What happens before "next" happens

The role of top-down brain oscillations in visospatial predictive learning

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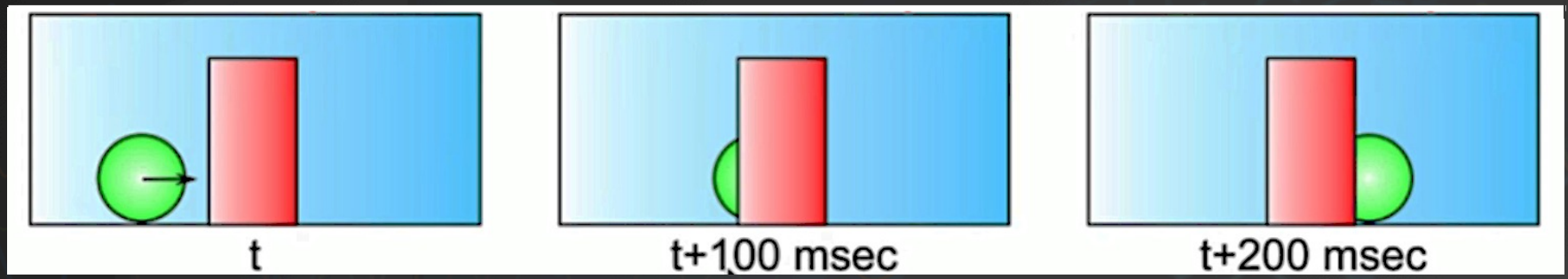
Schedule

Introduction

Predictive Learning



Key Points

- We are constantly predicting our future
- Learning signals (i.e., the prediction error) driven by the difference between the brain's top-down prediction and bottom-up real world information
- **Hypothesis**: Predictive learning occurs based on a temporal organization (alpha cycle, 100ms).

Schematic Illustration

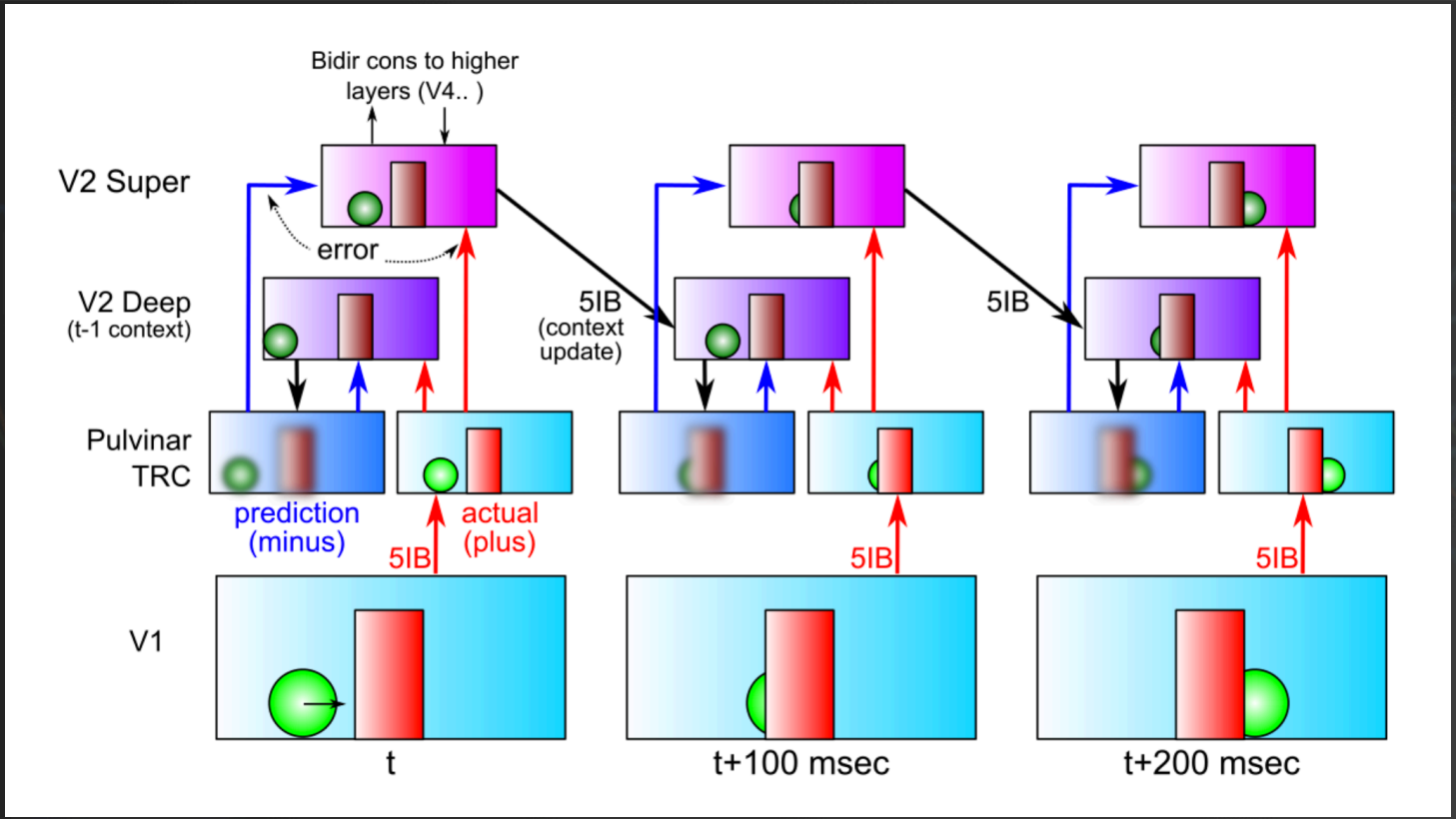


Figure: Schematic illustration of the temporal evolution of information flow during predicting visual sequences, over a period of three alpha cycles of 100 ms each (O'Reilly et. al, 2017).

- V2 Deep -> Prior 100ms info to generate predictions
- Actual input comes in next via 5IB from V1
- Temporal diff. between minus and plus phases

Alpha-band Oscillation

The alpha rhythm refers to brain oscillations within a frequency range of 8–12 Hz.

"Idling" state

- Alpha band reflects an "idling" state in which the underlying cortical regions are not engaged in any task related sensory information (Bauer et al., 2014)

Alpha associated with attentional modulation

- Top-down attentional processing results in reduced alpha power in attended and higher alpha power in unattended areas (Mathewson et al., 2009; Sigala et al., 2014)

Alpha associated with predication

- Low-frequency oscillations provide predictions via **feedback** connections, while gamma oscillations signal the mismatch of sensory input to these predictions (the prediction error) via **feedforward** connections (Sigala et al., 2014, van Kerkoerle et al., 2014)

Current Research

Current Research

What would be a good experimental paradigm to test predictive learning?

Experimental Design

Experimental Design

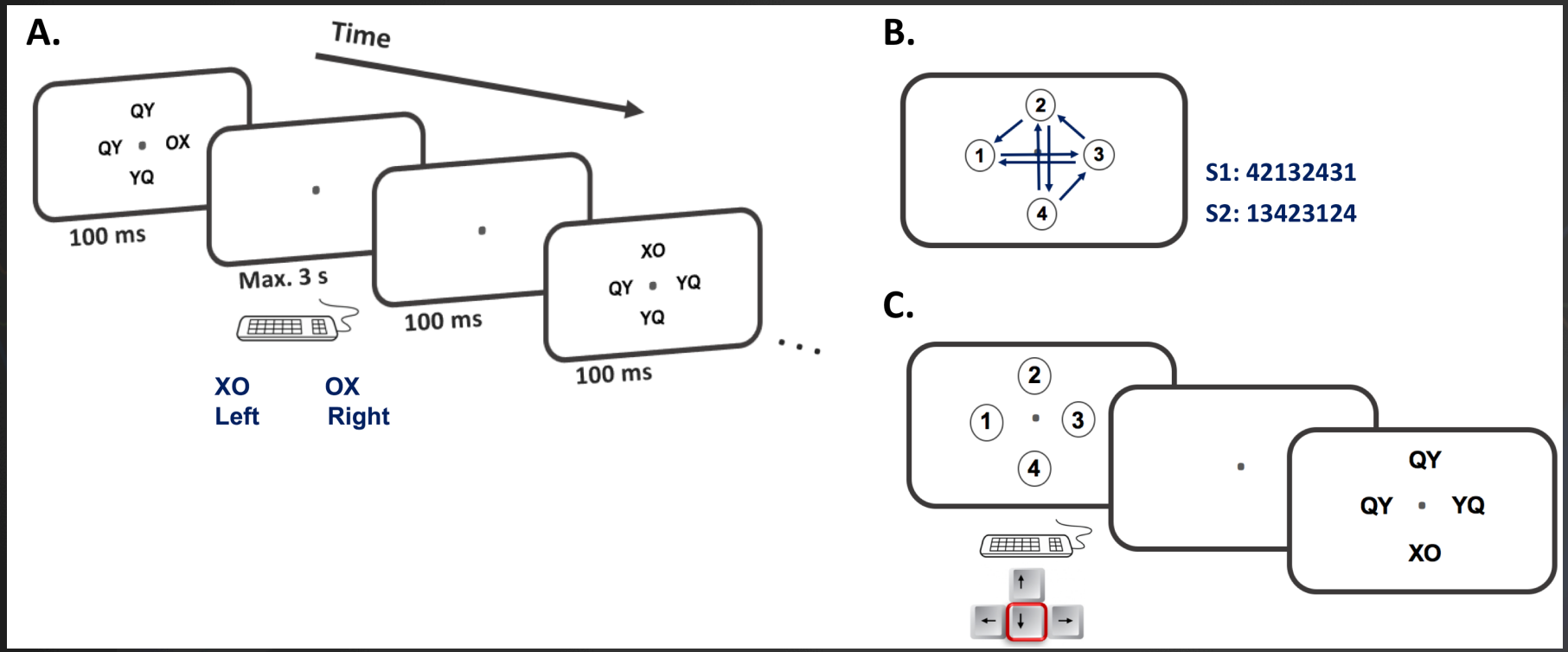


Figure: *N. Deroost et. al, "Spatial processing and perceptual sequence learning in SRT tasks" (2006).*

- **Statistical-sequence learning**
- **Pure perceptual learning**

Experiment 1

Procedure

Goal:

- Replicate the sequence learning without including any motor related learning

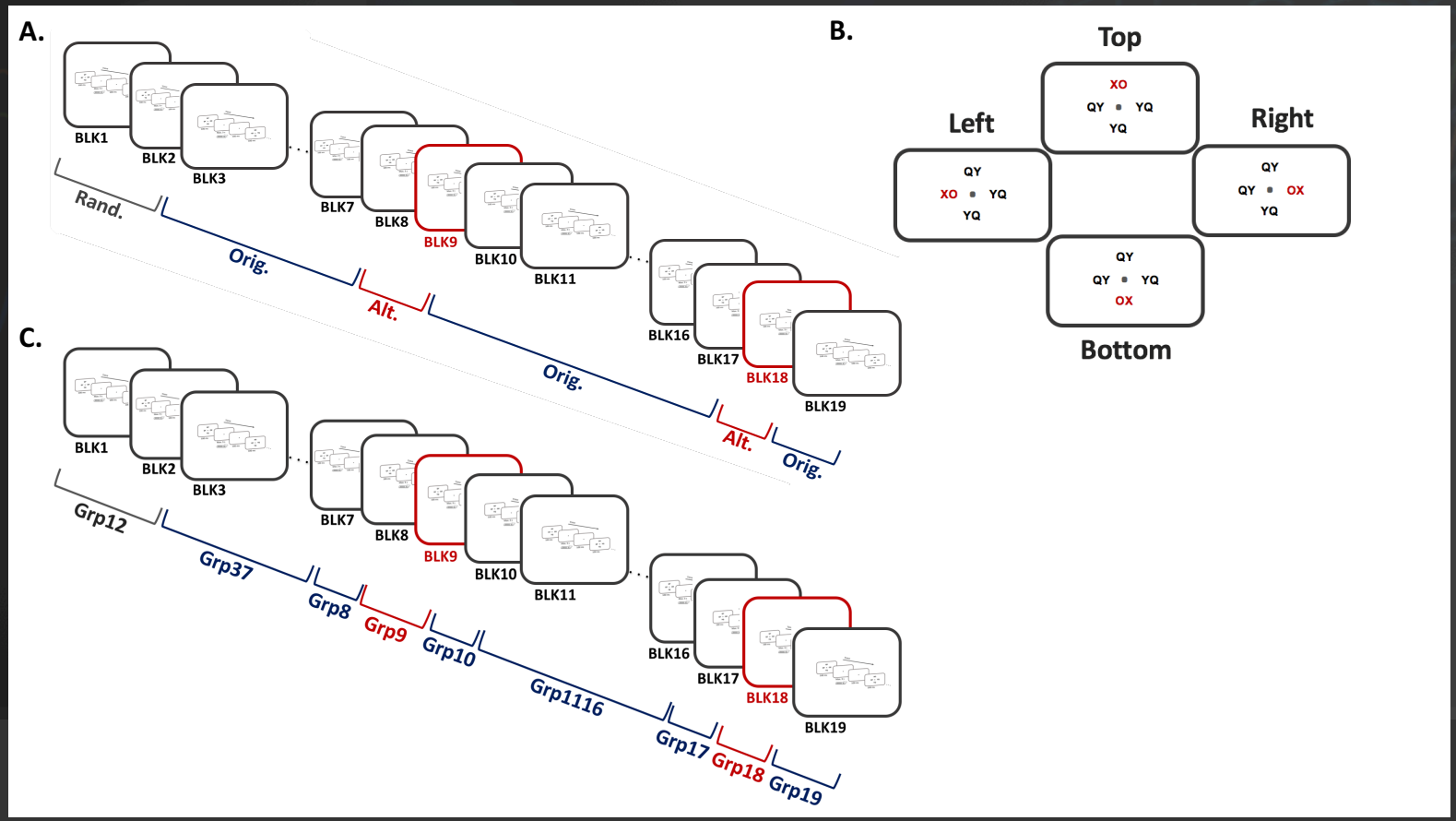
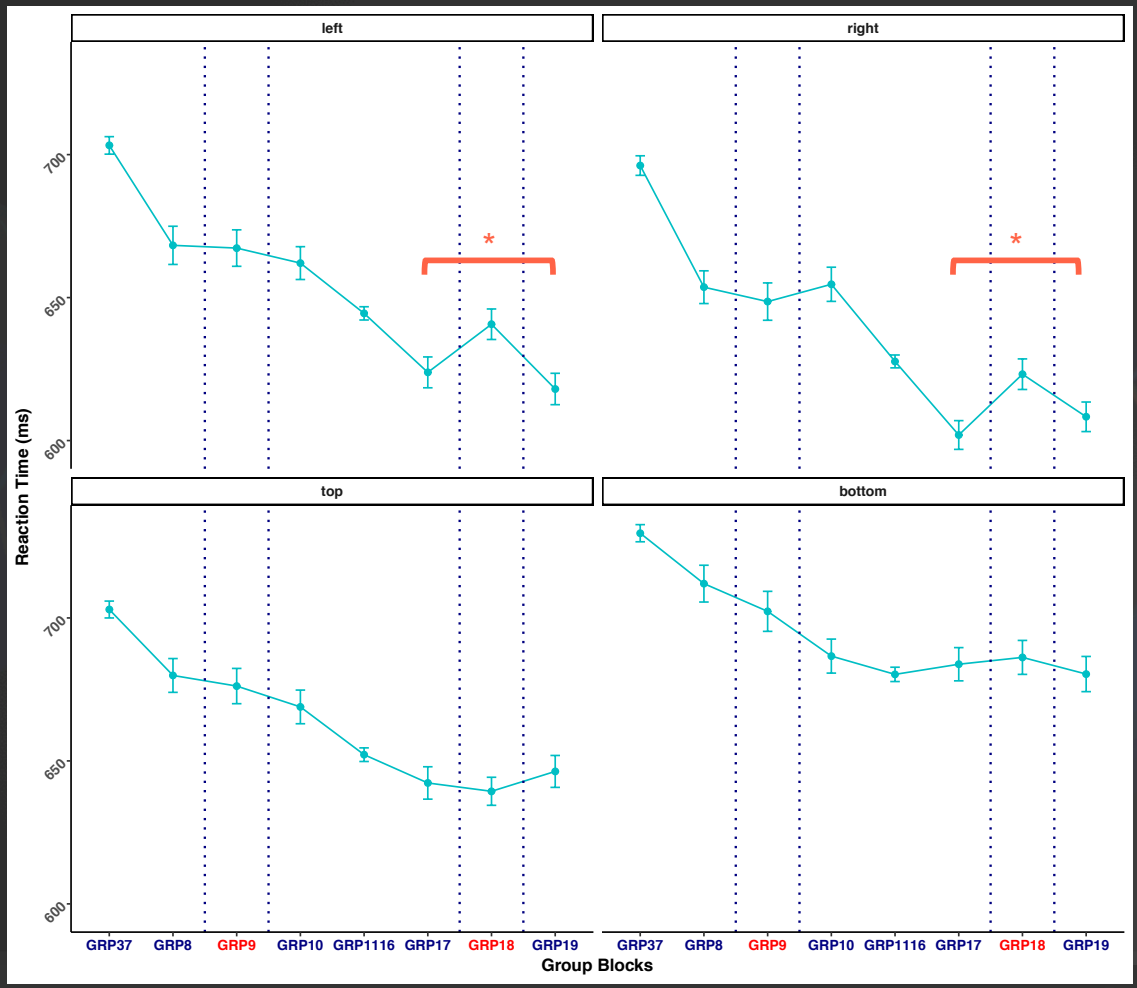


Figure: Illustration of the experimental procedure and groups

Behavioral Results

- **Seq. learning in left and right**
- **Loc. right fastest**
- **Loc. bottom slowest**



Key Question:

- Did our experimental paradigm show predictive learning behaviorally and without the confound of motor learning component?

Behavioral Results

- **Seq. learning in left and right**
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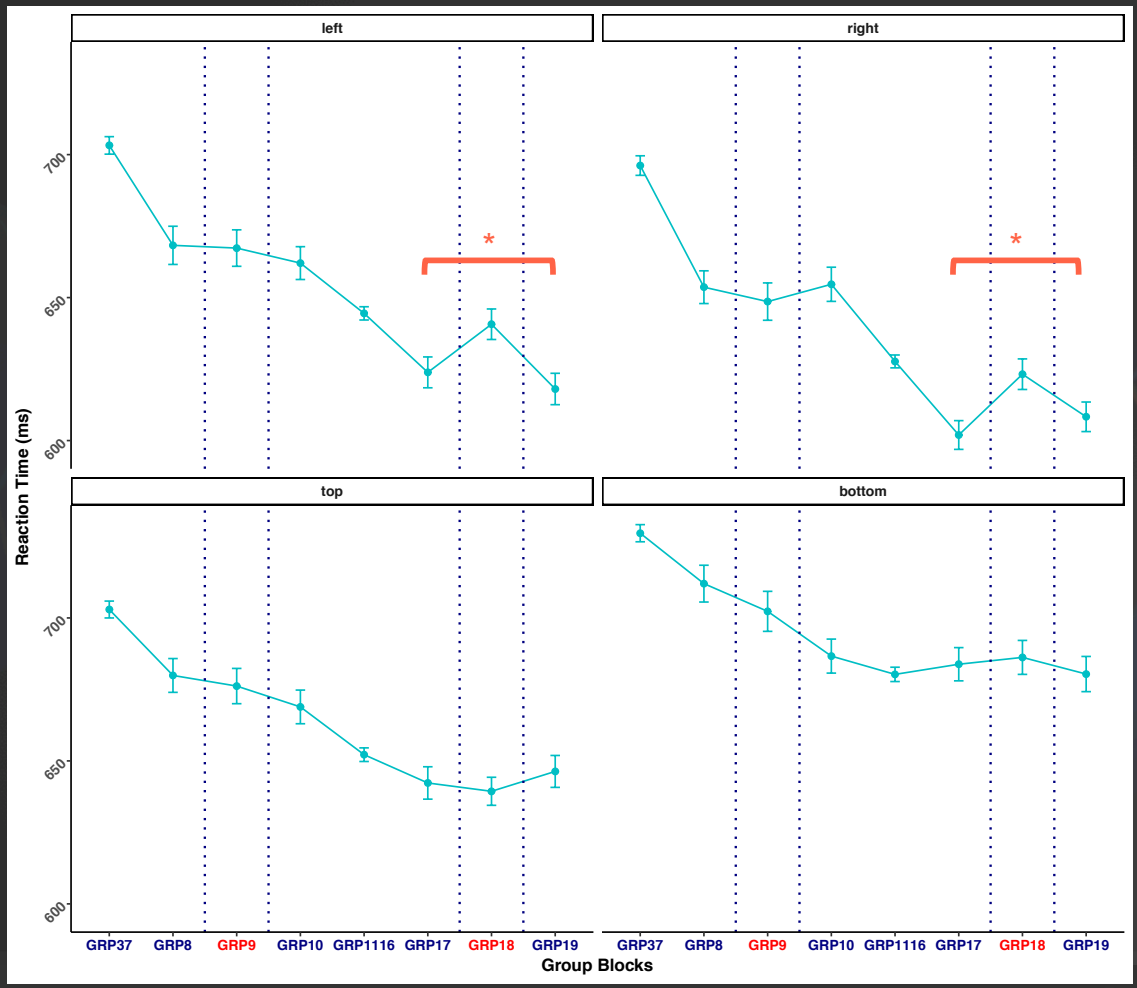


Key Question

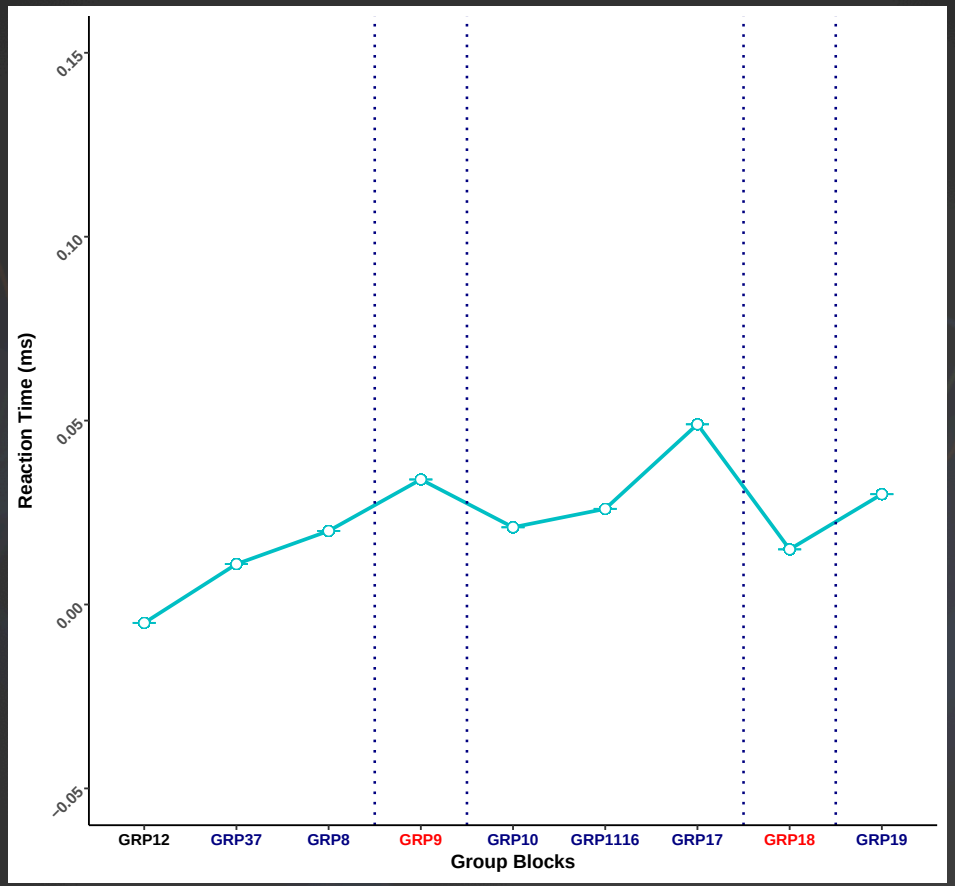
- Are there systematic differences in different locations?

Lateralization Index

Index$_{(RT)}$ =

$$\frac{RT(left\_target) - RT(right\_target)}{mean(RT(left + right\_targets))} \quad (1)$$

- **General Positive bias; advantage of location right**



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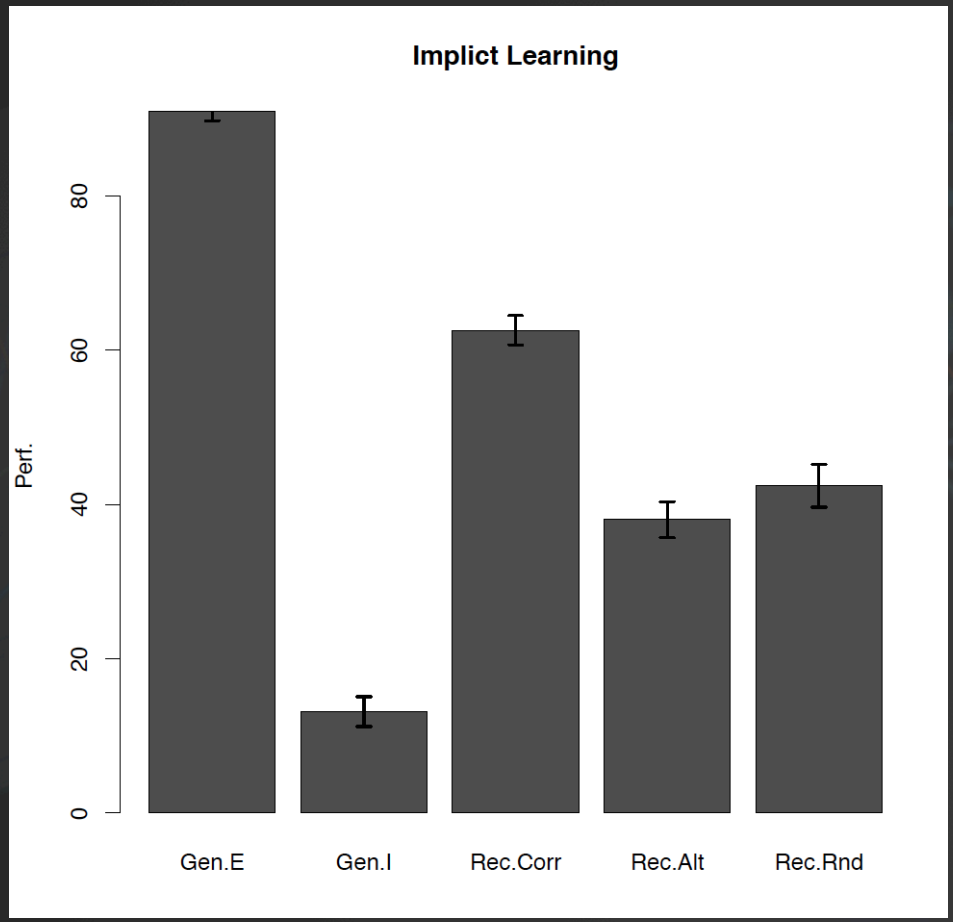
Implicit Learning



Summary

Key Findings:

- **General learning;** Faster responses over time.
- Fastest RTs in loc. right.
- Slowest RTs in loc. top.
- **Sequence-specific learning;** Quadratic trend over transition blocks in loc. **left**. and **right**. item
- **Systematic** differences in different locations.

Question

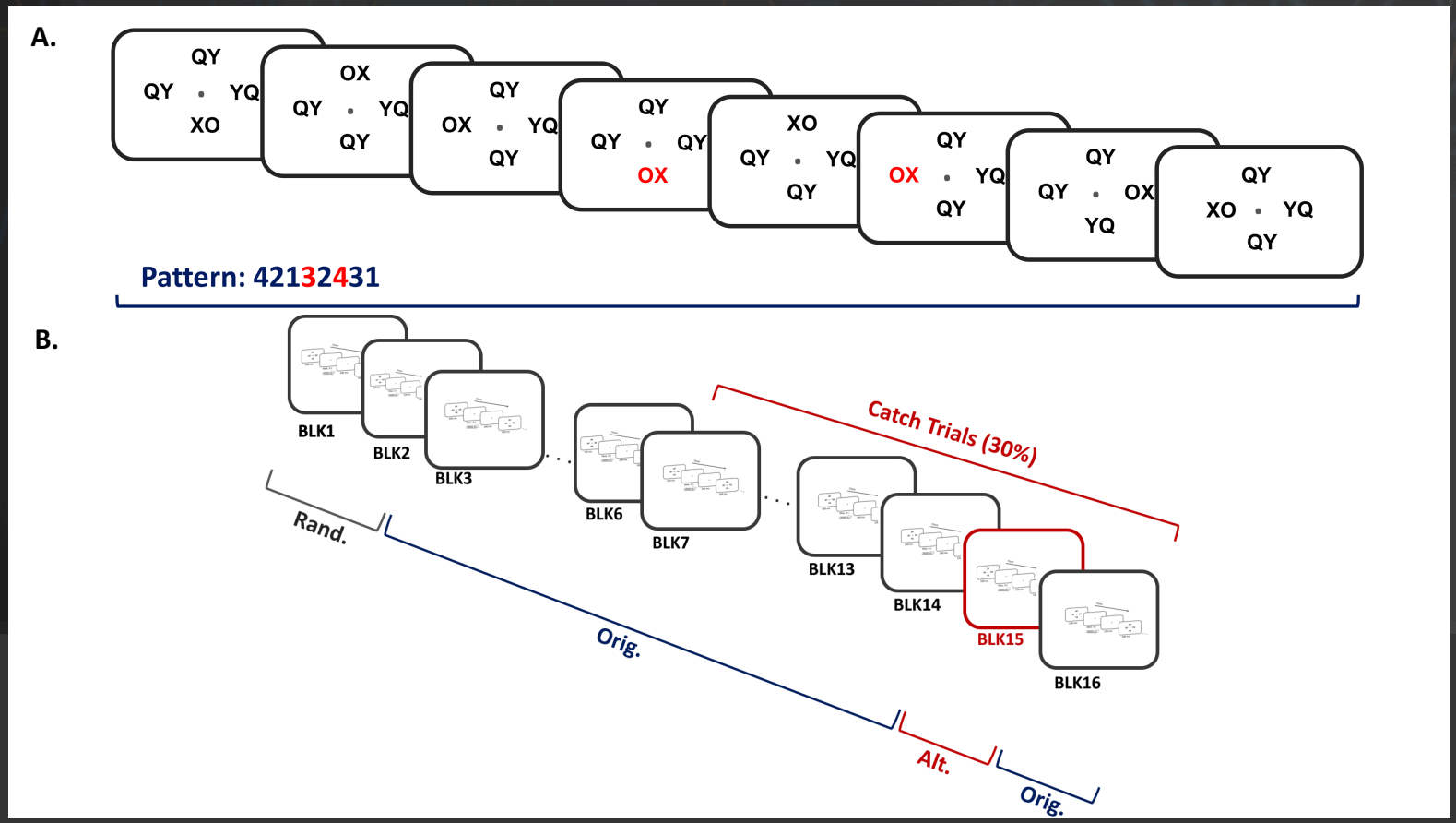
- How much of their learning is by an acquisition of sequence-specific/ predictive knowledge?

Experiment 2

Procedure

Goal

- Add **catch** trials to the experiment
  - Measuring a **trial-by-trial** predictive learning
  - Measure **prediction error** after recording EEG



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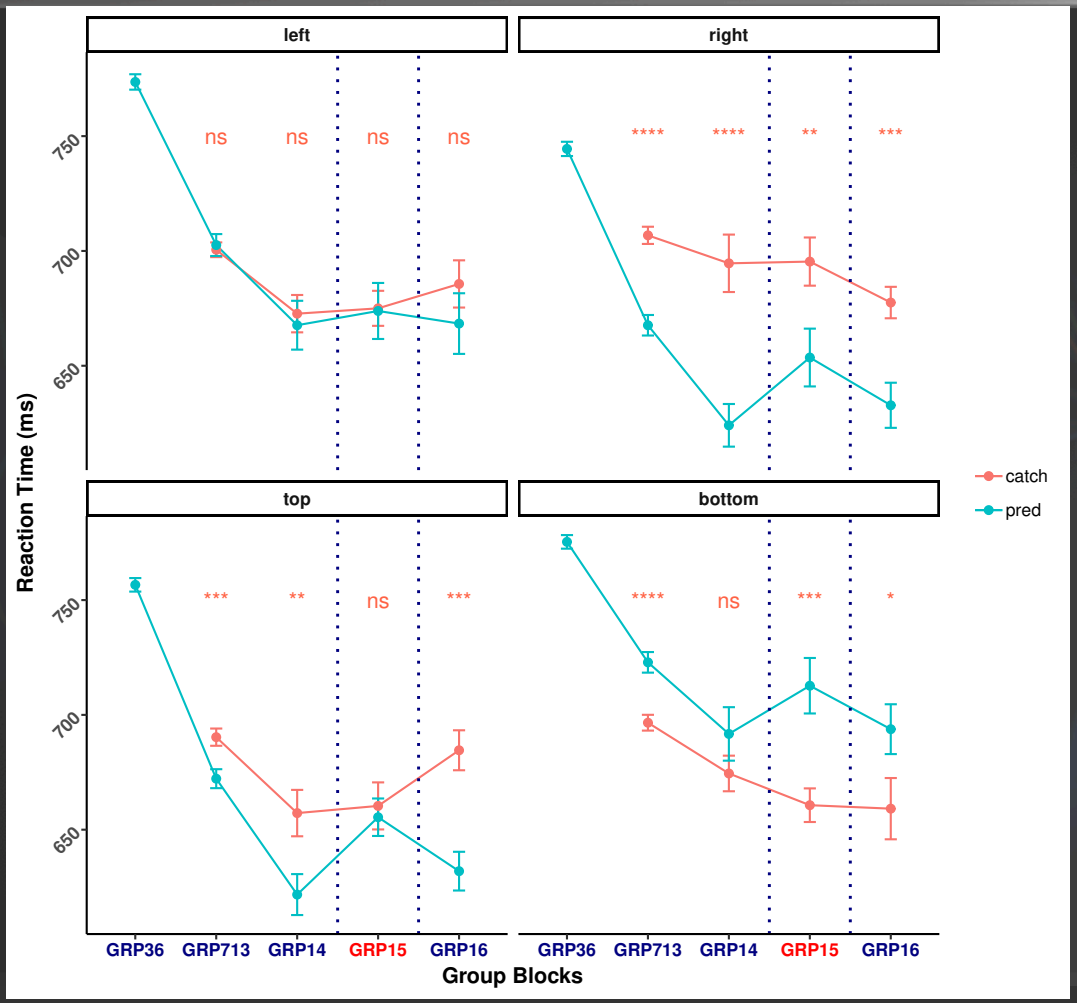


Key Question:

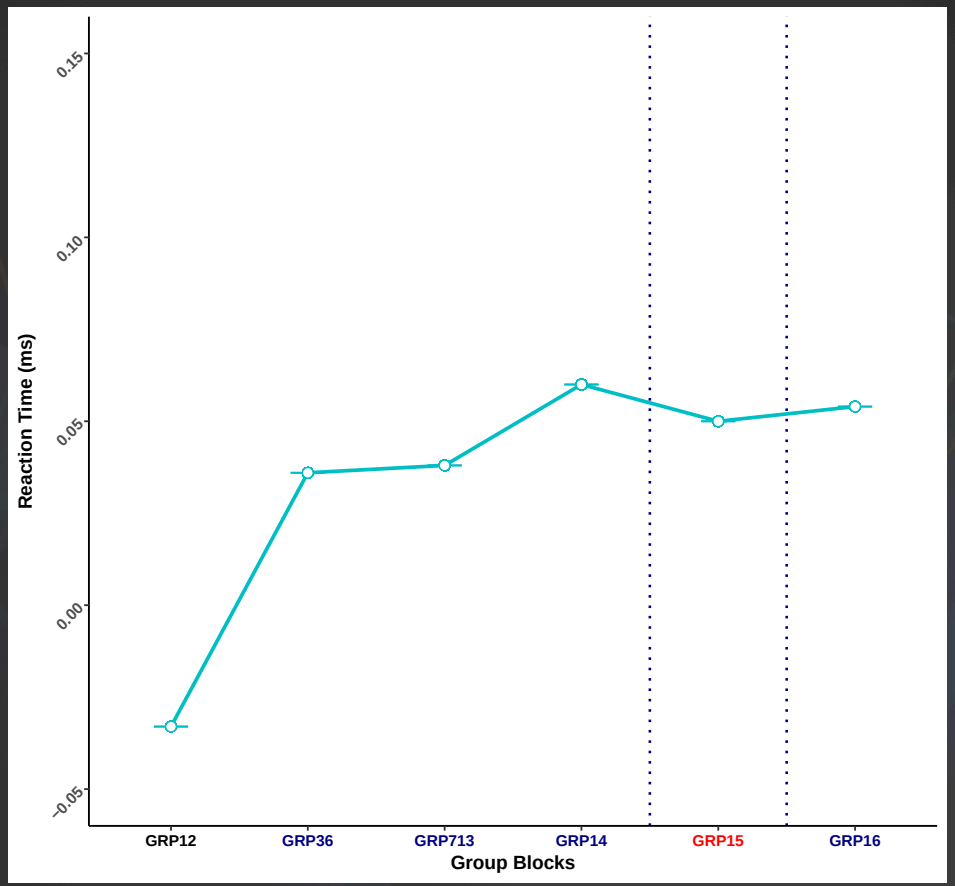
- Predictive learning behaviorally and without the confound of motor learning component?

Lateralization Index

Index$_{(RT)}$ =

$$\frac{RT(left\_target) - RT(right\_target)}{mean(RT(left + right\_targets))} \quad (2)$$

- **General Positive bias; advantage of location right**



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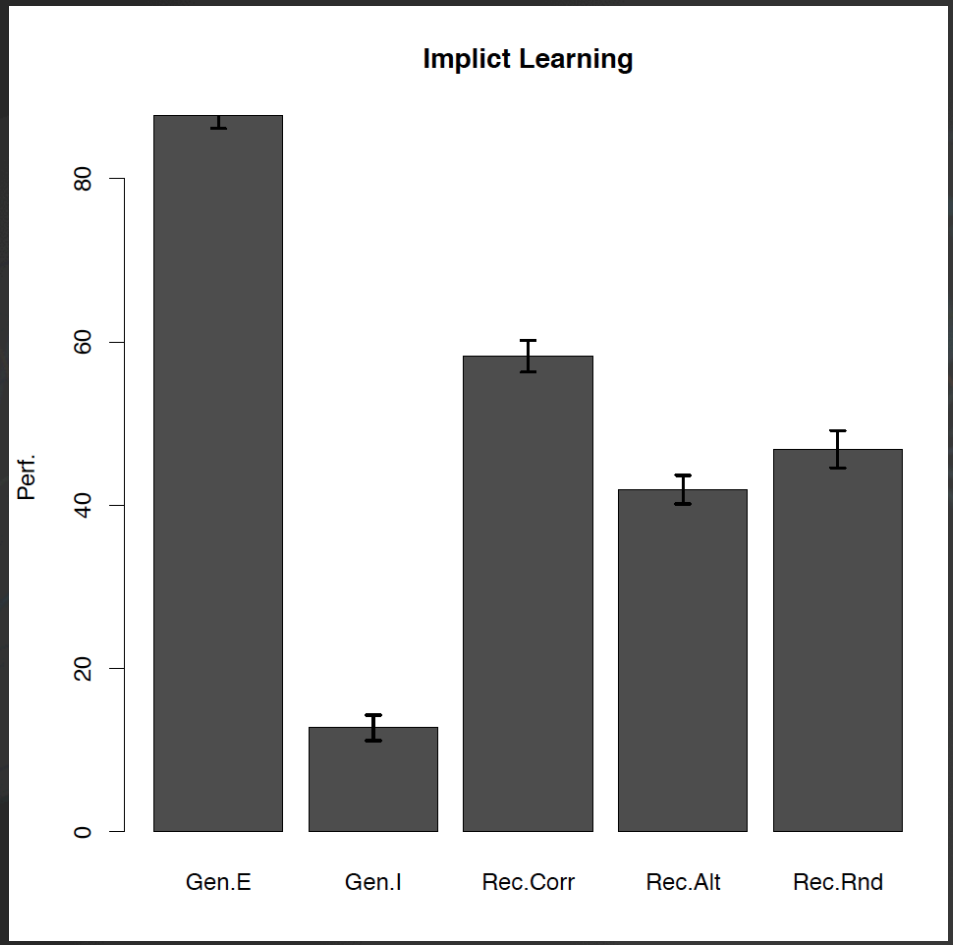
Implicit Learning



Summary

Key Findings:

- **General learning;** Faster responses over time.
- Fastest RTs in loc. right.
- Slowest RTs in loc. top.
- **Sequence-specific learning;** Quadratic trend; only in location **right** and **not left**.
- **Systematic** differences in different locations.

Next step:

- After observing promising behavioral results, we recorded EEG.

Key Question:

Are behavioral improvements in RTs driven by predictive learning or some other form of learning?

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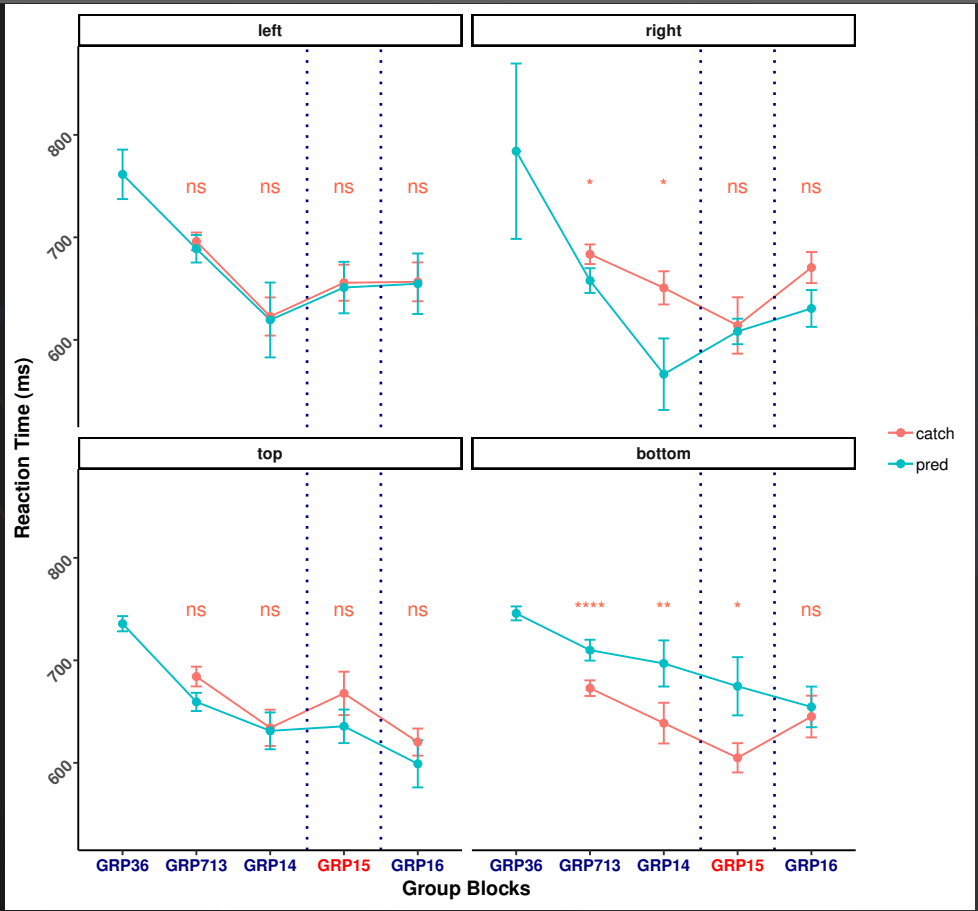
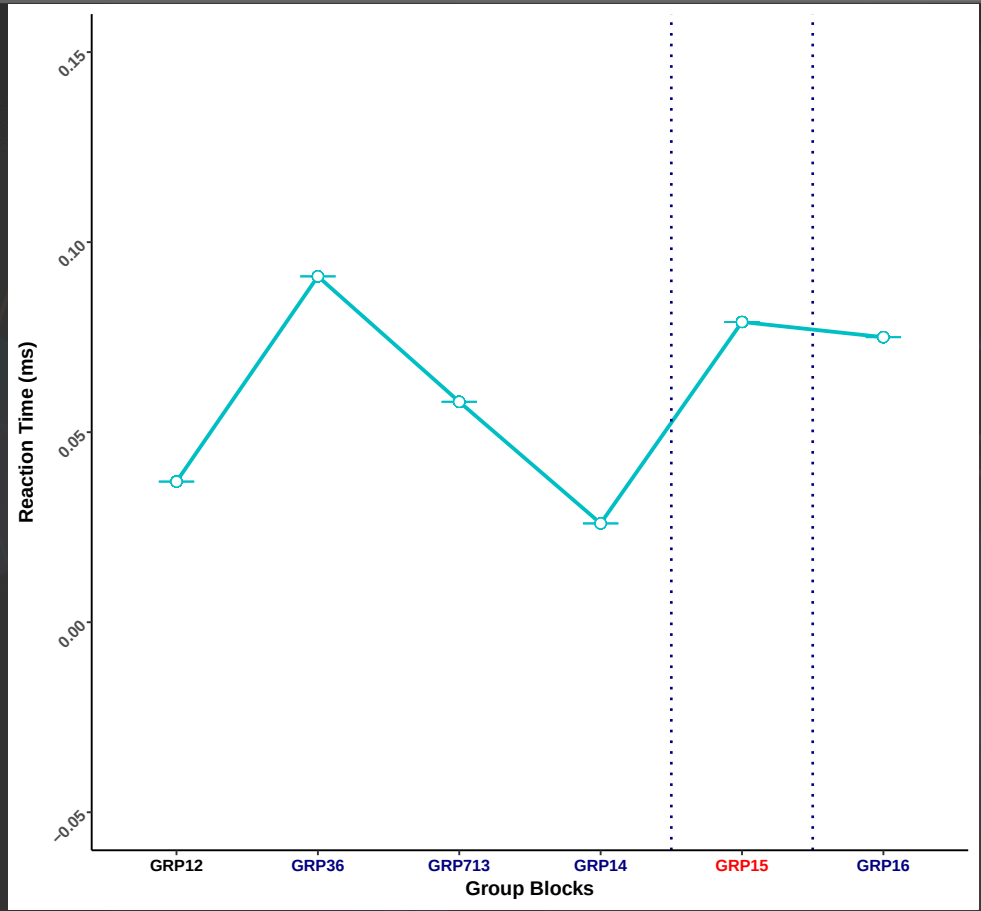
Are behavioral improvements in RTs driven by predictive learning or some other form of learning?

- **If predictive learning is at work -> brain differences prior to the stimulus onset.**

Experiment 2 - EEG study

Behavioral Results





Key Question:

- Predictive learning and without the confound of motor learning component?

Summary

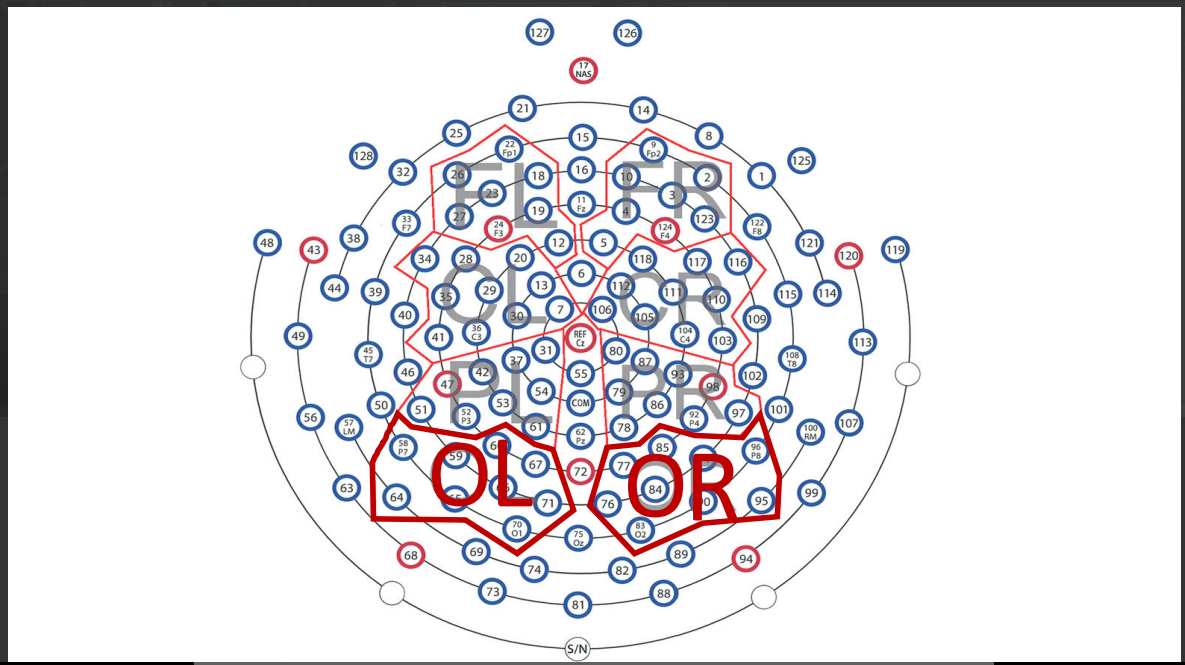
Key Findings:

- **General learning;** Faster responses over time.
- Fastest RTs in loc. right.
- Slowest RTs in loc. top.
- **Sequence-specific learning;** NO significant quadratic trend over transition blocks.
- Only 11 subjects.
- **Systematic** differences in different locations.

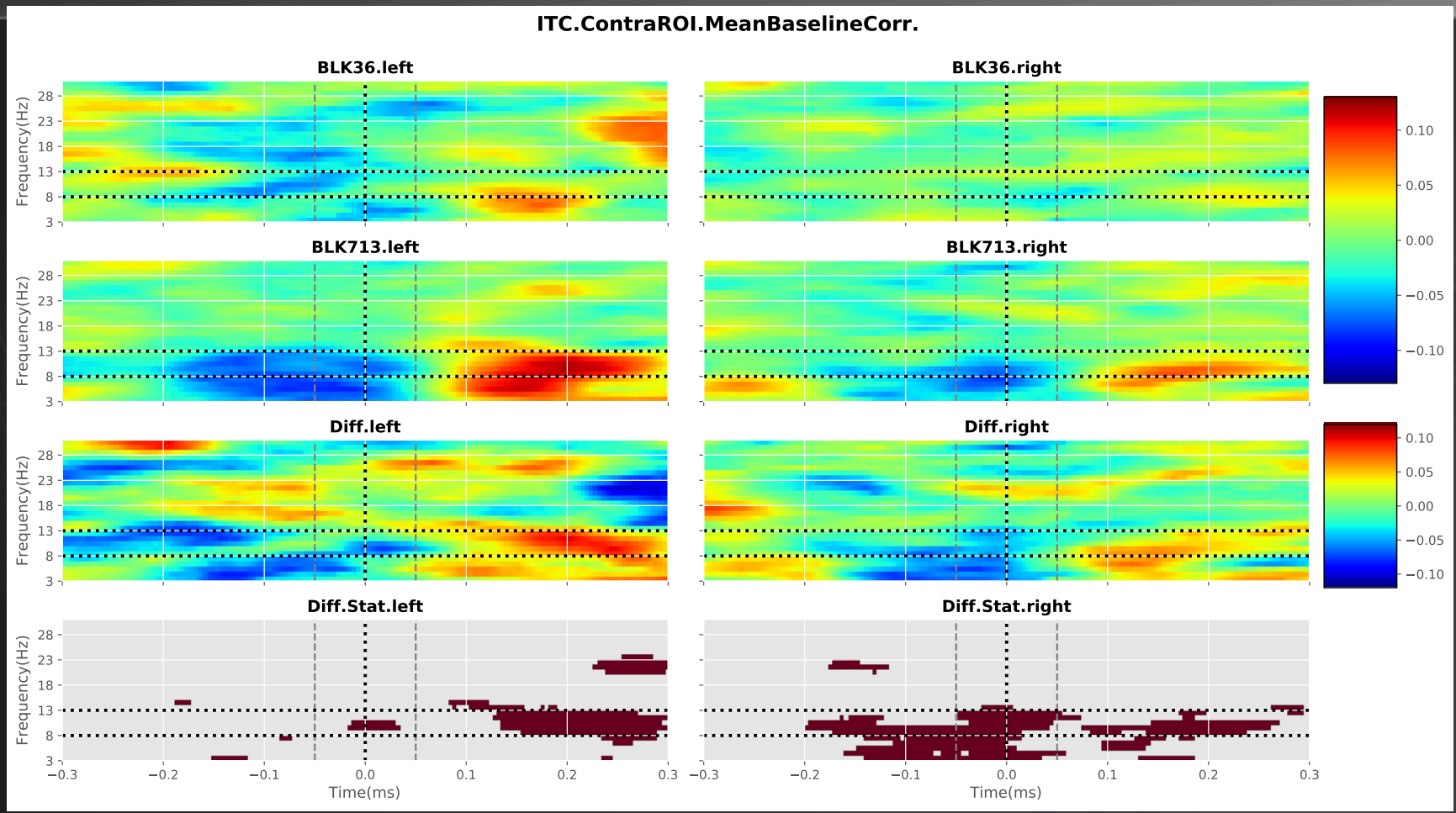
Summary

Key Findings:

- General **positive bias** of lateralization index.
- Strong indications of the usual left/right asymmetries,
- Thus our EEG analyses need to treat these locations each **separately**.

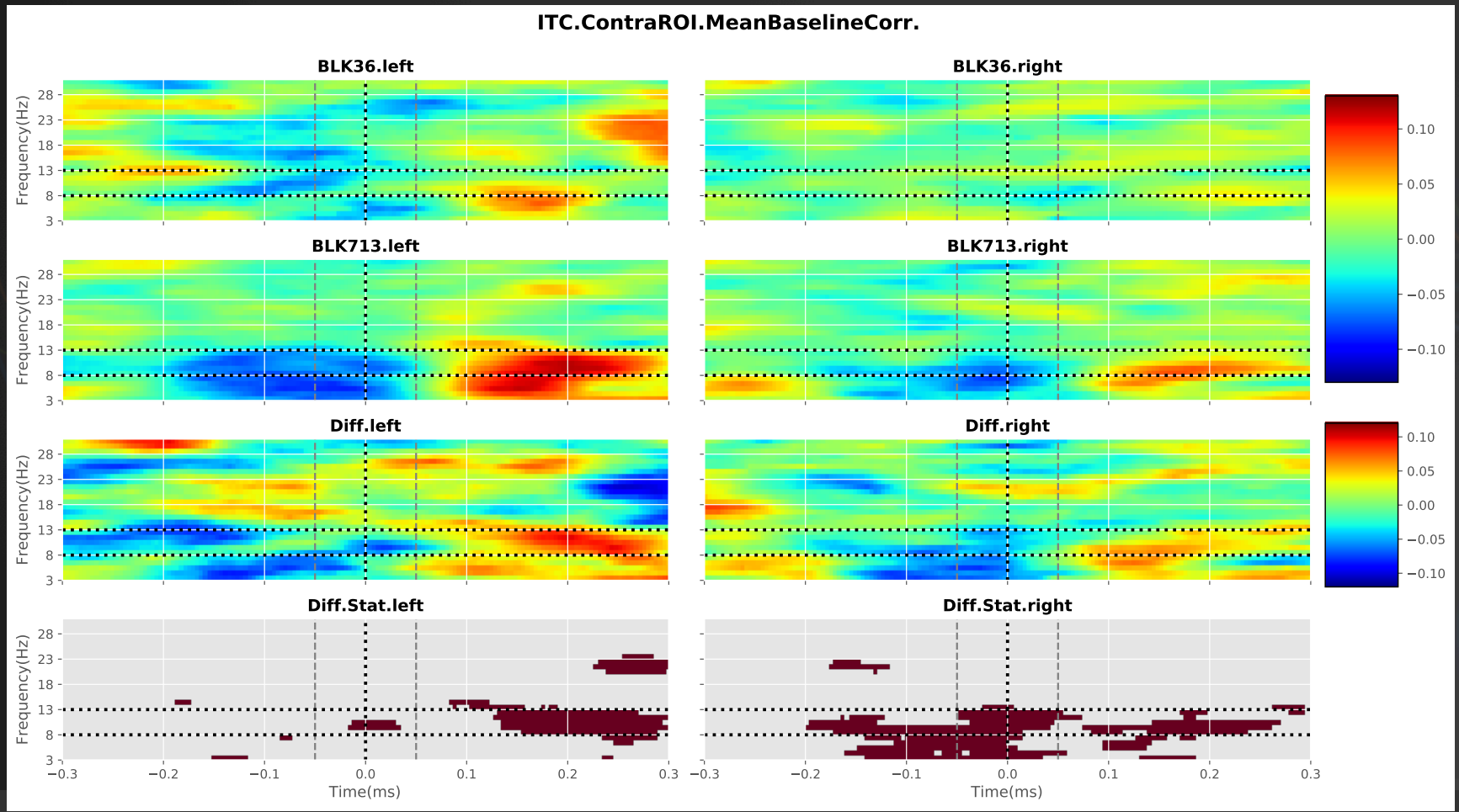


Time- Frequency Results



- **ITC; timing is embedded in phase.**
- **Pre-stim. neg. anticipatory alpha -> Post-stim. pos. confirmatory alpha; Inline with our hypo. of temporal alpha signature.**

Time Frequency Results



- **Baseline correction; Grand mean.**

Summary

Key Findings:

- **General learning;** Faster responses over time.
- Fastest RTs in loc. right.
- Slowest RTs in loc. top.
- **Sequence-specific learning;** Only location **right**.
- **Systematic** differences in different locations.
- **Pre-stim.** neg. anticipatory alpha -> **Post-stim.** pos. confirmatory alpha; **Inline with our hypo. of temporal alpha signature.**

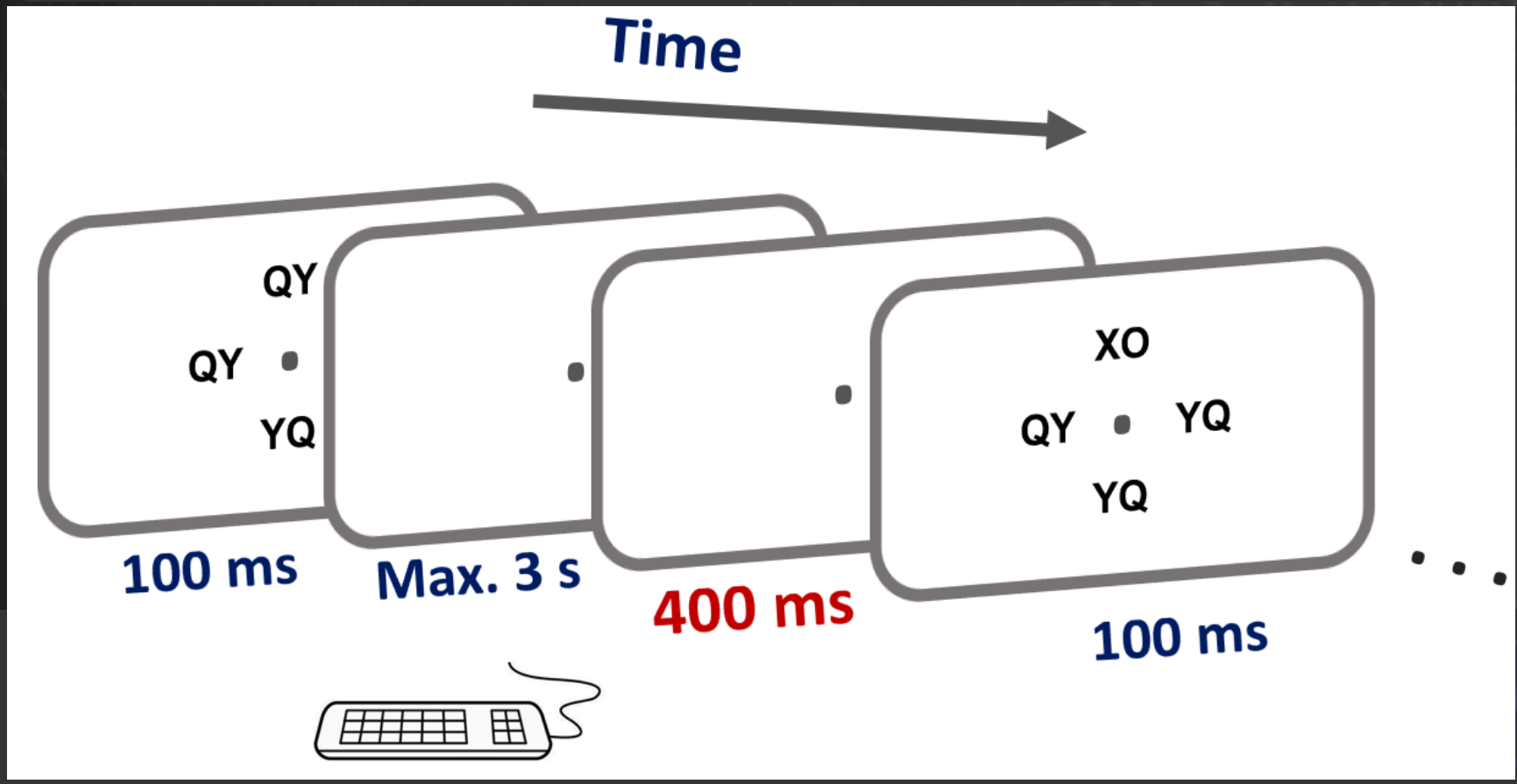
Next step:

- Increasing baseline.

Summary

Next step:

- Increasing baseline.

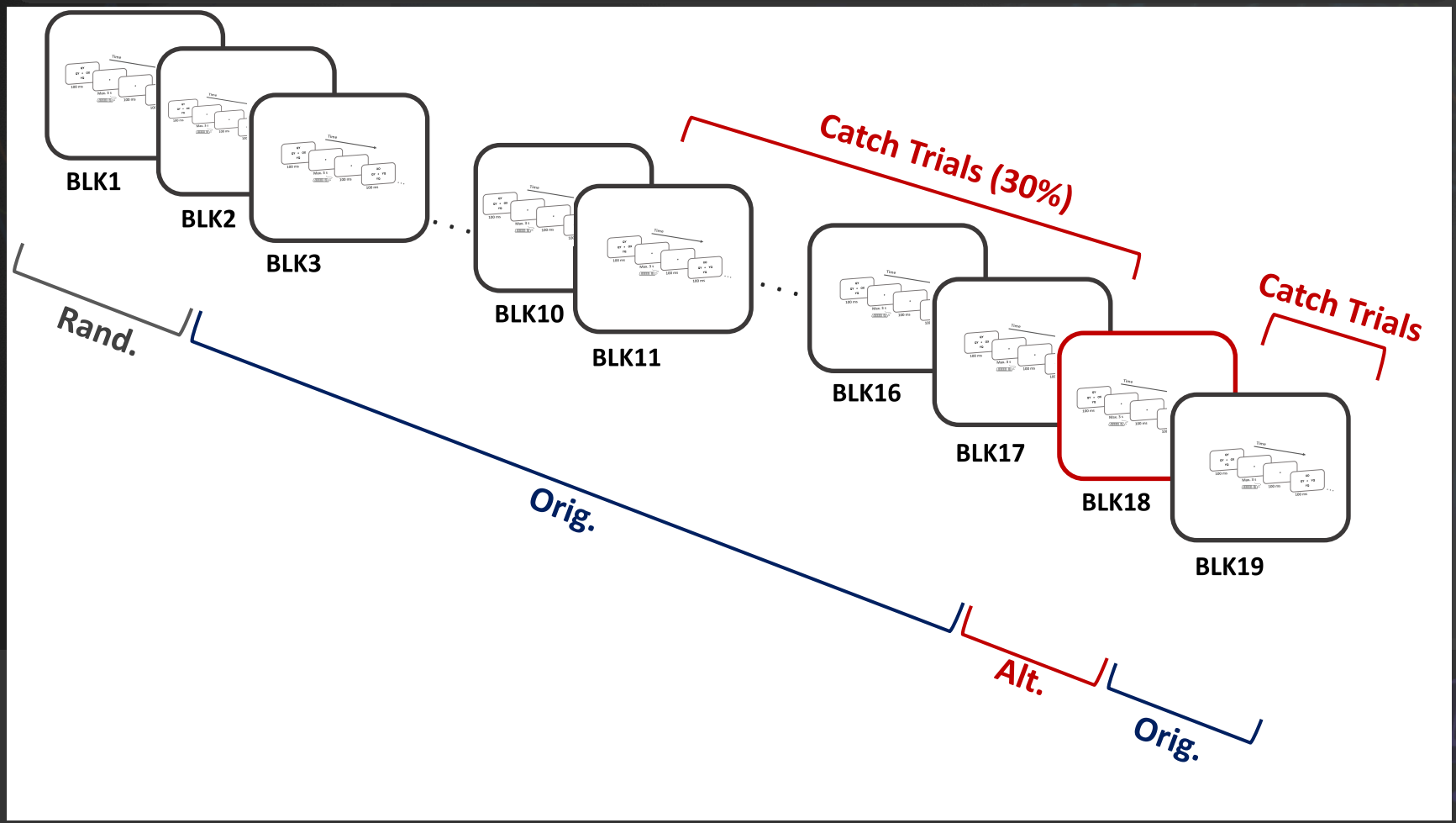


Experiment 3

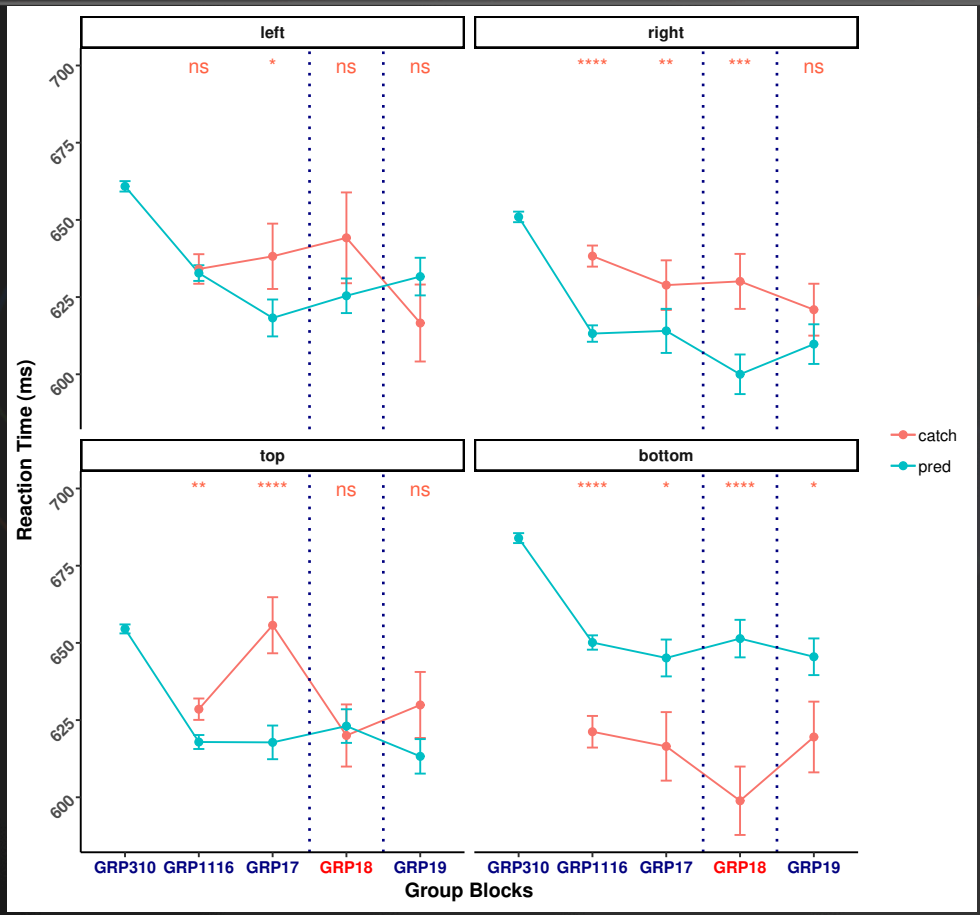
Procedure

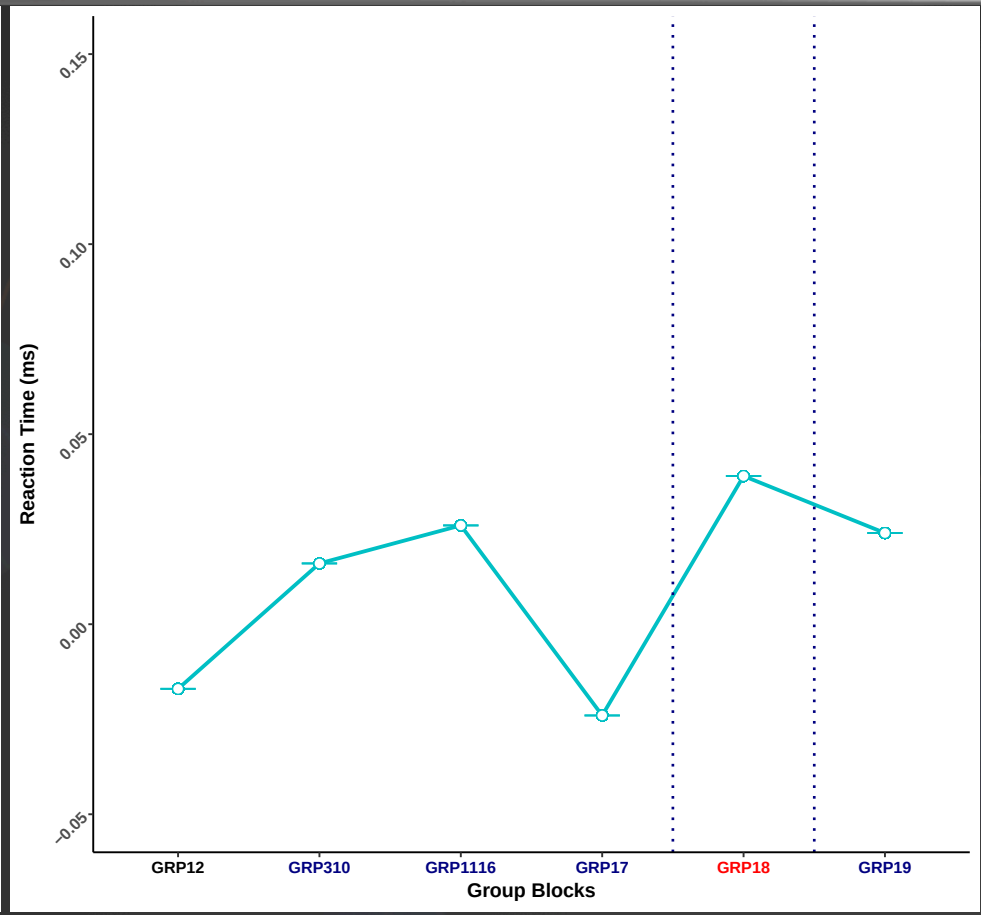
Goal:

- Replicate the previous findings after increasing the ISI.



