Oscillatory and hemodynamic correlates during goal-directed Navigation: A combined EEG-fMRI study using a virtual T-maze task

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Theoretical Background

- Maze learning represents an interaction of spatial memory (medial temporal lobe) and reinforcement learning (midbrain dopamine system and prefrontal cortex)
- **Previous EEG** studies:
  - Spatial navigation: time-locked to choosing a **navigational path** [1,2]
    - **theta oscillations** over right-posterior locations
    - **latency difference** in the onset of the **NT170** in response
  - Reinforcement learning: time-locked to positive **feedback** [1,3]
    - **theta oscillations** over fronto-central locations
    - **reward positivity** masking the N2
- **Previous fMRI** studies:
  - Spatial navigation: **right parahippocampal cortex** (rPHC) as the source of the spatial-related theta effect
  - Reinforcement learning: **anterior midcingulate cortex** (ACC) as the reward-related theta effect [4]
- Aims of this study:
  1. **Replicate** results from EEG and fMRI studies using **simultaneous EEG-fMRI**.
  2. Establish a link between multimodal goal-directed navigation correlates using **multimodal data fusion**.

Methods

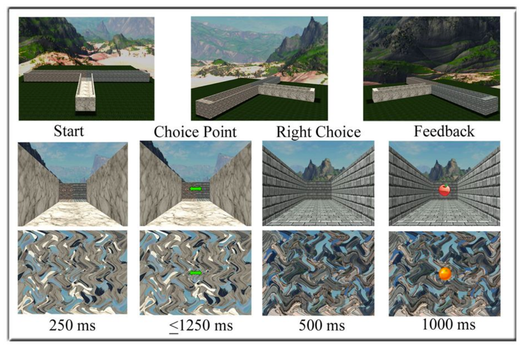

Fig. 1 T-maze task, Fig. 1 from Baker, Umemoto, Krawitz, & Holroyd (2015).

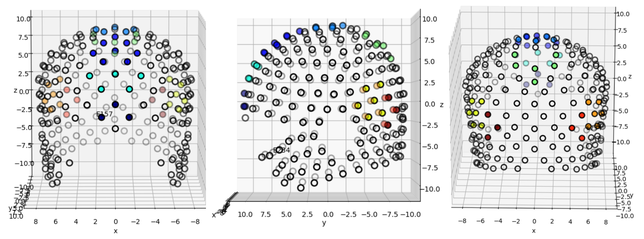

Fig. 2 Electrode clusters used in the EEG analysis to replicate standard 10-10 system electrode positions (Fpz, Fz, FCz, Cz, Pz, P8, P9, PO8, PO9).

Acquisition details

- All subjects (**N=16**) tested using MR compatible 256 channel HydroCel Geodesic Sensor Net and 4 lead ECG
- MRI data: resting state, functional T-maze task collection, structural T1, DWI
- Approx. 15 minutes of virtual T-maze (190 trials, 450 volumes)
- Localization of specific electrode positions using Global Positioning System (GPS)

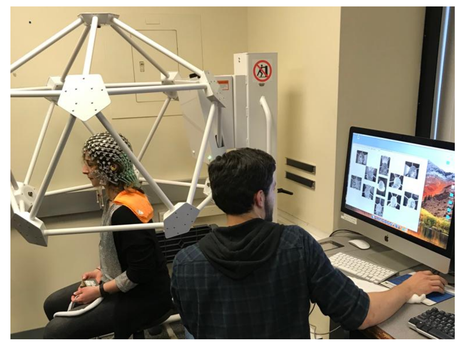

Fig. 3 GPS applied with 256 channel HydroCel Geodesic sensor net.

fMRI, EEG, & multimodal results

Aim 1: Replication (unimodal results)

