Semantic and syntactic predictions in reading aloud and visuo-motor statistical learning: an fMRI study in dyslexic students

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Réunion Mensuelle de Neuroimagerie

Marseille | 13.06.2024

Context effects are ubiquitous in reading

It was a windy day, the boy went outside to fly his ____

Ehrlich & Rayner (1981); Ferreira & Qiu (2021); Kutas & Federmeier (2011); Staub (2015)

verb pronoun **NOUN**

Fluent and skilled reading involves the ability to predict upcoming words using semantic and syntactic information (Chang et al., 2006; Pickering & Garrod, 2013).

1 Investigate whether we can identify different neural networks for semantic and syntactic predictive processes in reading.

Are good predictors good statistical learners ?

Recent research has shown a growing interest in the link between statistical learning (SL) and language …

Word segmentation (Swingley, 2005; Thiessen et al., 2013)
Phonological learning (Thiessen & Saffran, 2003, 2007)
Syntactic learning (Kidd & Arciuli, 2016)
Sentence comprehension (Misyak & Christiansen, 2012)
Reading ability (Arciuli & Simpson; Siegelman & Frost, 2015)
Dyslexia (Ozernov-Palchilk et al., 2023; Staels & Van Den Broeck, 2017)

… and studies have used SL paradigms to investigate whether SL abilities can explain inter-individual differences in reading abilities.

But inconsistent results have been found on the relation between SL and reading abilities.

(Boeve et al., 2023; Ren et al., 2023).

2 Does the ability to make predictions in the domain of language rely on the domain-general ability of extracting statistical regularities, i.e., statistical learning ?

What about university students with dyslexia ?

Dyslexia and (predictive) reading

➡ High-level linguistic information to compensate low-level orthographic and phonological deficits in adults with dyslexia.

(Cavalli et al., 2016 ; Stanovich, 1980)

➡ The facilitatory effect of word predictability has been shown to vary with reading ability.

(Weiss et al., 2023)

Dyslexia and statistical learning

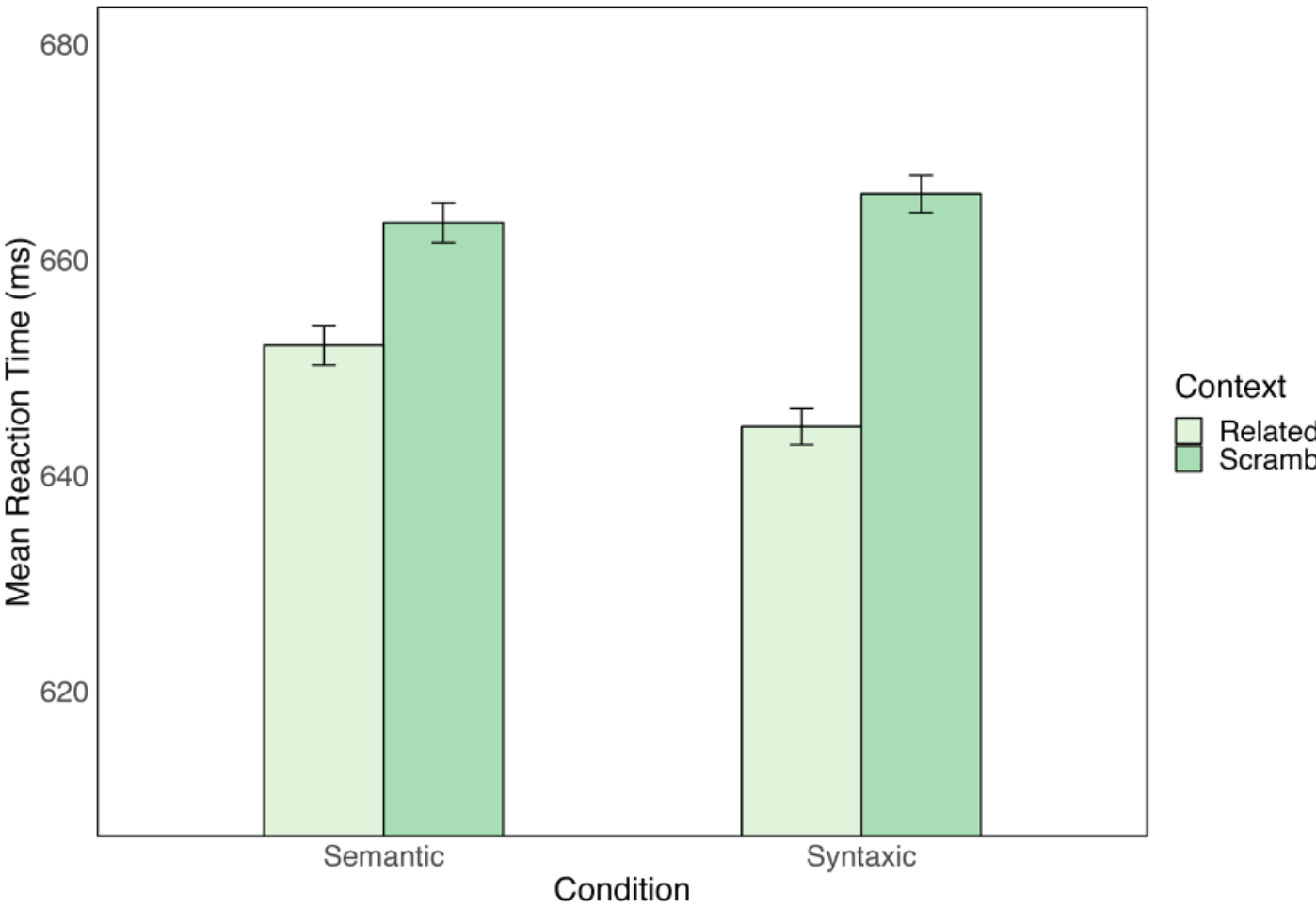Inconsistent results have been found !

(Ozernov-Palchilk et al., 2023; Staels & Van Den Broeck, 2017)

3 Investigate whether there are group differences in predictive reading and in statistical learning between university students with and without dyslexia.

Objectives & Hypothesis

Semantic vs syntactic prediction

1. Behavioral

Gavard & Ziegler (2022, 2024).

2. Neural

Inferior frontal gyrus[5]
Pars orbitalis (BA47)

Frontal lobe

Prefrontal regions[13]

Inferior frontal regions[125]

Temporal regions[125]
Superior and midlle

Temporal lobe

Anterior temporal lobe[15]

Precentral gyrus[34]

Precuneus[34]

Parietal lobe

Angular gyrus[14]

Occipital lobe

Occipital regions[4]

Anterior Insula[3]

Superior
Anterior ←→ Posterior
Inferior

[1]Semantic processing (*)
[2]Syntactic processing (**)
[3]Semantic prediction (Carter et al., 2019)
[4]Syntactic prediction (Carter et al., 2019)
[5]Word predictability (Bonhage et al., 2015; Schuster et al., 2020)

(*) Friederici, 2003, 2011 ; Kiehl et al., 2002 ; Kuperberg et al., 2000, 2008 ; Newman et al., 2001 ; Price, 2012 ; Zhu et al., 2009

(**) Bonhage et al., 2015 ; Henderson et al., 2016 ; Lopopolo et al., 2017 ; Schuster et al., 2016

Objectives & Hypothesis

| Semantic vs syntactic prediction | Predictive reading in dyslexia |
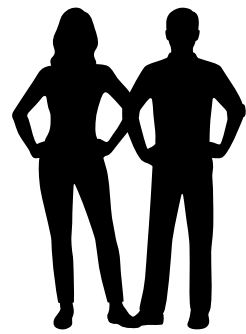
Dyslexic students ➜ Better predictors ?
Cavalli et al., 2016; Snowling, 2000; Stanovich, 1980

Objectives & Hypothesis

| Semantic vs syntactic prediction | Predictive reading in dyslexia | **Visuo-motor SL in dyslexia** |
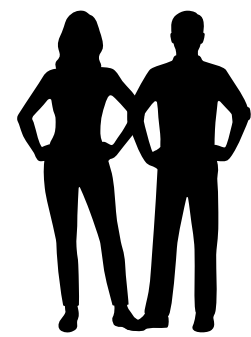
Dyslexic students ➔ Better predictors ?

Cavalli et al., 2016; Snowling, 2000; Stanovich, 1980

➔ Worse predictors ?

Lukasova et al., 2016; Ozernov-Palchik et al., 2023; Przekoracka-Krawczyk et al., 2017

Objectives & Hypothesis

| Semantic vs syntactic prediction | Predictive reading in dyslexia | Visuo-motor SL in dyslexia | Link between predictive reading and SL |
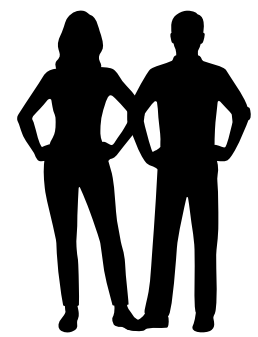
Dyslexic students → Better predictors ?
→ Worse predictors ?

1. Behavioral

Predictive reading

General reading abilities

SL abilities
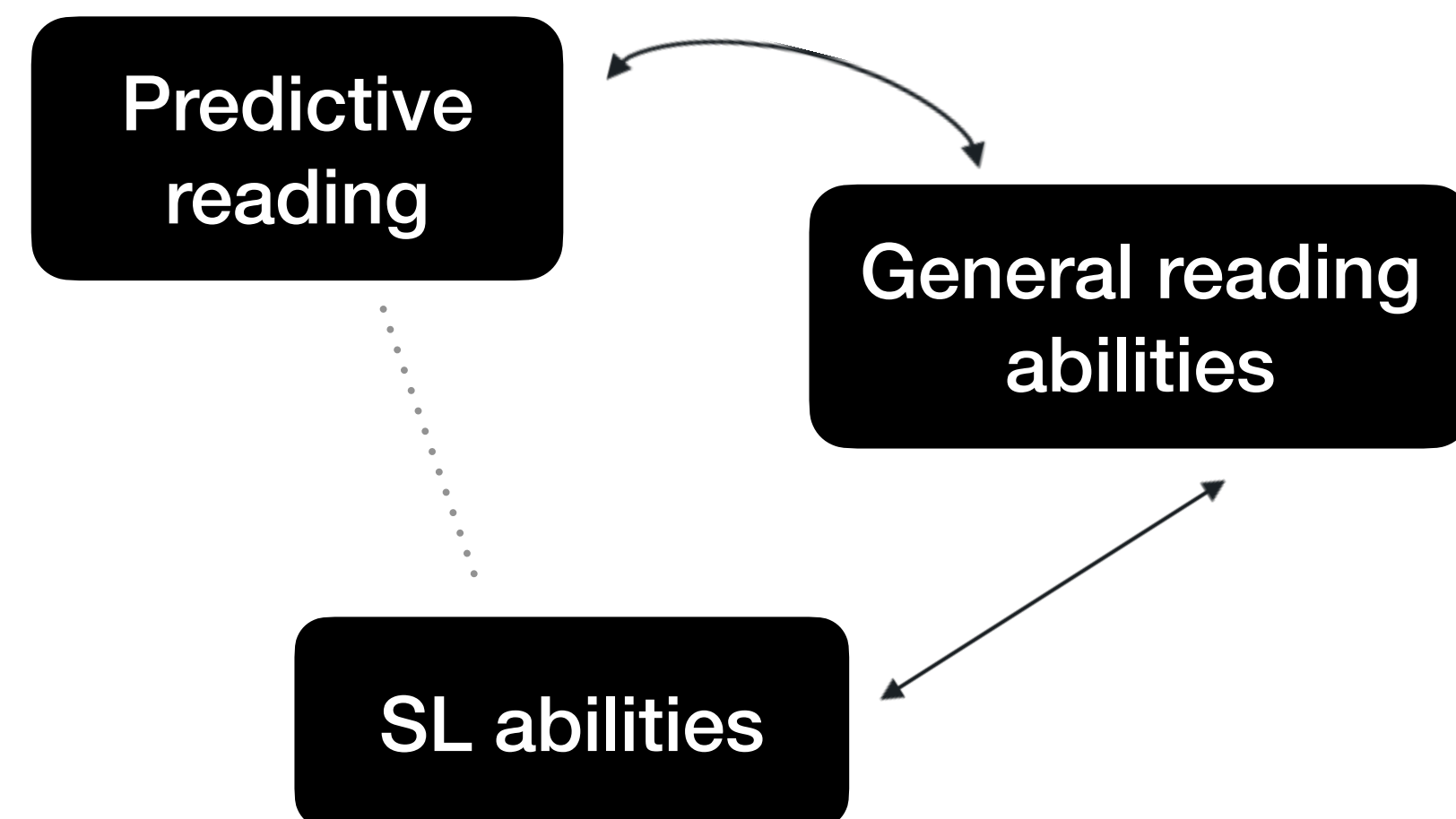
Gavard & Ziegler (2024). *Journal of Cognition.*

2. Neural ▶

Visuo-motor SL

Word reading

Both tasks

Left   Right
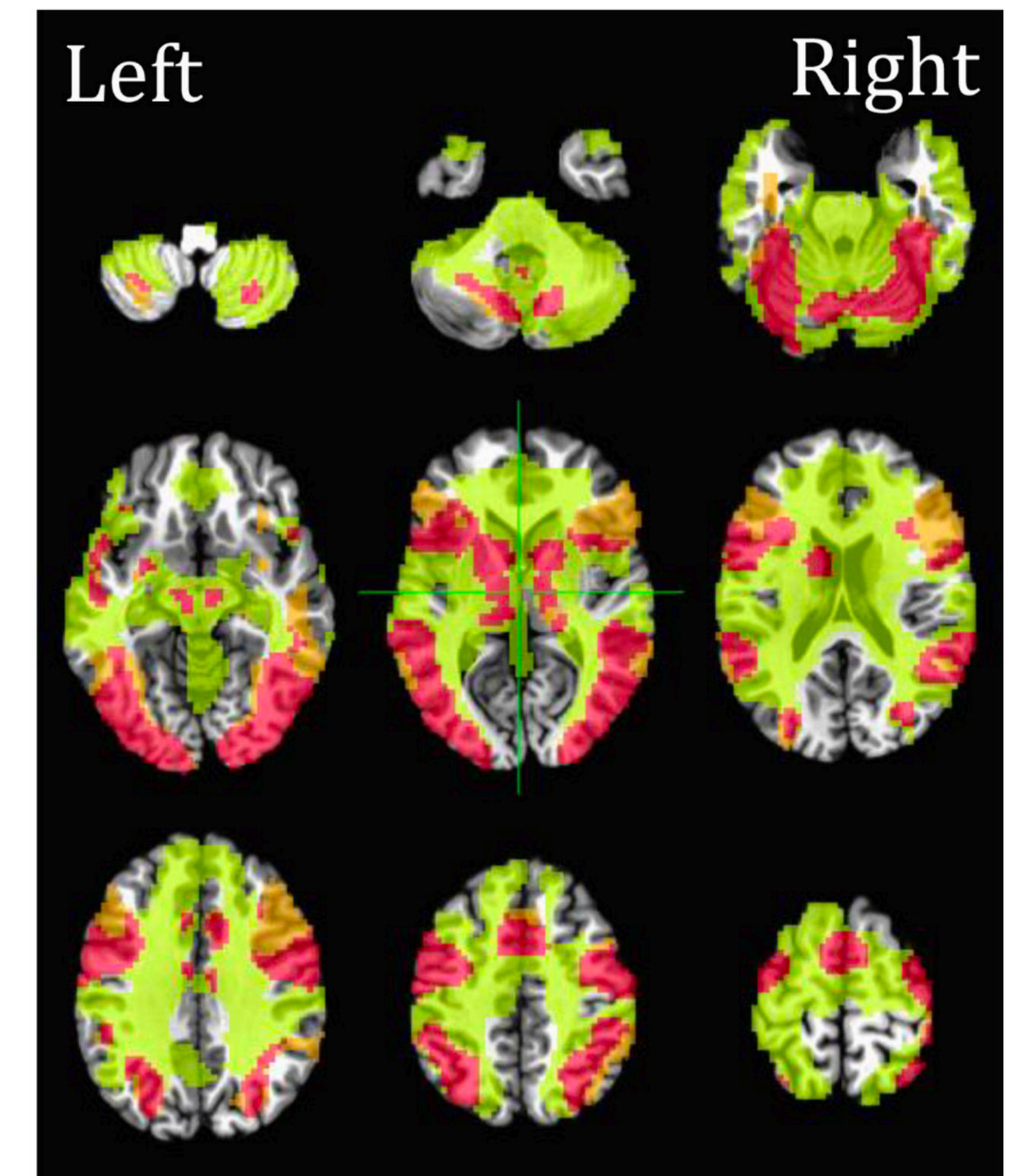
Hung et al. (2019). *Scientific Studies of Reading.*

The predictive reading task
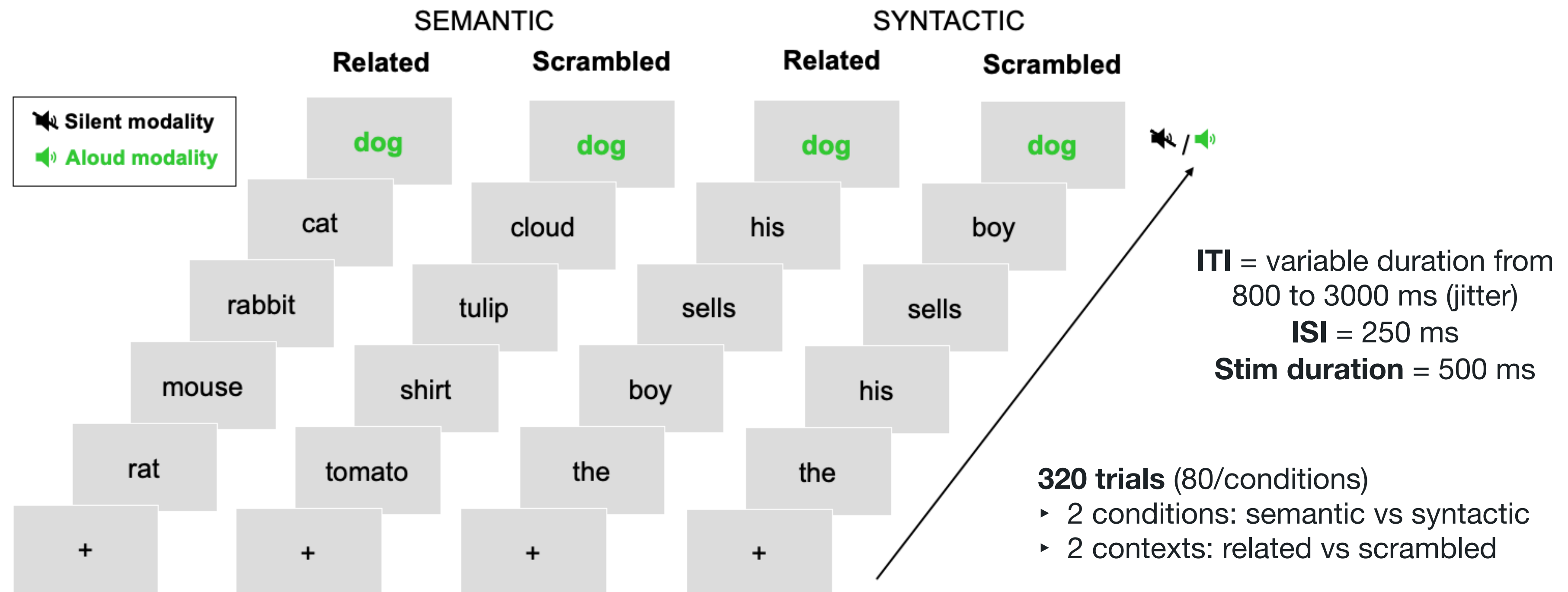
Gavard & Ziegler (2022). *Experimental Psychology.*

Instruction: participants had to read the words silently and read the green words aloud as quickly and accurately as possible.

The Serial Reaction Time task

Overall procedure
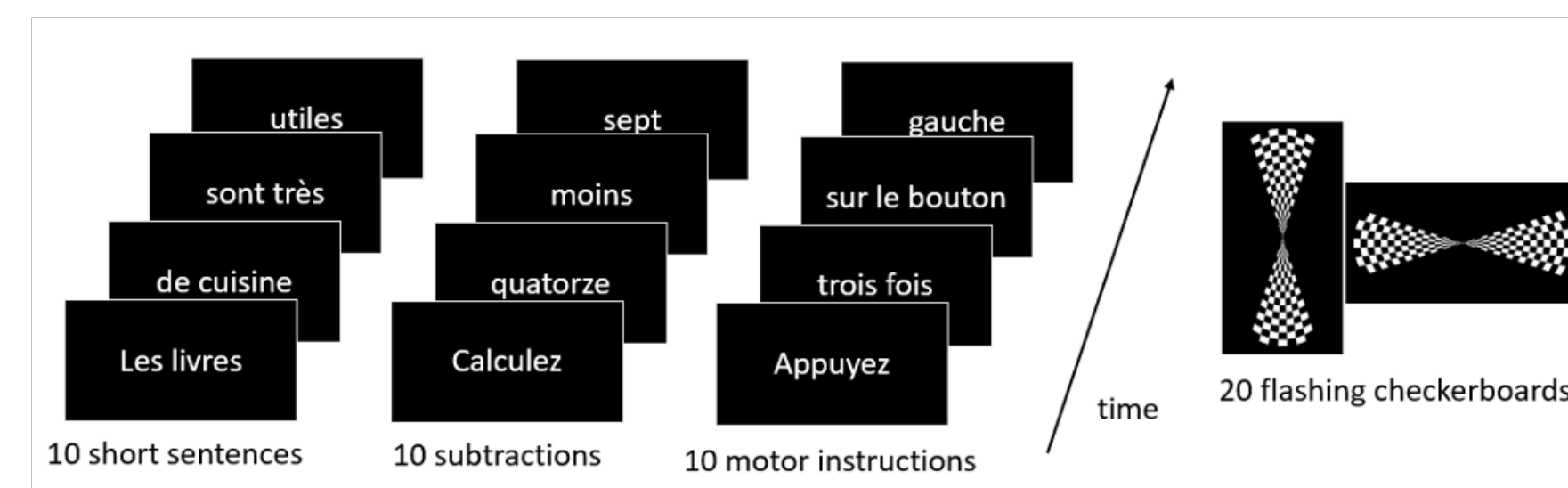

MRI Scanner 3T Tesla
Centre IRM-INT@CERIMED,
Marseille
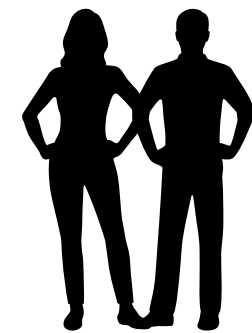
50 subjects: 25 typical readers & 25 dyslexic students

