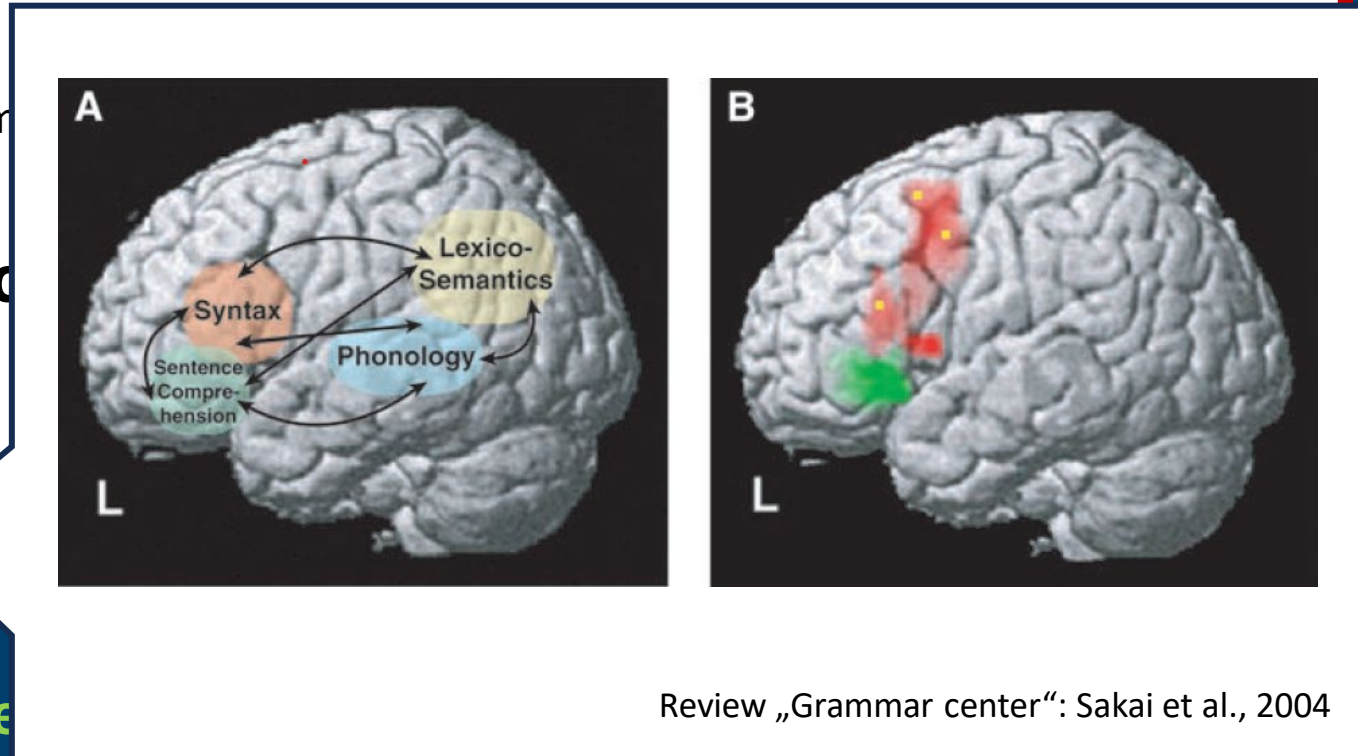
Meta-Analysis Executive Function: Nee et al., 2014

Discussion – Overlap grammar and arithmetic

Overlap

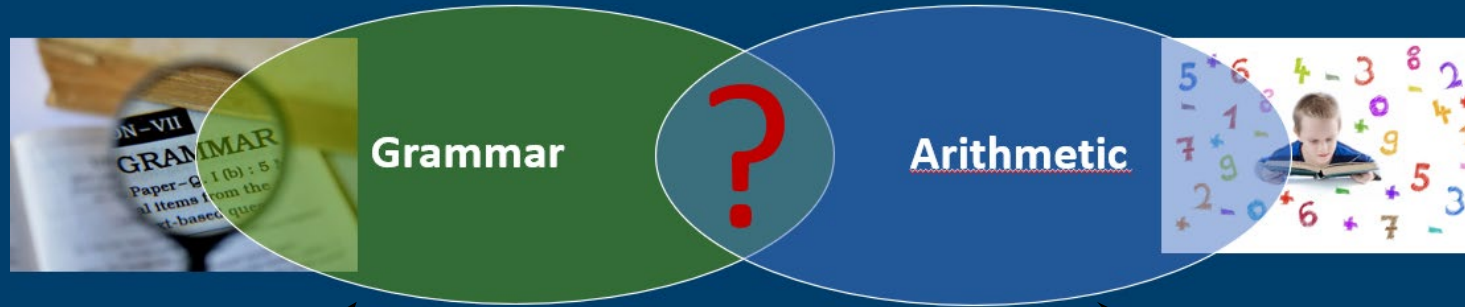
- **Multiple demand network** (e.g., review: Fedorenko et al., 2024)
- **Executive demand** (e.g., m)
- “hierarchical dependence” (e.g., Fadiga et al., 2009)
- “grammar center” (Sakai et al., 2004)

+ evidence of **domain separate me**



Review „Grammar center“: Sakai et al., 2004

Discussion – studies included in the converge analysis



4 of 8 studies
↓
contrasts
problem complexity



8 of 13 studies
↓
contrasts
problem complexity

Future Studies/Limitations

→ studies on separate **age groups**

contrasting

- ✓ **grammar** processing
- ✓ **arithmetic** processing
- ✓ **executive function** processing

→ in **large** problems **AND** **small** problems

→ **visual** testing **AND** **auditory** testing

Future Studies/Limitations

Does impairment in higher-order cognitive processing (e.g., executive function, working memory) underlie comorbid learning disorders?



e.g., Peng & Fuchs, 2014; Peng et al., 2020; Viesel-Nordmeyer et al., 2023

Thank you for your attention!



PhD Nurit
Viesel-Nordmeyer



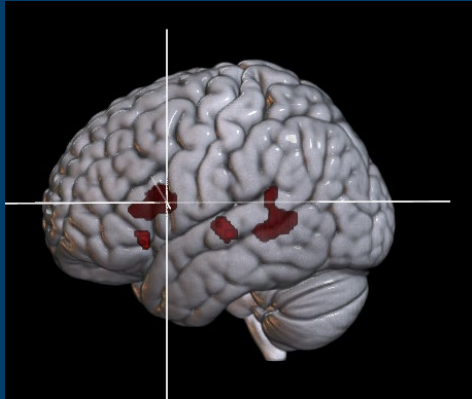
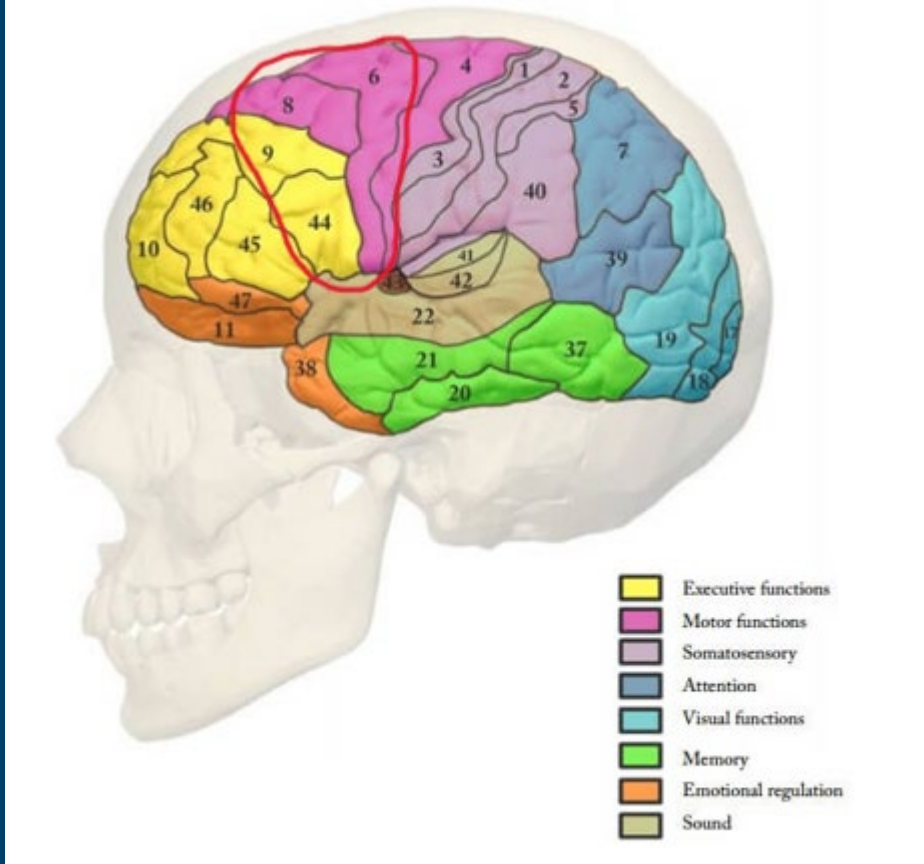
PhD Johannes
Ziegler