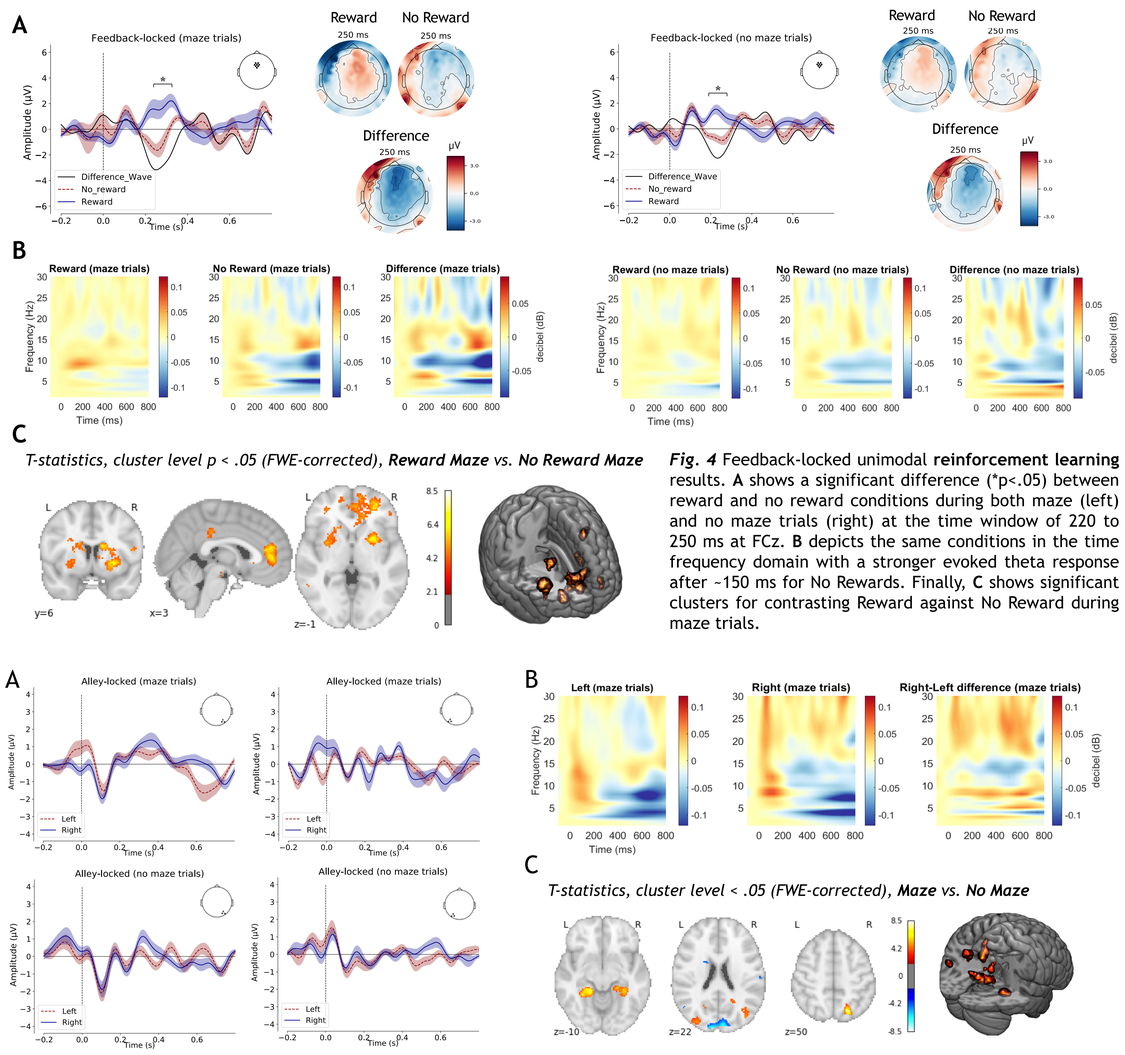

Fig. 4 Feedback-locked unimodal **reinforcement learning** results. **A** shows a significant difference (*p<.05) between reward and no reward conditions during both maze (left) and no maze trials (right) at the time window of 220 to 250 ms at FCz. **B** depicts the same conditions in the time frequency domain with a stronger evoked theta response after ~150 ms for No Rewards. Finally, **C** shows significant clusters for contrasting Reward against No Reward during maze trials.

Fig. 5 Unimodal **spatial navigation** results divided by rightward and leftward choices. **A** panels display the replication of the lateralized NT170 latency effect. Only the top left ERP (right hemisphere, maze trials) has an earlier onset of the NT170 component for right alleys. In the **B** panels, time frequency results for each alley during maze trials as well as their difference image is shown. **C** has the corresponding significant voxel clusters for contrasting navigating in a real life maze (red) as opposed to scrambled images (blue).

Left vs. Right contrast for Maze vs. No Maze, *p < .001 whole brain level*

Feedback contrast for Maze vs. No Maze, *p < .001 whole brain level*

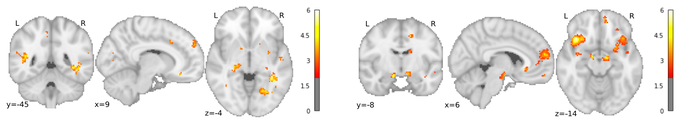

Fig. 6 Differential contrasts highlighting navigation and feedback differences between Maze vs. No Maze. Whole brain results show uncorrected voxel clusters from Left vs. Right alley (left) and Reward vs. No Reward (right) stronger for maze trials compared to no maze trials

Aim 2: Multimodal data fusion (source localization and joint ICA)