Total duration in the scanner: **63 min**
✳ T1 (anatomic MRI) + Fieldmaps ~ 5 min
✳ T2* : functional MRI for the predictive reading task ~ 25 min
✳ T2* : functional MRI for the serial reaction time task ~ 17 min
✳ Localizer task (Pinel et al., 2007) ~ 5 min
✳ Diffusion-weighted magnetic resonance imaging (DWI or DW-MRI) ~ 11 min

Subject installation → T1 + Fieldmaps → T2* Predictive Reading task (5 runs) → T2* SRT task (3 runs) → Localizer (1 run) → DWI

Pinel et al. 2007

Semantic and syntactic prediction in reading

Objective 1

Behavioral results

A. Semantic condition

B. Syntactic condition
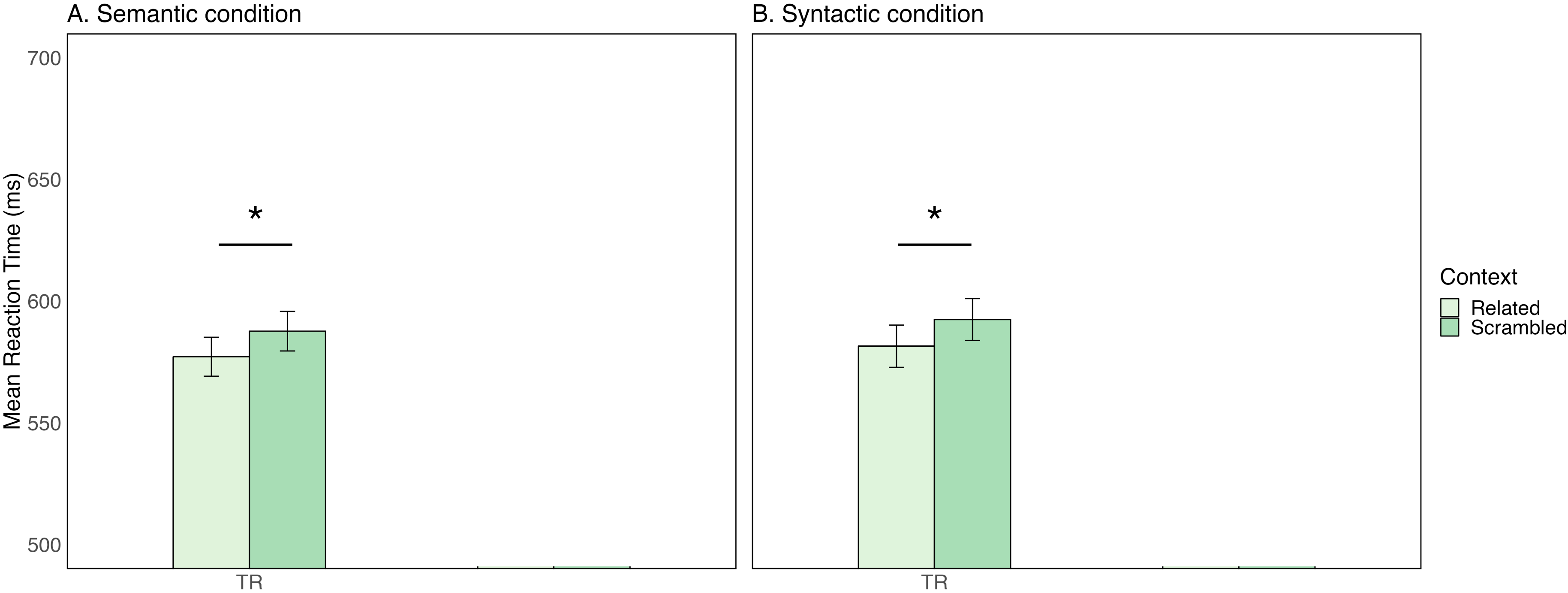
Semantic and syntactic prediction in reading **in dyslexia**

Objective 1 | **Objective 2**

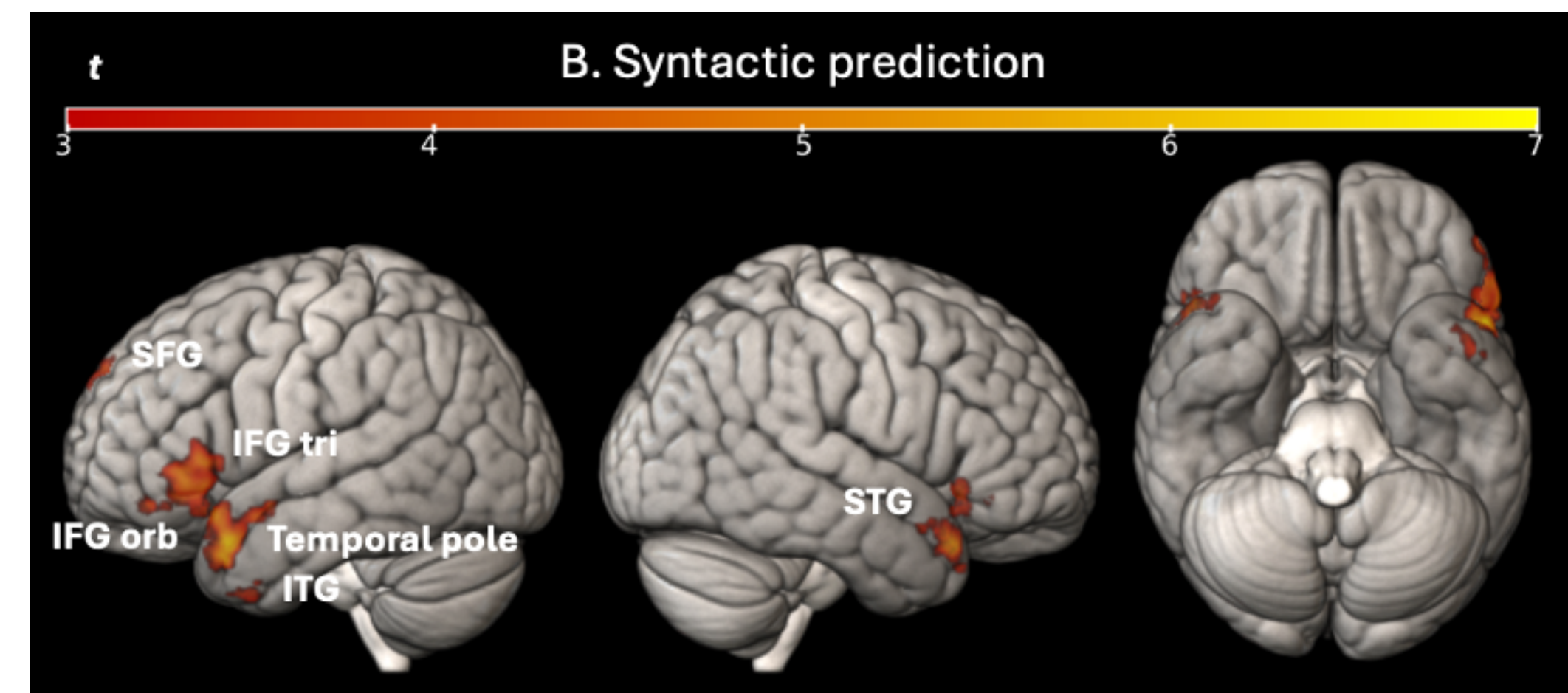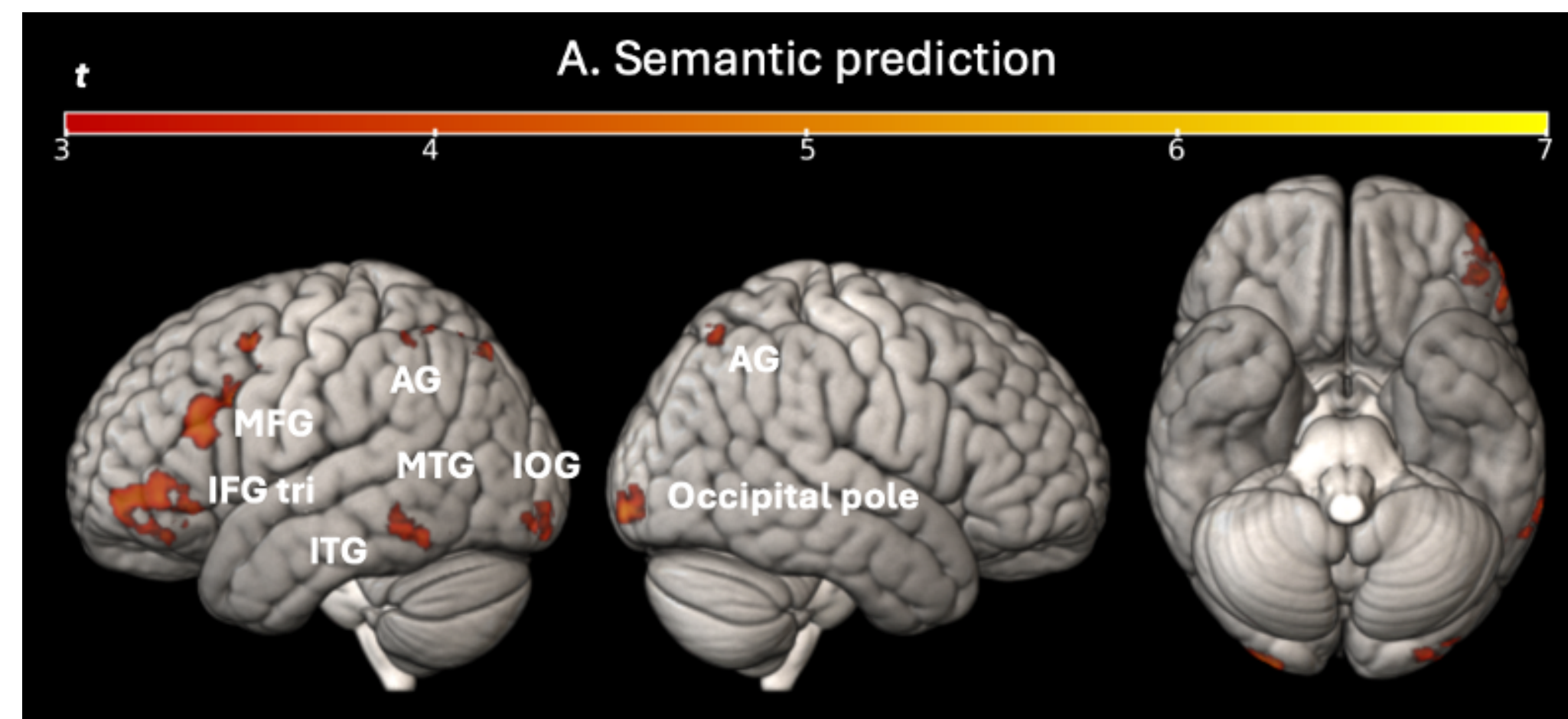Behavioral results

A. Semantic condition

B. Syntactic condition
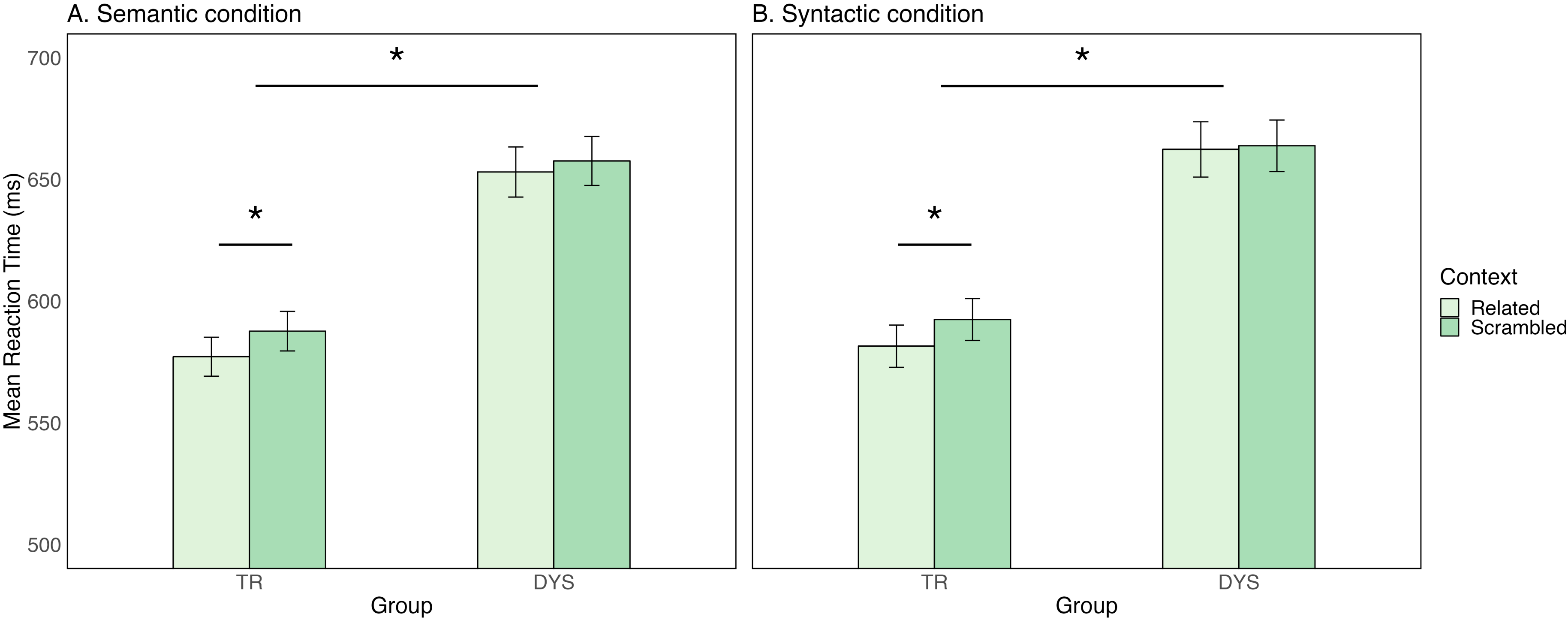
Semantic and syntactic prediction in reading

Objective 1

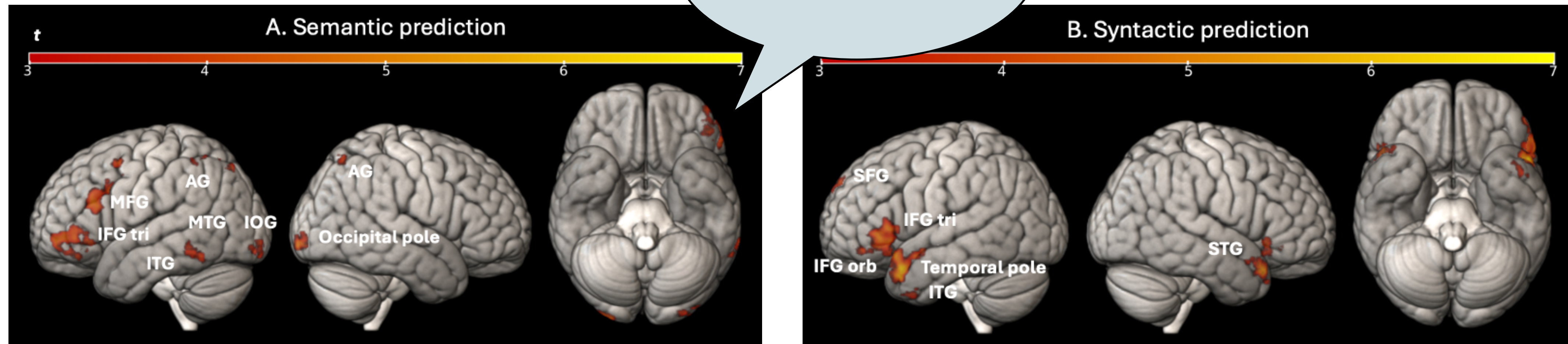Whole brain results
one-sample t-test

+ R frontal operculum

Semantic and syntactic prediction in reading **in dyslexia**

Objective 1   **Objective 2**

Whole brain results
two-sample t-test

**NO GROUP
DIFFERENCES**

A. Semantic prediction

B. Syntactic prediction

Semantic and syntactic prediction in reading

Objective 1

*PSC ~ prediction * group * reading fluency*
+ (1+ prediction|subject)

Region of interest results

Hypothesis
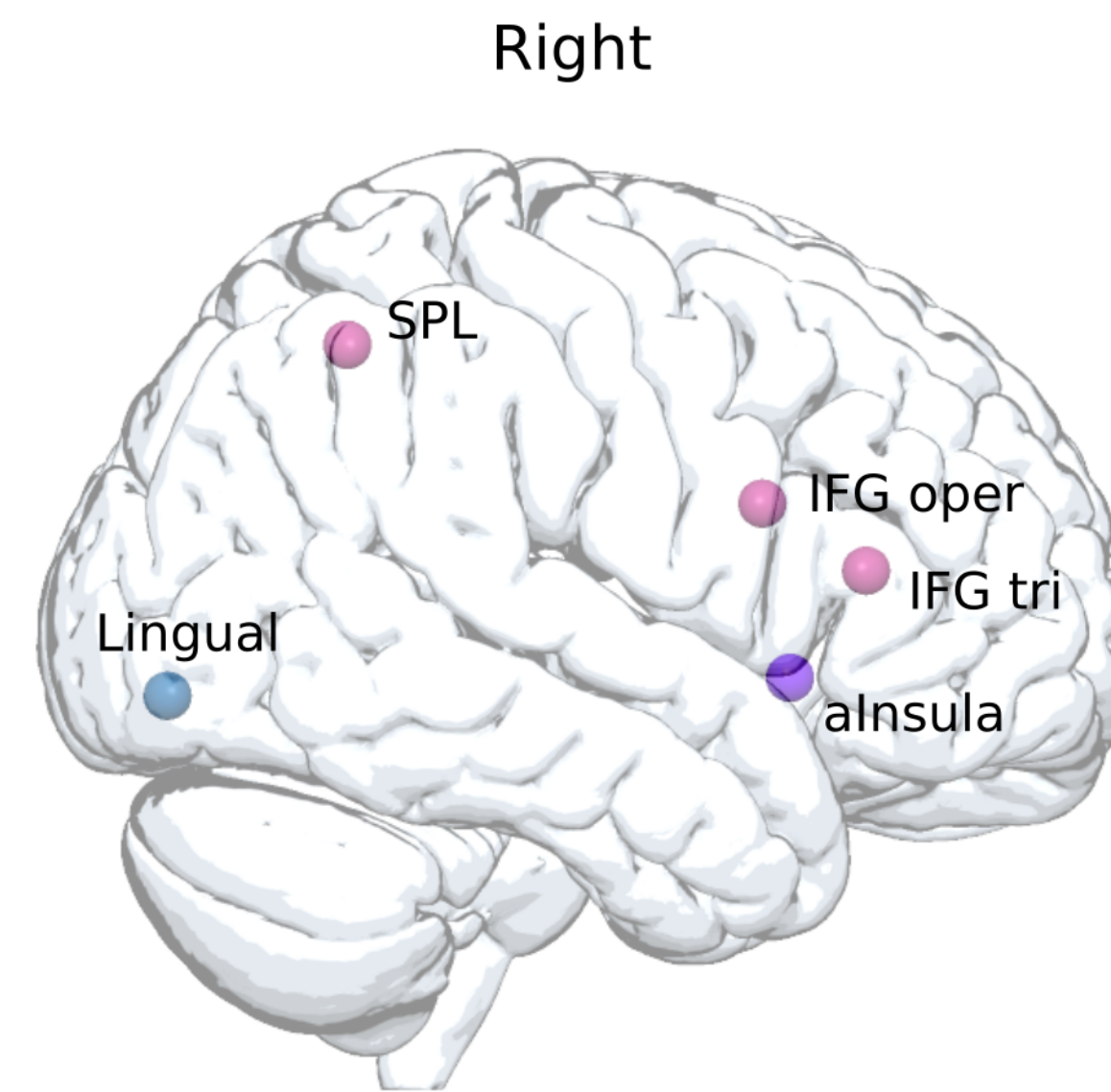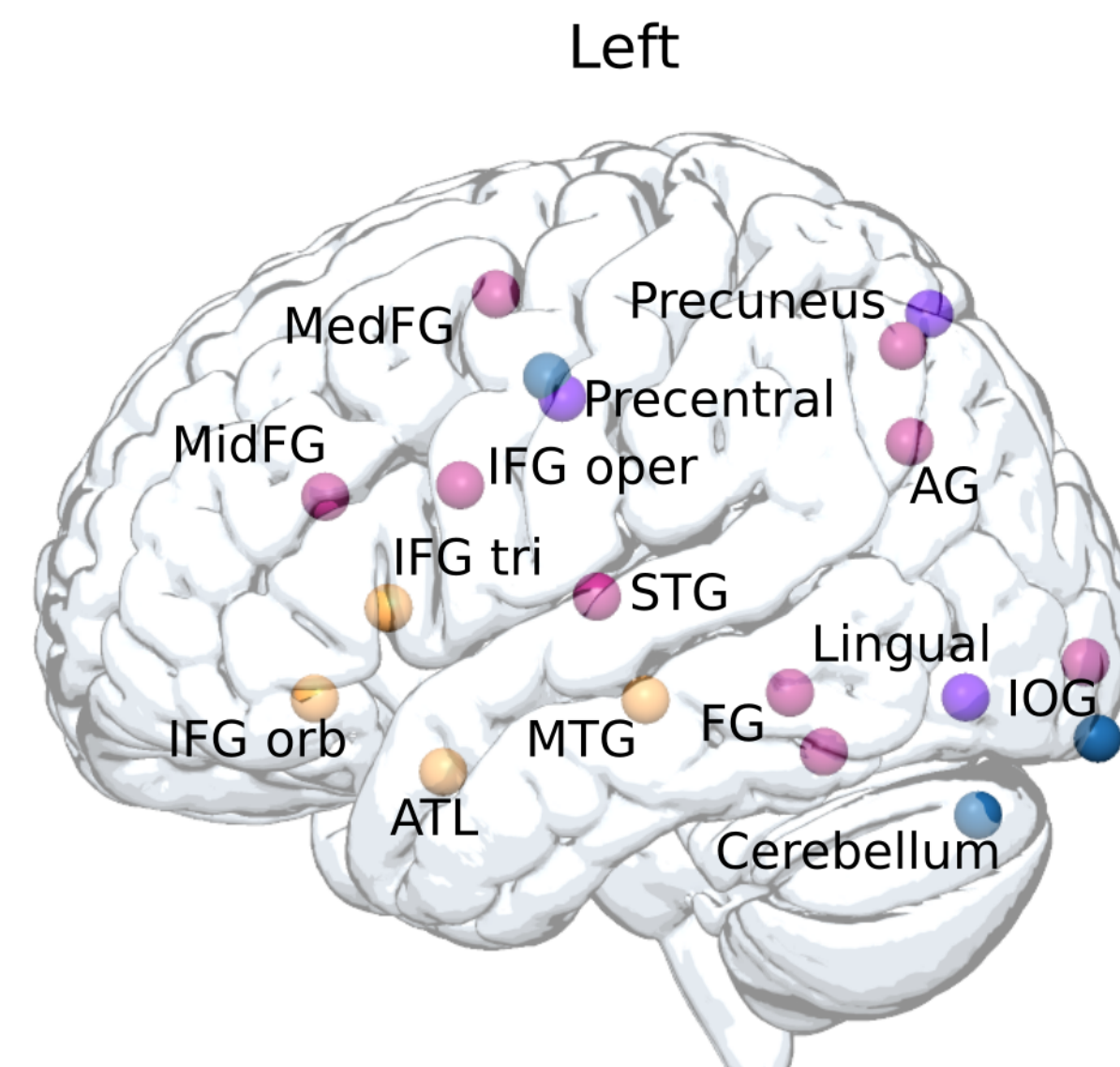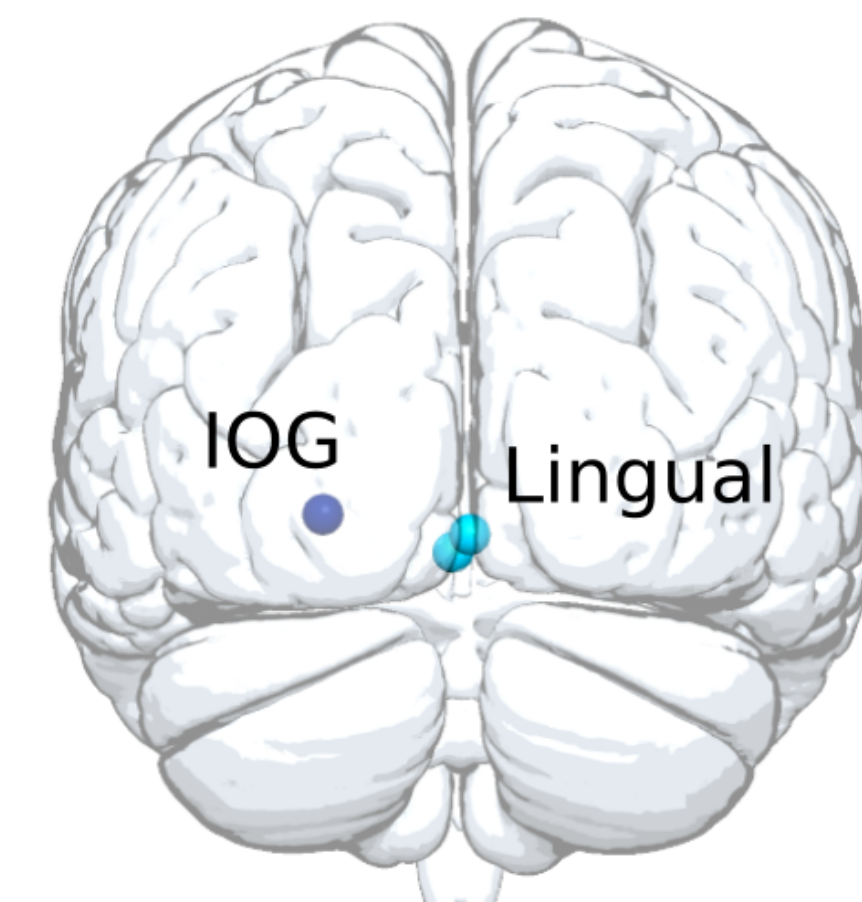
Carter et al. (2019) ; **Murphy et al. (2019)** ; **Schuster et al. (2020)**

A. Prediction

● PSem
● PSyn

Semantic and syntactic prediction in reading in dyslexia

Objective 1   **Objective 2**
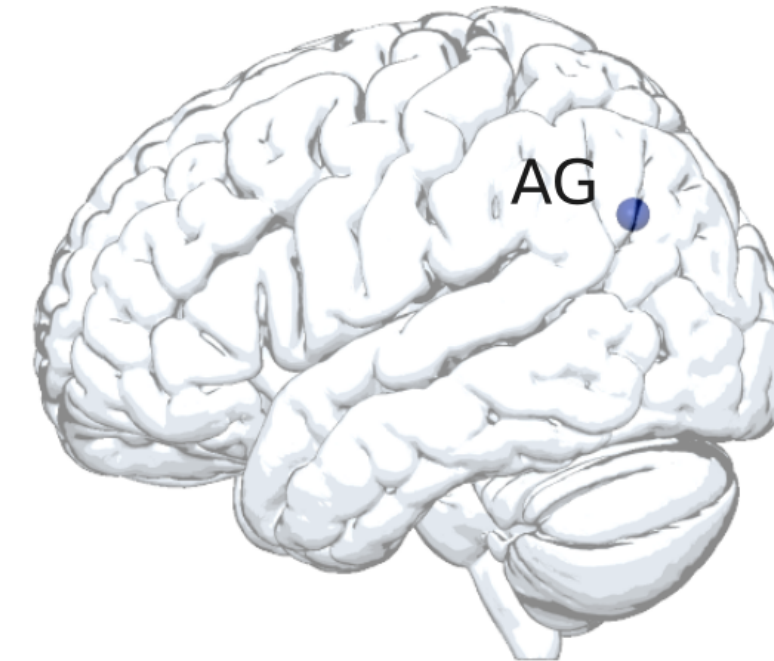
Region of interest results