Behavioral Results

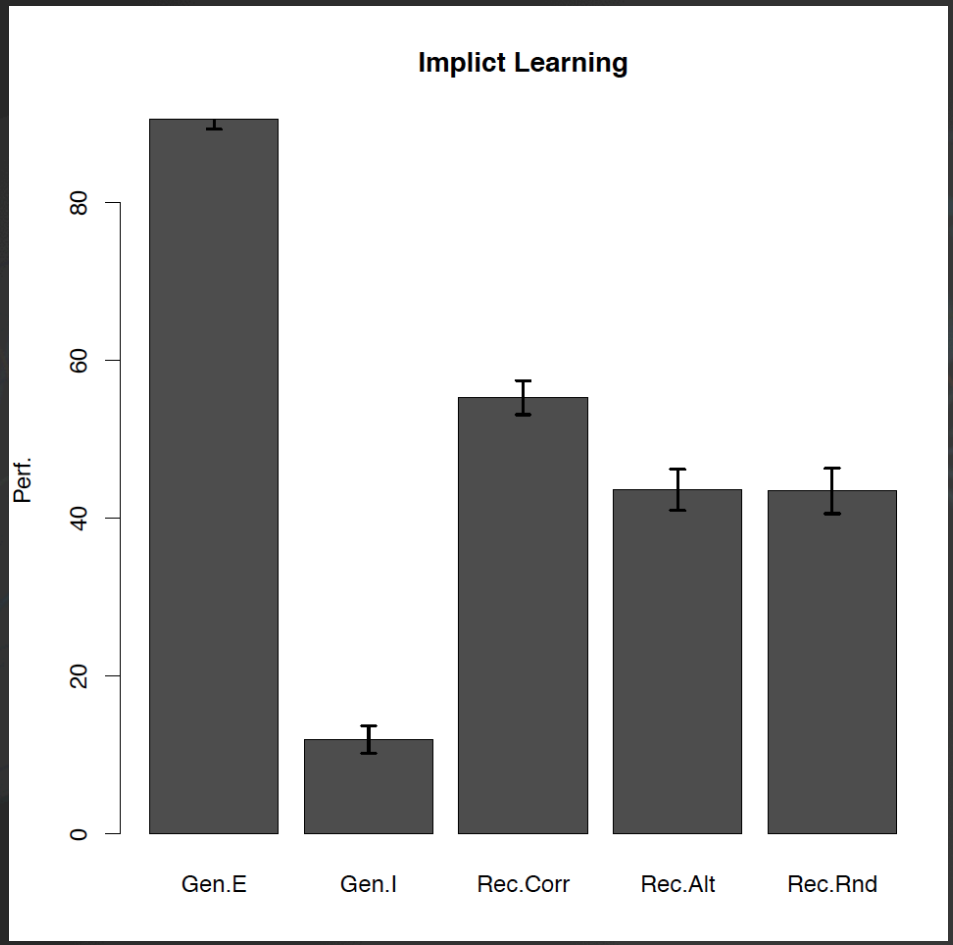




Key Question:

- Predictive learning and without the confound of motor learning component?

Implicit Learning

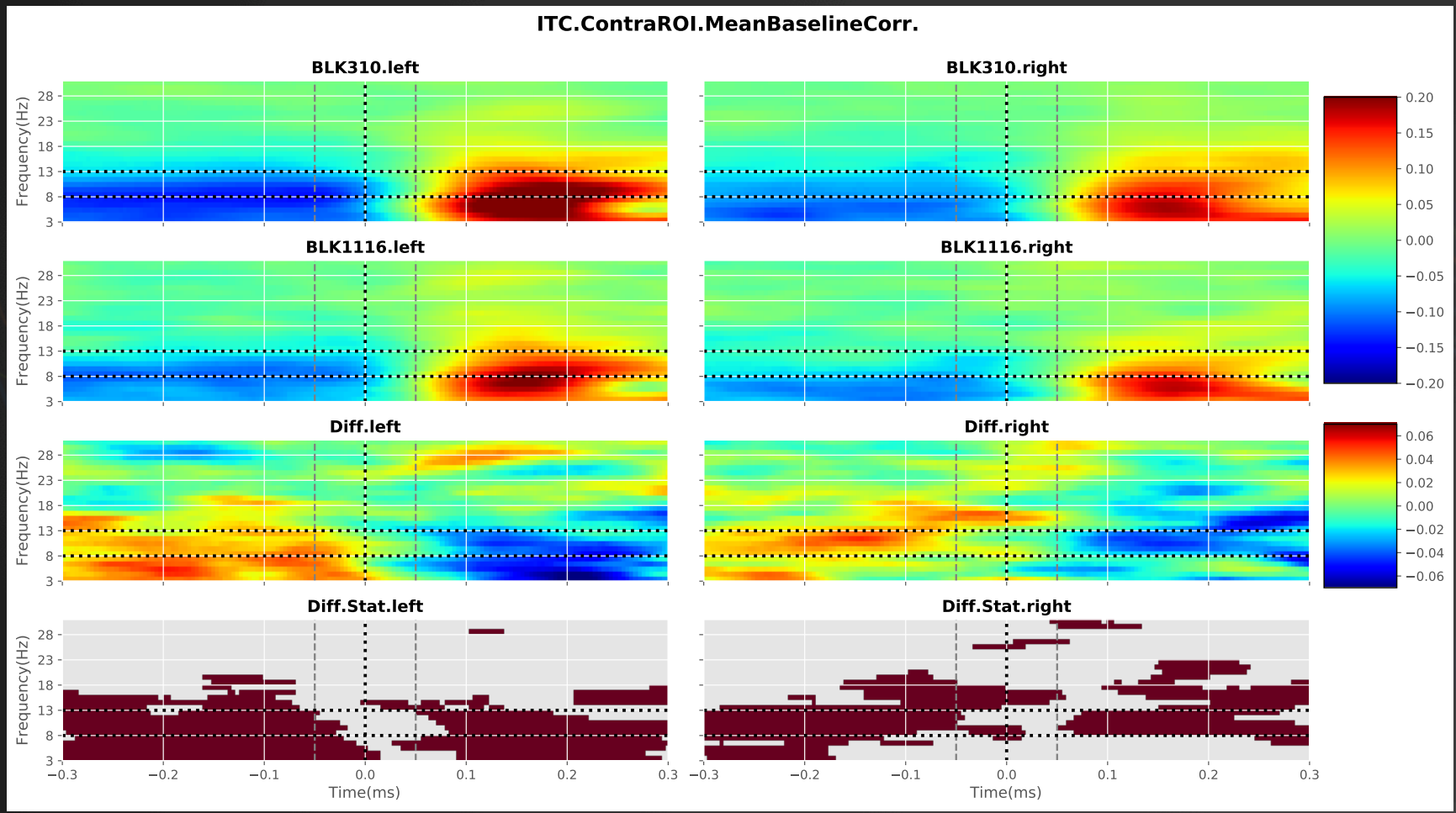


Summary

Key Findings:

- **General learning;** Faster responses over time.
- Fastest RTs in loc. right.
- Slowest RTs in loc. top.
- **Sequence-specific learning;** NO significant quadratic trend over transition blocks.
- **Consistent with Exp2.EEG**
- **Systematic** differences in different locations.

Time-frequency results



- **Pre-stim.** neg. anticipatory alpha -> **Post-stim.** pos. confirmatory alpha;
  Inline with our hypo. of temporal alpha signature.

Discussion

Discussion

The main issue

- Later windows also have catch trials

Future Work

- separate learning effects from catch trial effects by splitting earlier windows to two different groups.

Discussion

If predictive learning driving learning

- specific to the location of the upcoming target stimulus,
- not just a generic "preparatory" brain signature that could be associated with the timing.

Future Work

- Calculated the lateralization index as a difference between the activity of two hemifields.

Discussion

Key Question:

These signatures associated with,

- What frequency bands? what is their specific timing?

Future Work

- Using confirmatory tests.

Discussion

What happens when predictions are violated vs. confirmed?

- Is there evidence of this overall increase in alpha coherence during post-stimulus?
- Is it modulated by the correct (predicted) vs. incorrect (catch) prior prediction?

Future Work

- Analysing catch trials.
- Only include pre-stimulus time window data.
- Group predictive trials to faster vs. slower, or more vs. less accurate trials

Summary

Summary

- Our main hypothesis was that every alpha cycle (≈100 ms) the brain repeats a prediction-followed-by-outcome learning episode.
- To test our hypothesis, we have designed a series of sequential learning experiments where subjects have implicitly learned what will happen next.
- We believe that a main prediction of predictive learning -> distinctive brain signatures in the **alpha** band during the **pre-stimulus** window.
- We found such a signature, consistent with our hypothesis.

Acknowledgement

My Supervisors and committees

- Randall O'Reilly
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- Ananta Nair

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- Hamideh
- Marjan
- MahYas

End!