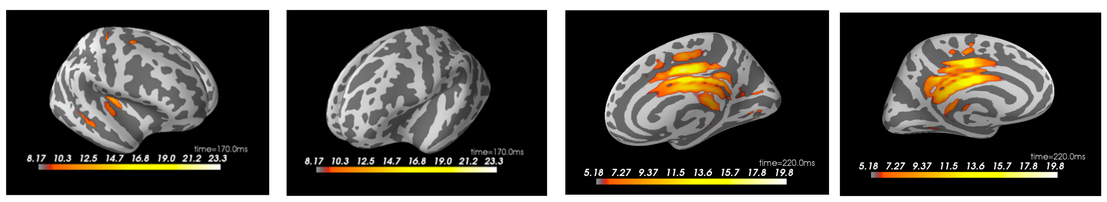

Fig. 7 Morphed group average for source localization of 3 subjects. Color-coded is the goodness of fit value for left and right hemisphere at 170 ms for the rightward NT170 grand average (left panels). Individual anatomical T1 images (source space) were coregistered with individual electrode positions (sensor space). Panels on the right show the source localization results for the reward positivity at 220 ms performed with the same subjects.

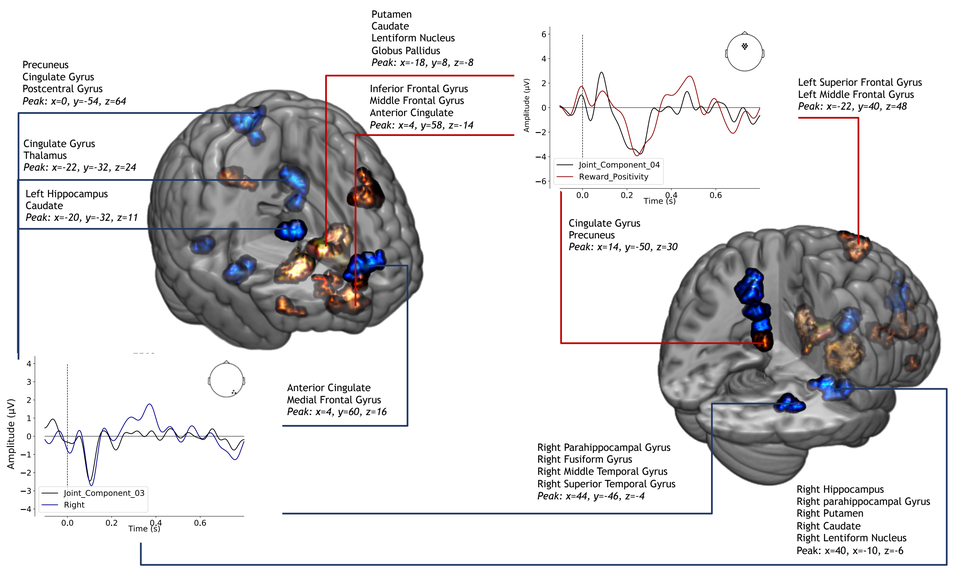

Fig. 8 Two selected components from the Joint Independent Component Analysis. Voxel clusters represent standardized Z-values thresholded at >2. Blue and red spatial clusters showed identical linear covariation to the ERP time course at FCz and PO8 respectively when extracting spatial and temporal components simultaneously from the joint mixed matrix. Black lines show the temporal variation of the extracted joint feature. Red and blue lines represent the averaged ERP (reward positivity in red, right NT170 in blue). Peak voxel positions are in MNI coordinate space.

Conclusions

- **Aim 1:** Most **EEG and fMRI** results could be replicated
  - Both reward positivity and NT170 latency difference between alleys were found
  - Despite increased background noise, time frequency results yielded similar trends as in previous studies
  - Consistent spatial navigation (hippocampus, PHC, precuneus) and feedback clusters (ACC and dorsolateral prefrontal cortex)
- **Aim 2:** Identified spatio-temporal patterns of EEG-fMRI data with jICA …
  - … linking reward positivity after feedback to medial prefrontal regions and ventral striatum …
  - … and NT170 time-locked to navigating through right alleys of the maze to right hippocampal and parahippocampal clusters
- **Future directions:**
  - Test prefrontal-parahippocampal interaction by analyzing theta-gamma coupling: Prefrontal induced gamma power and parieto-occipital theta power, accompanied by activations in the respective spatial clusters

References

[1] Baker, T. E., & Holroyd, C. B. (2008). Which way do I go? Neural activation in response to feedback and spatial processing in a virtual T-maze. *Cerebral Cortex*, *19*(8), 1708-1722.

[2] Baker, T. E., & Holroyd, C. B. (2013). The topographical N170: electrophysiological evidence of a neural mechanism for human spatial navigation. *Biological psychology, 94*(1), 90-105.

[3] Li, P., Baker, T. E., Warren, C., & Li, H. (2016). Oscillatory profiles of positive, negative and neutral feedback stimuli during adaptive decision making. *International Journal of Psychophysiology, 107*, 37-43.

[4] Baker, T. E., & Holroyd, C. B. (2008). Which way do I go? Neural activation in response to feedback and spatial processing in a virtual T-maze. *Cerebral Cortex*, *19*(8), 1708-1722.

Github repository:

Lab website: