EEG correlates of decision dynamics underlying hierarchical working-memory gating

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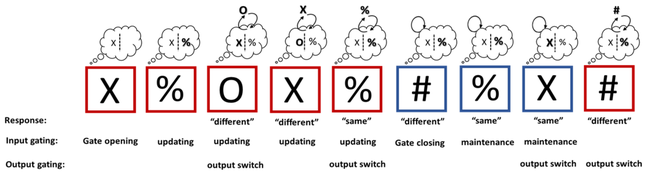
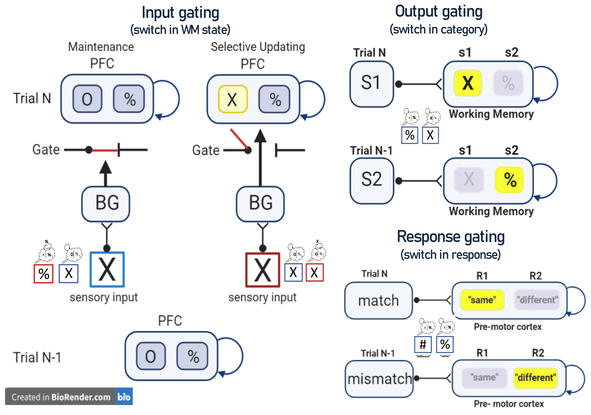
The hierarchical fronto-striatal gating model

- Effective cognitive control depends on a hierarchical gating network which regulates motor and cognitive action selection, including WM updating [1-4].
- The higher level circuit gates task-set and WM information into PFC (**"input gating"**), contextualizing gating decisions at the lower levels.
- The mid-level level circuit selects context-relevant information from the PFC (**"output gating"**) to guide response selection.
- The lower level circuit selects the motor response (**"response gating"**) that is appropriate given the output-gated information.

Methods: Selective gating paradigm (modified reference-back task)

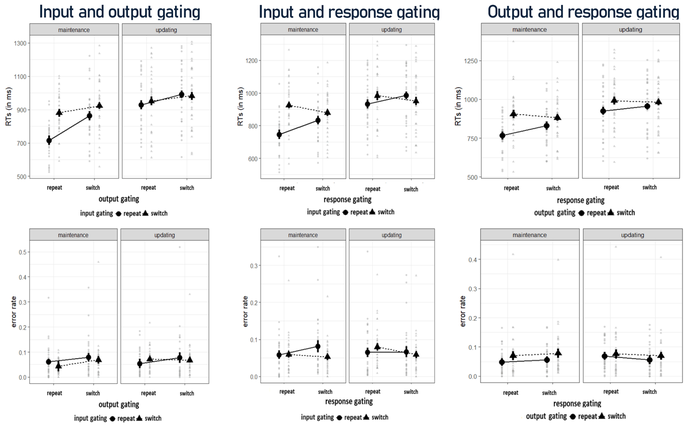


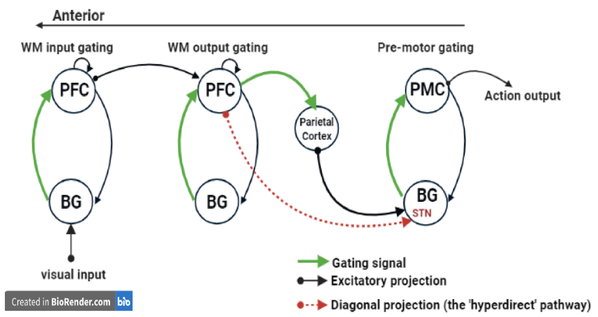
- The reference-back is a WM updating task [5] that was previously used to study the mechanisms that underlie input gating.
- In the present study, a category manipulation was added to the task to separately learn about *selective* input and output gating in humans.
- In this version of the task participants were asked to indicate whether the stimulus in each trial was the same as or different from the most recent **red stimulus** from the **same category** (letter or symbol).
- Only red trials additionally required WM updating, whereas blue trials required maintenance in WM.



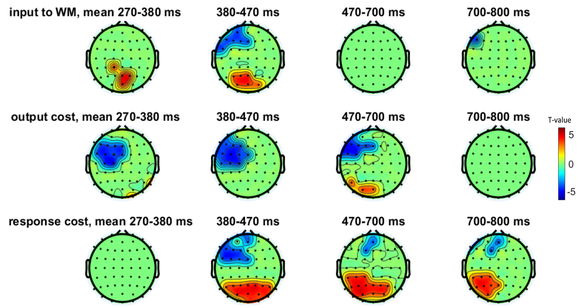
Gate switching := selecting the representation that was not selected in trial t-1.

Behavioral evidence for parallel processing across hierarchical levels



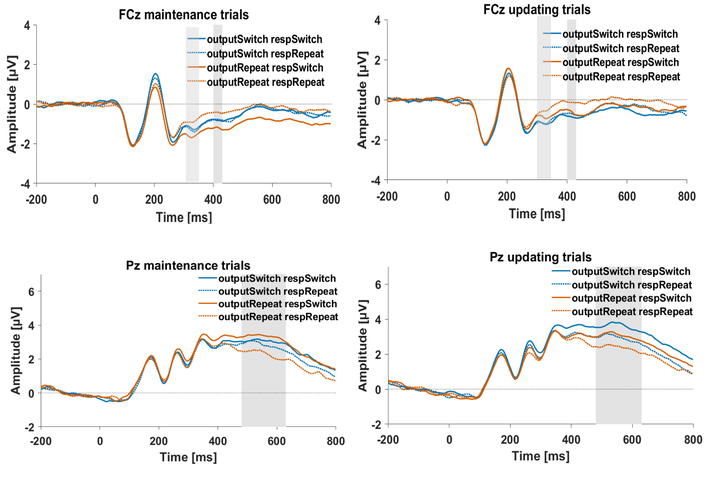


EEG GLM results

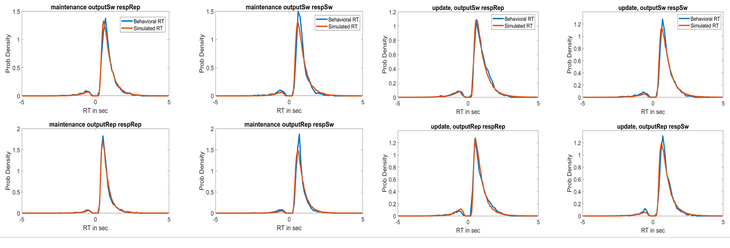


ERP evidence for hierarchical dynamic regulation

ERP at Pz and FCz exhibited respectively, elevated positive and negative activity during response switching when there is no need for higher level output gating. In Pz this effect was limited to maintenance trials.



Posterior predictive check



Model: hierarchical dynamic regulation of gating decisions

- Each gating decision is accomplished by parallel gating mechanisms.
- The "decision threshold" at the response level is raised when there is conflict at higher level frontal representations, allowing decisions to be delayed until cognitive uncertainty is resolved, via the 'hyperdirect pathway' (from mPFC to the STN)[8-9]

Prediction: neural correlates of cognitive conflict adjust decision thresholds during WM gating

EEG GLM analysis

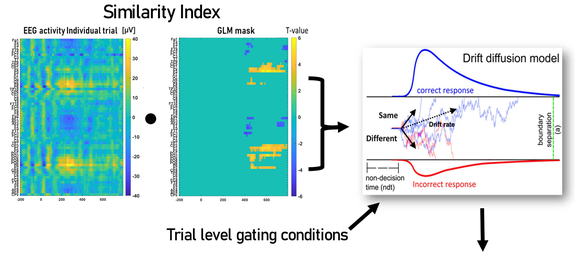
- A regression approach was used to simultaneously extract the effect of gate switches at all levels on the EEG signal, regressing out RT.
- We identified significant masks (clusters of electrodes and time points) that showed significant sensitivity to each gating decision.
- GLM masks demonstrate mostly parallel processing across levels

Hierarchical DDM with EEG decoding

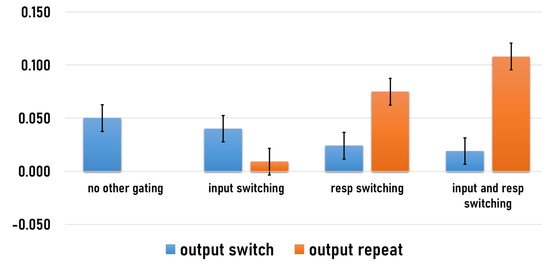
- We tested the evidence accumulation processes for selecting correct and incorrect responses during the reference-back task [6-7].
- A similarity index (dot-product) was calculated to generate a trial-by-trial index of associated cognitive process (e.g., how much is the brain in an "response gating" state).
- HDDM [8] was used to test if DDM parameters (threshold and drift-rate) were dynamically modulated by trial-to-trial variations in the EEG similarity index.

HDDM EEG evidence for hierarchical dynamic regulation

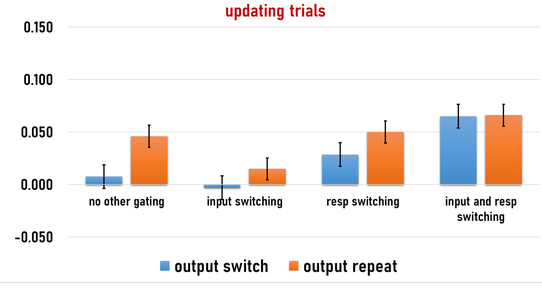
Similarity Index



Threshold adjustment during output gating by the EEG index of response switch cost
maintenance trials



Threshold adjustment during output gating by the EEG index of response switch cost
updating trials



Goal

The aim of this study was to:

- characterize the dynamics that support input, output, and response gating
- identify dynamic interactions that affect decision parameters for action selection

Summary & Conclusion

- We tested how the decision parameters (threshold and drift rate) are modulated on a trial-to-trial basis by the level of gating conflict.
- Behavior and EEG results suggest that input, output, and response gating mostly operate in parallel [1,2,4,5].
- HDDM EEG regression model showed that the EEG index of response switch cost modulated the output gating threshold. These findings demonstrated that the gating architecture follows a hierarchical top-down influence wherein the engagement of WM updating or output switching can override the motor effects in a top-down way.
- This top-down effect was also demonstrated in the ERP where the response switch activity increased when higher-level processes were *not* involved.
- The finding in FCz electrode is consistent with the idea of a mid-frontal EEG mechanism of cognitive control [11] that regulates the threshold via the mPFC-STN network [7,9] during response conflict.
- Drift rate results (not shown) suggest facilitation when parallel gating circuits are engaged in congruent gating decisions (e.g., response switching and output gate switching).

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Acknowledgements

We are grateful to Romy Frömer and Matt Nassar for generously sharing code and advice.
This research was supported by THE ISAREL SCIENCE FOUNDATION (grant No. 96/19). And by Fulbright United states - Israel Educational Foundation

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