A. Prediction
- PSem
- PSyn
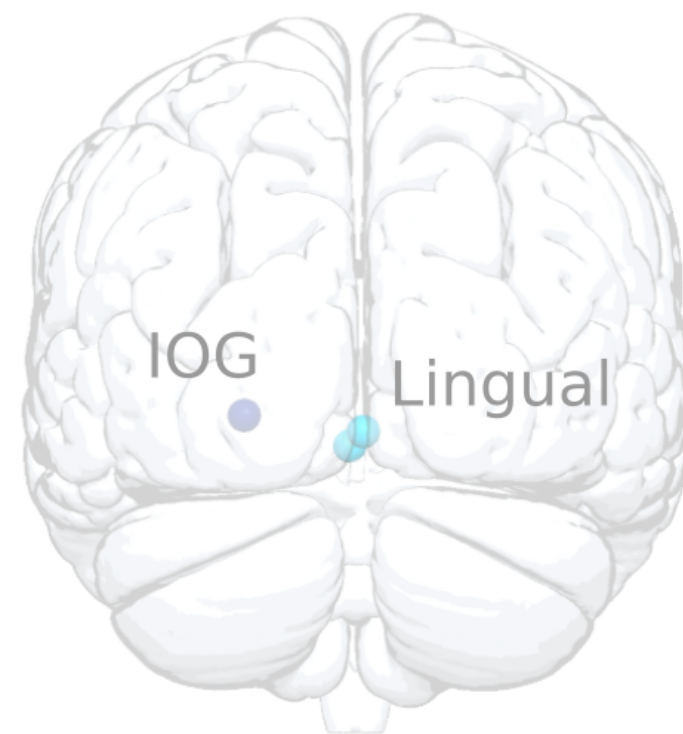
B. Group
- TR
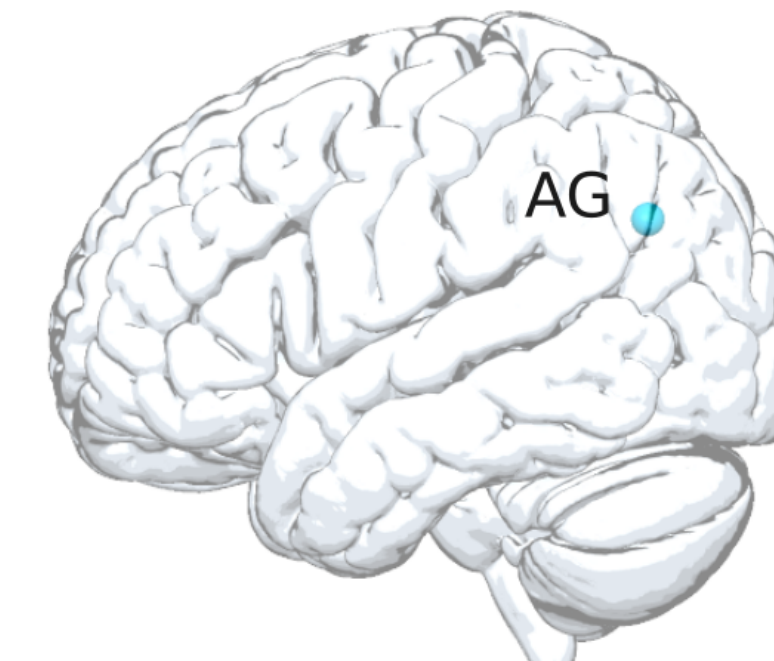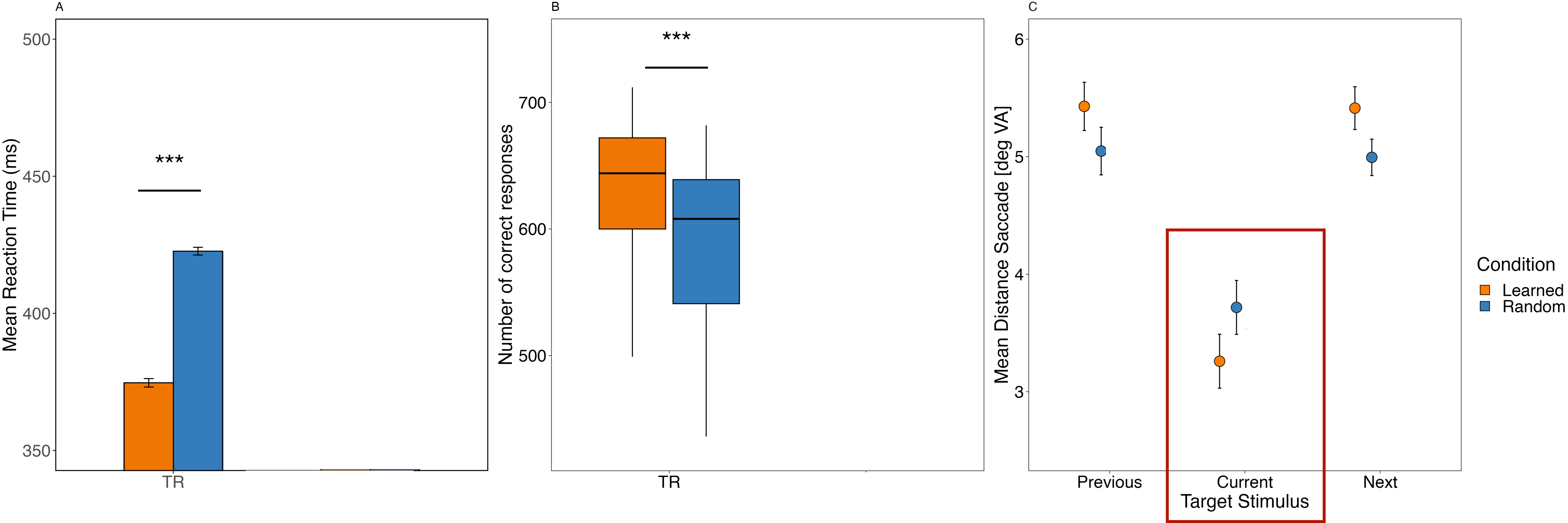- DYS
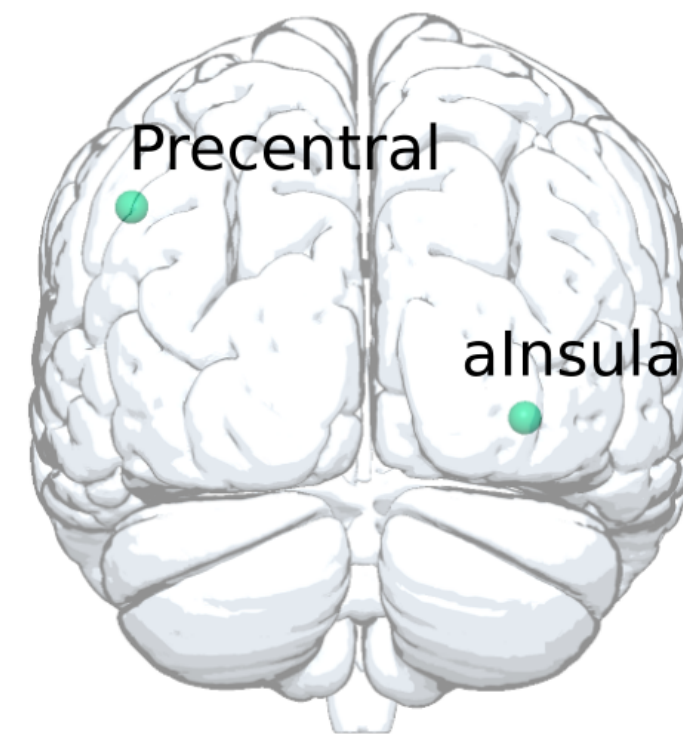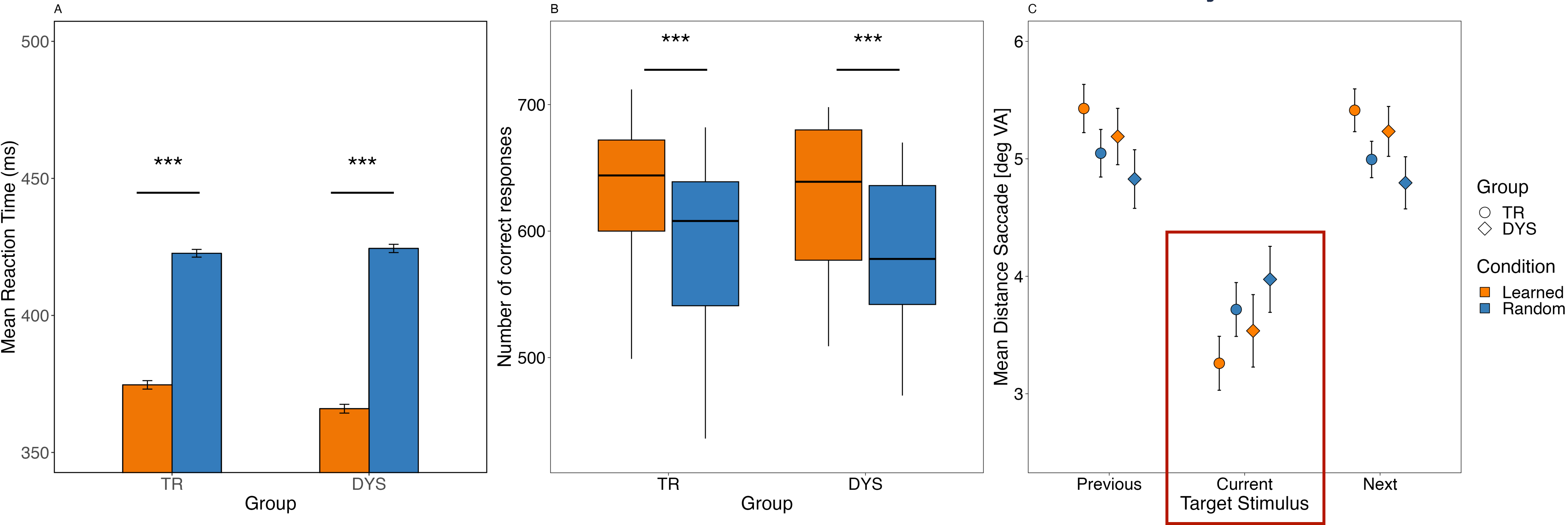
C. Prediction x Group

Visuo-motor statistical learning

Objective 1   Objective 2   **Objective 3**

<u>Behavioral results</u>

Visuo-motor statistical learning **in dyslexia**

Objective 1 → Objective 2 → **Objective 3**

Behavioral results

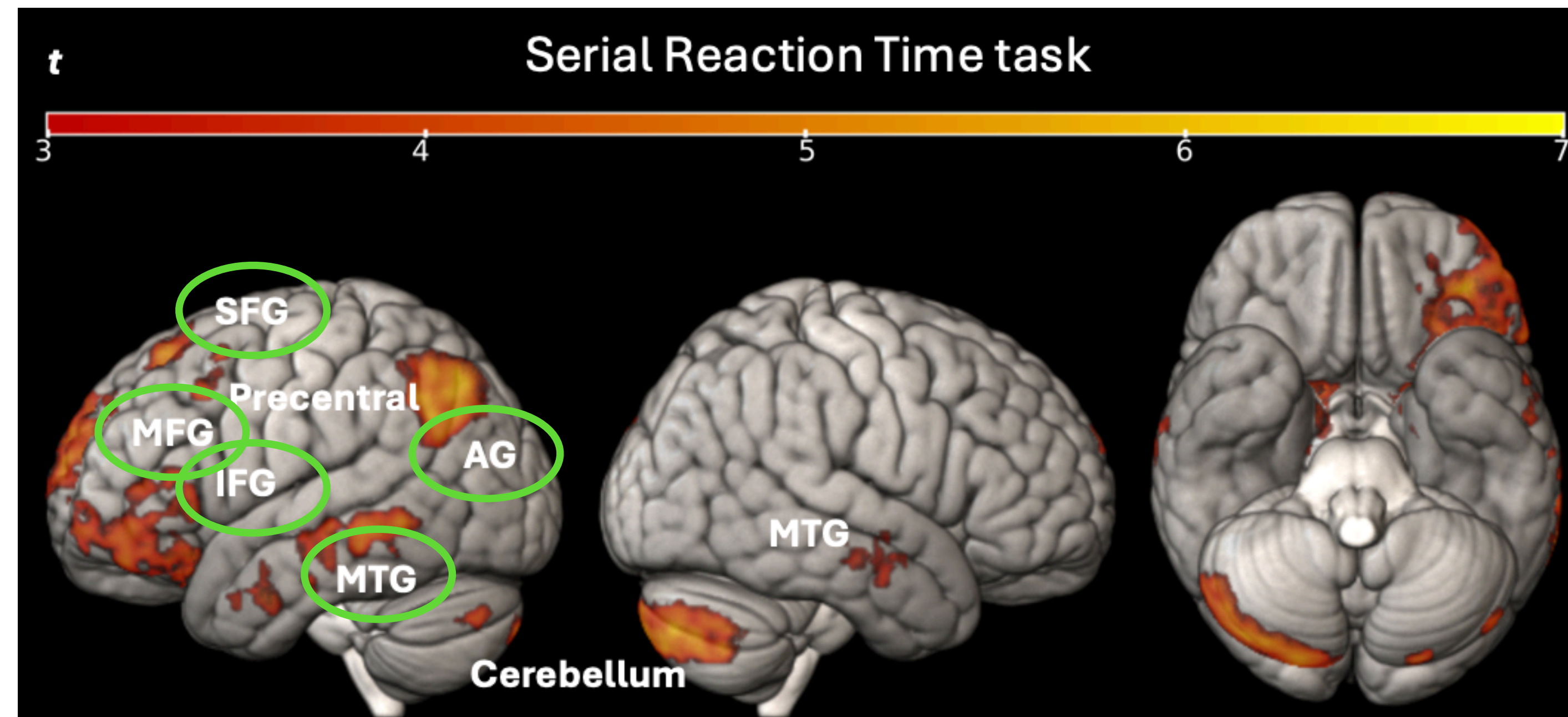# Visuo-motor statistical learning

Objective 1 | Objective 2 | **Objective 3**

<u>Whole brain results</u>
one-sample t-test

Brain areas that also appear to be involved in the predictive reading task

Serial Reaction Time task

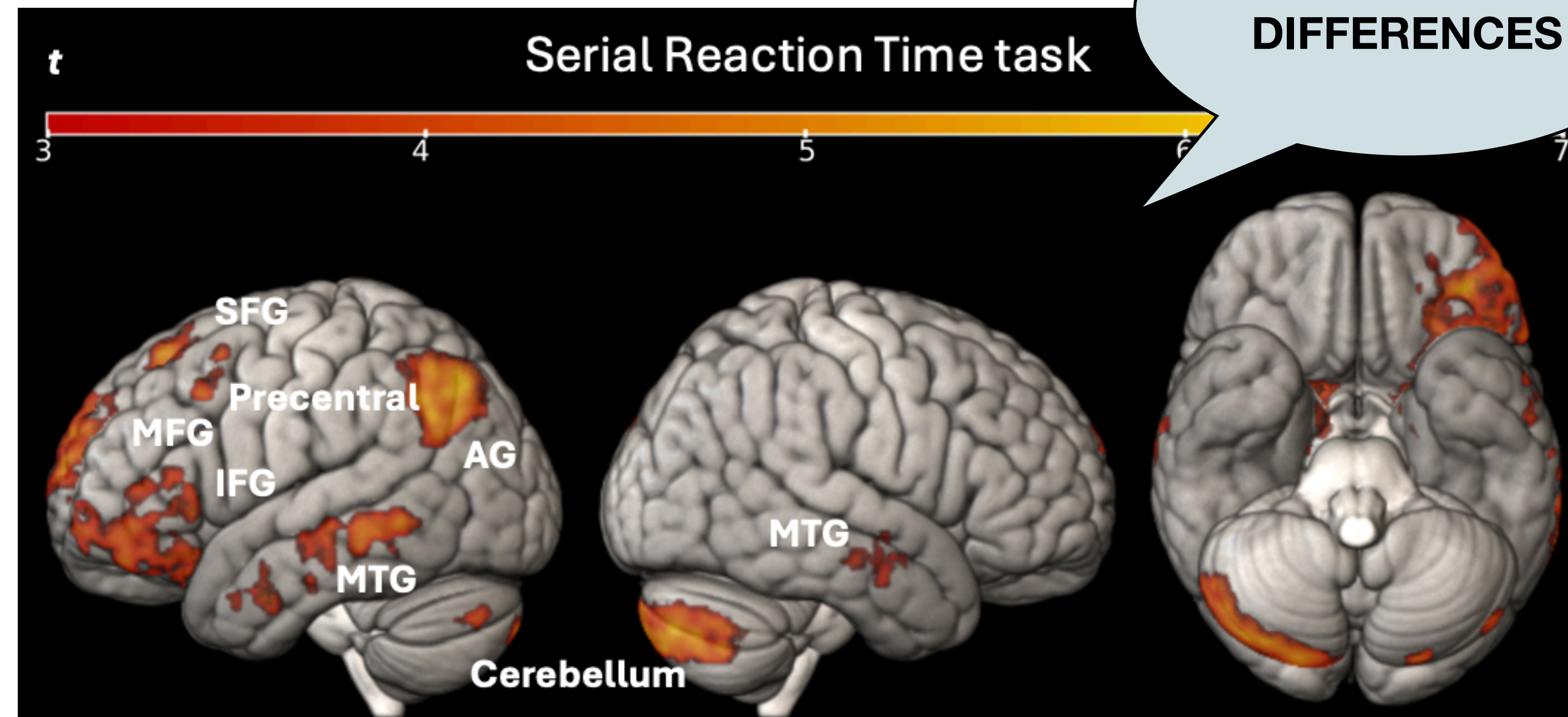+ L/R postcentral, R lingual, R cuneus, L/R thalamus, L amygdala, L/R caudate, R putamen

Visuo-motor statistical learning **in dyslexia**

Objective 1   Objective 2   **Objective 3**

Whole brain results
two-sample t-test

NO GROUP DIFFERENCES

The link between linguistic and non linguistic predictions

Objective 1 | Objective 2 | Objective 3 | **Objective 4**

For the **dyslexic** group only !
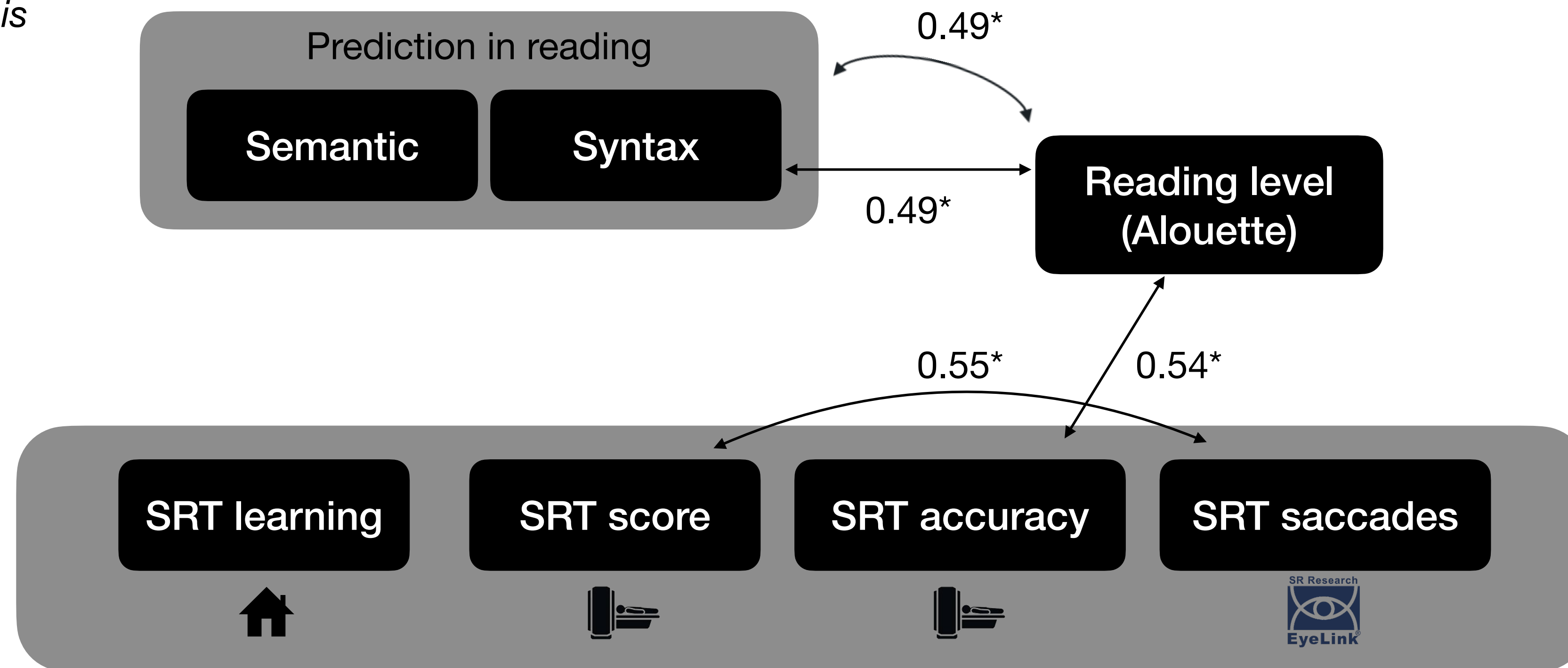
<u>Behavioral results</u>
correlation analysis

Prediction in reading

Semantic | Syntax

0.49*

0.49*

Reading level (Alouette)

0.55* 0.54*

SRT learning | SRT score | SRT accuracy | SRT saccades

The link between linguistic and non linguistic predictions
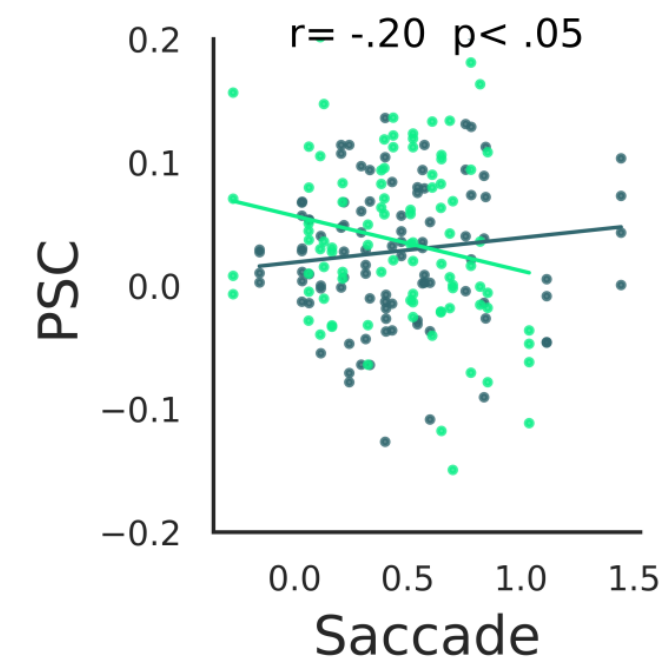
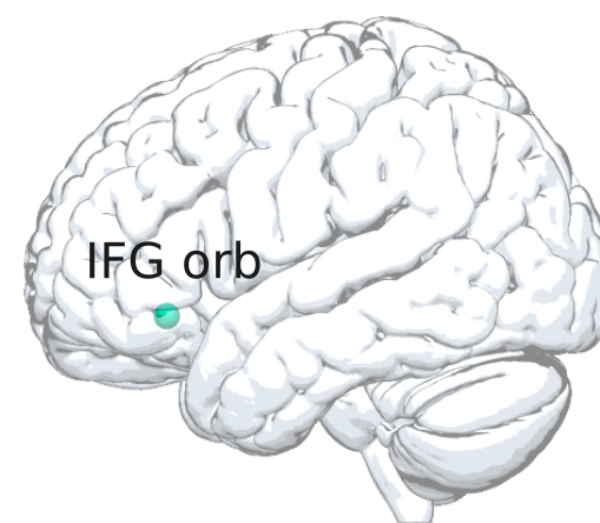Objective 1   Objective 2   Objective 3   **Objective 4**