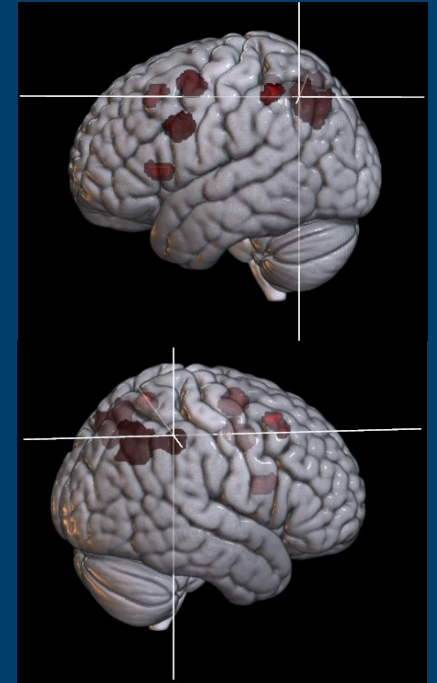
PhD Jérôme
Prado



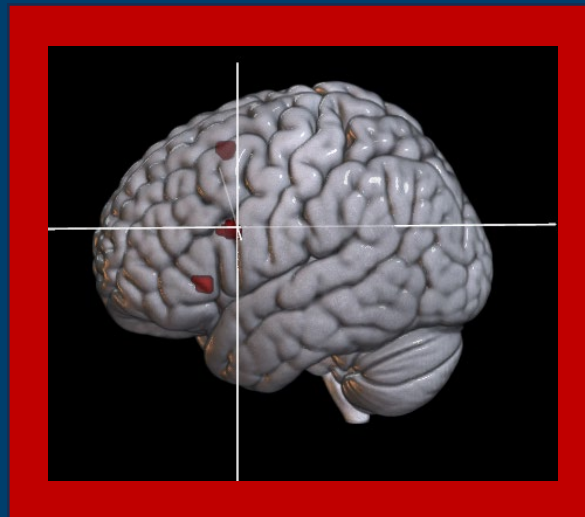
Results



Grammar vs. Arithmetic



Arithmetic vs. Grammar

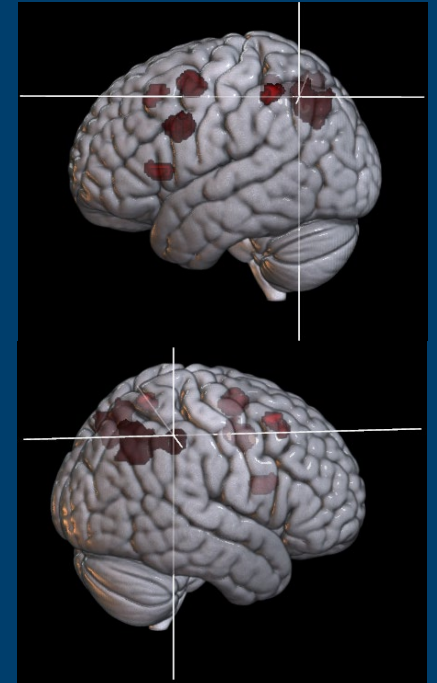
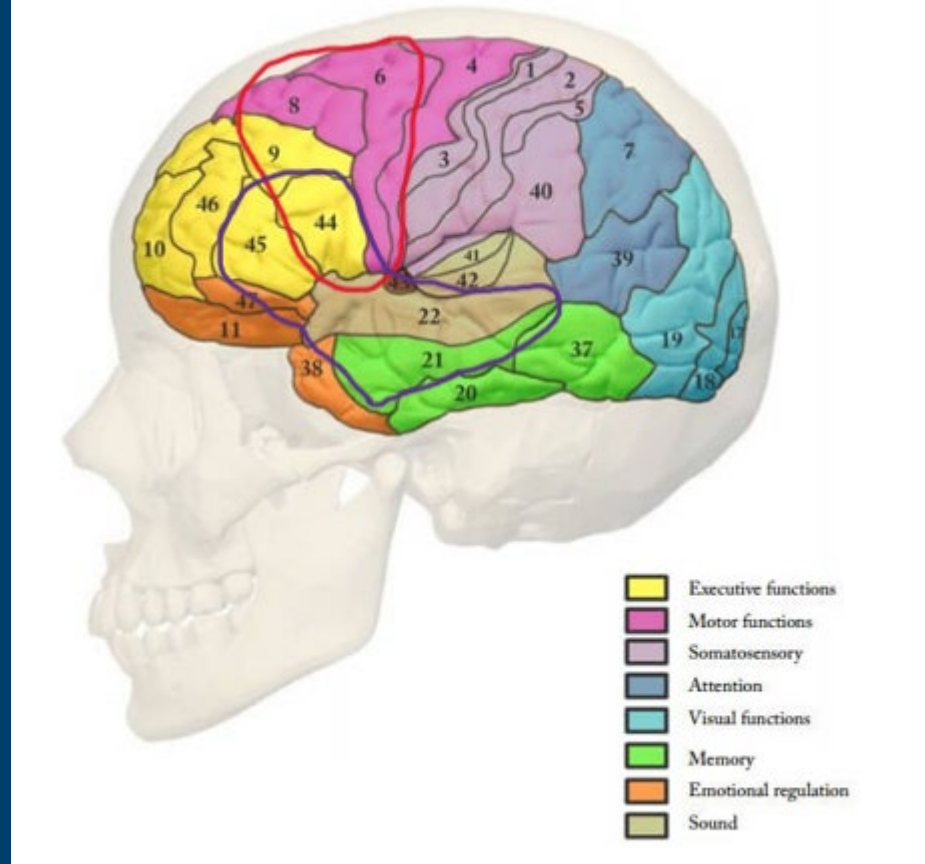
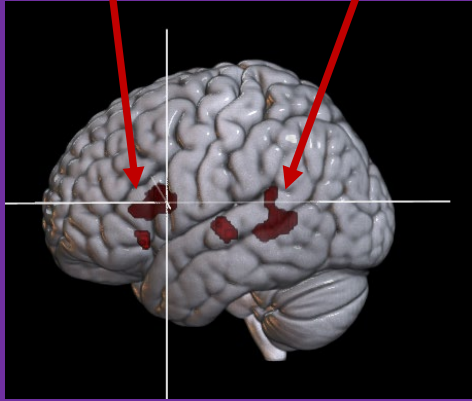


Grammar
&
Arithmetic

Results

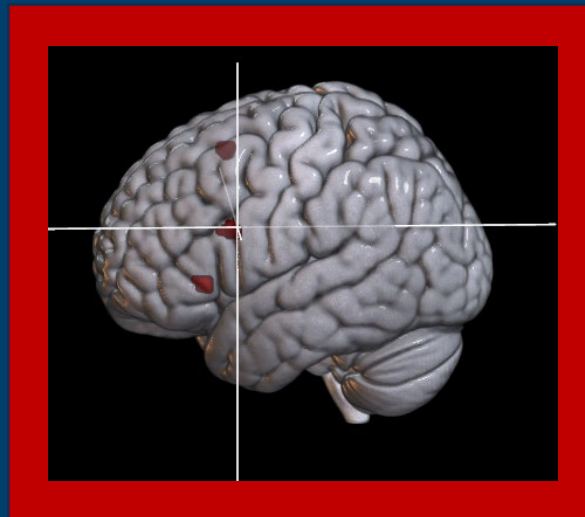
Left IFG

Left MTG



Grammar vs. Arithmetic

Grammar
&
Arithmetic



Arithmetic vs. Grammar