*PSC ~ group * behavioral measure of SRT + (1|subject)*

Region of interest results
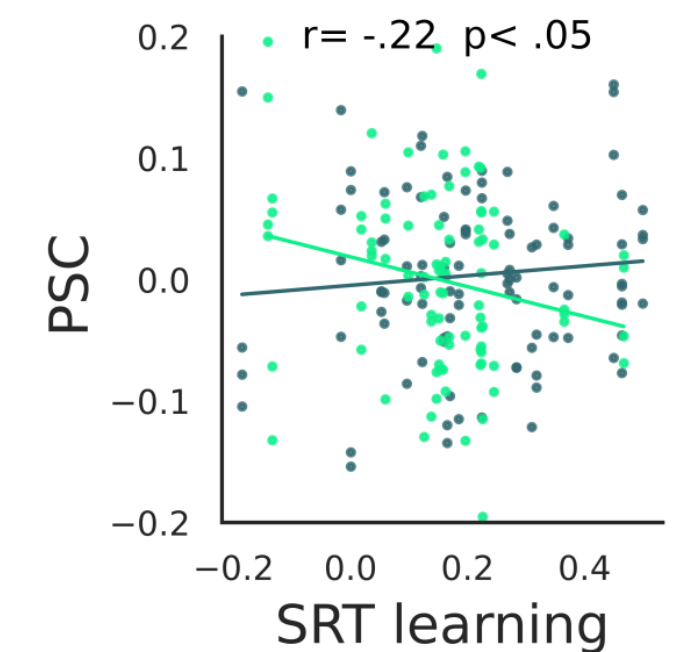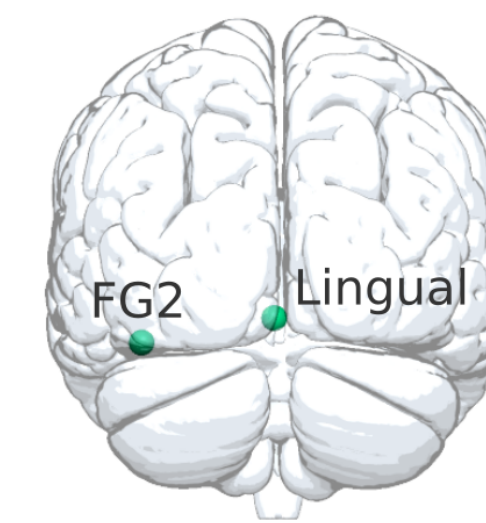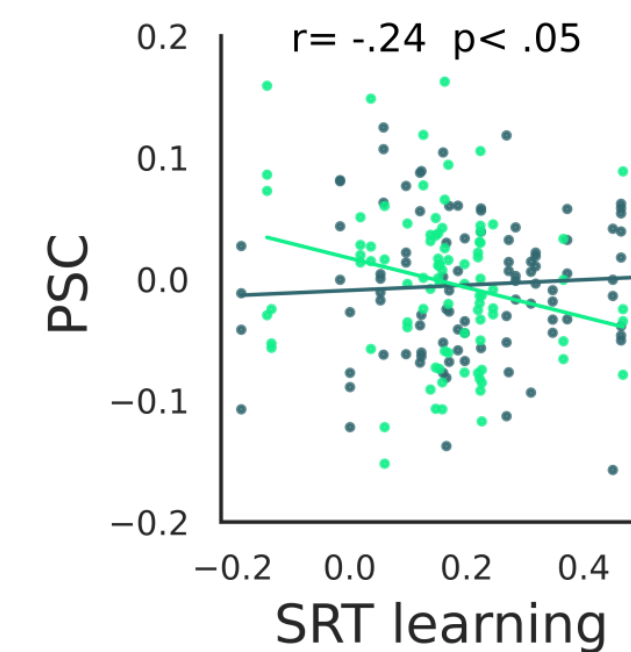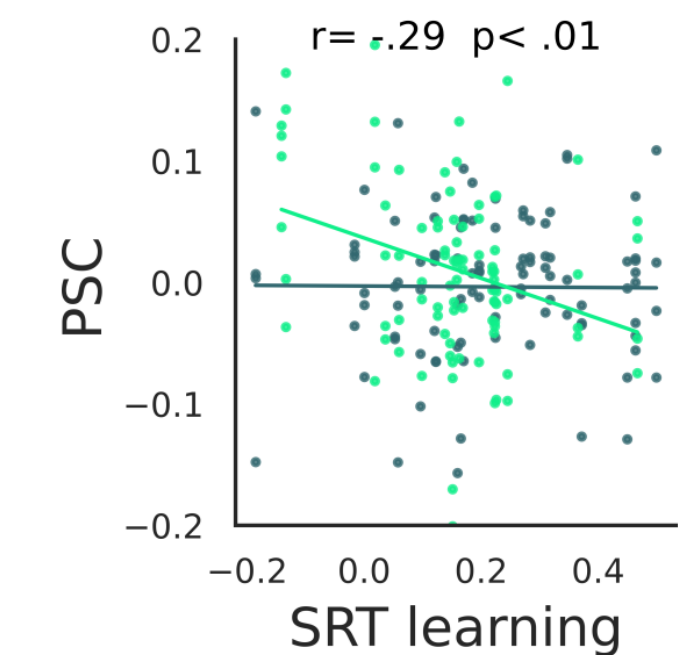

A. Group x Saccade

Group
● TR
● DYS

IFG orb

r= -.20 p< .05

B. Group x SRT score

r= .17 p=.09

MedFG
Precentral

r= .29 p<.01

C. Group x SRT learning

r= -.24 p< .05

FG2   Lingual

r= -.22 p< .05

IFG oper

r= -.29 p< .01
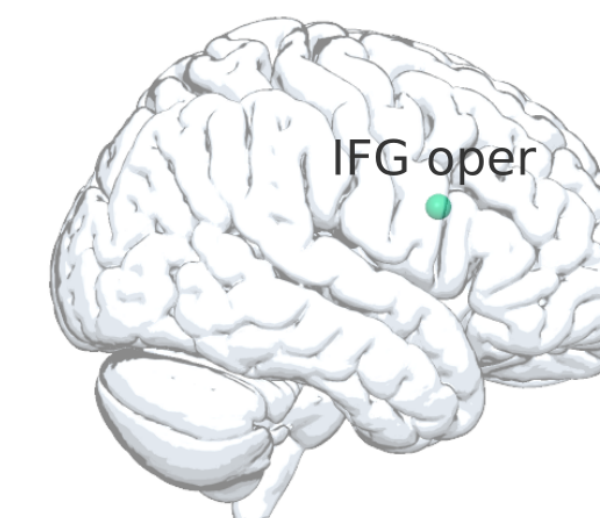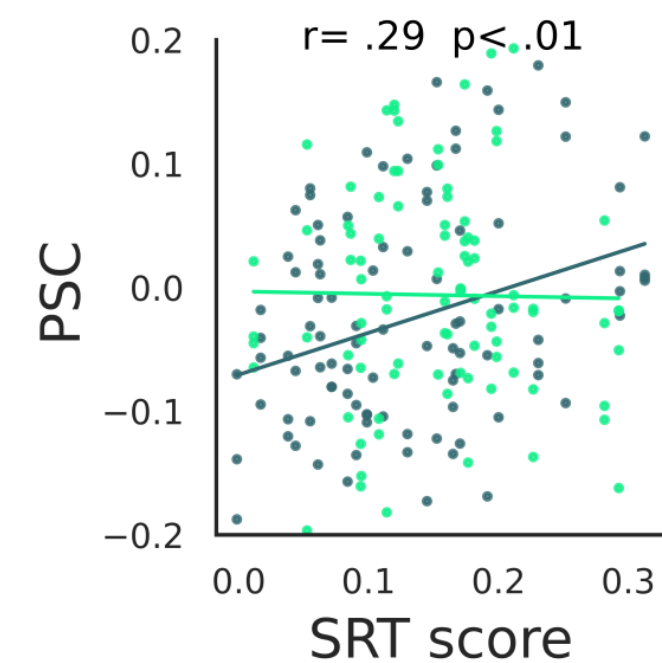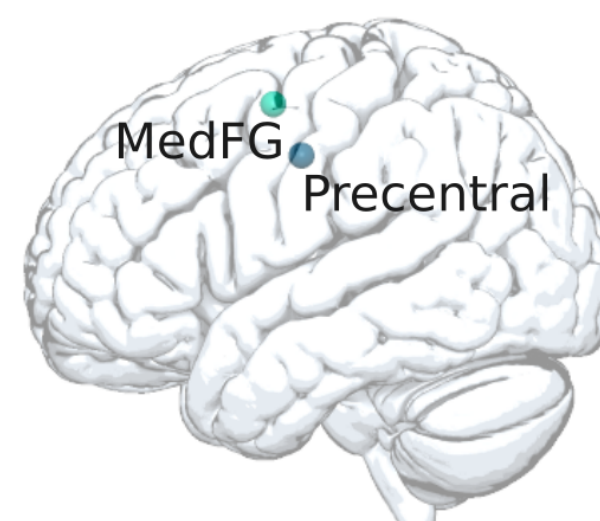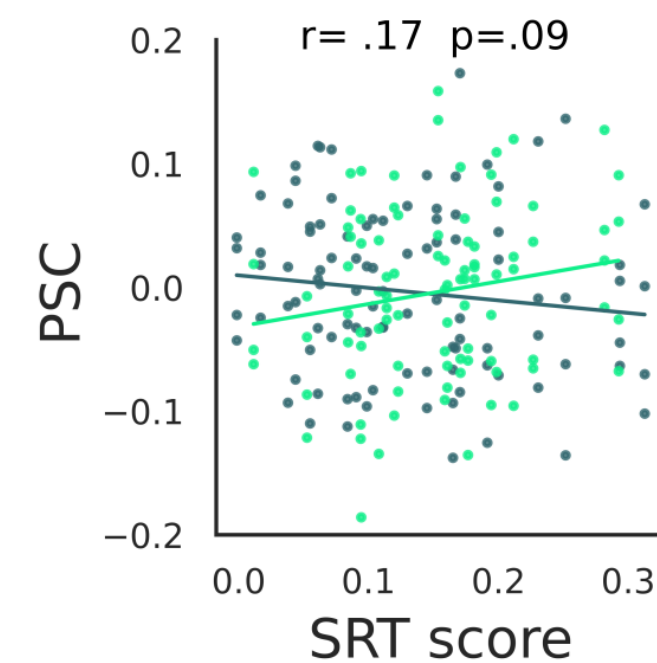
Take home message

Semantic vs syntactic prediction	Predictive reading in dyslexia	Visuo-motor SL in dyslexia	Link between predictive reading and SL

1 Linguistic predictions can be based on different sources of high-level linguistic information.
Semantic and syntactic predictions are distinct and do not necessarily rely on a common mechanism (Bonhage et al., 2015; Gavard & Ziegler, 2024).

2 Students with dyslexia rely on brain structures involved in high-level linguistic prediction possibly to compensate for their low-level difficulties in single word perception and production.
Result in line with the compensatory hypothesis in dyslexia (Cavalli et al., 2024).

3 Contrary to the literature suggesting a SL deficit in dyslexia, we did not find that students with dyslexia had problems with sequence learning and automatization (Ozernov-Palchik et al., 2023).

4 Brain areas activated during the SRT task seems to be also involved in our predictive reading task, especially in university students with dyslexia.
Could predictive reading and visuomotor SL abilities play a compensatory role in dyslexia?

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