Prefrontal lesions disrupt oscillatory signatures of spatiotemporal integration in working memory

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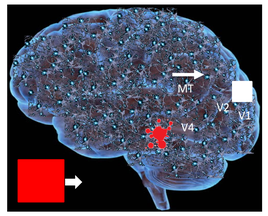
Introduction

- **Background: feature binding problem**
  - To perceive the world, the brain must constantly bind different features into a unified representation, e.g., "a red square in motion"
  - Feature integration theory (FIT) focuses on attention [1]
  - Binding-by-synchrony (BBS) focuses on synchrony between regions of visual cortex [2]

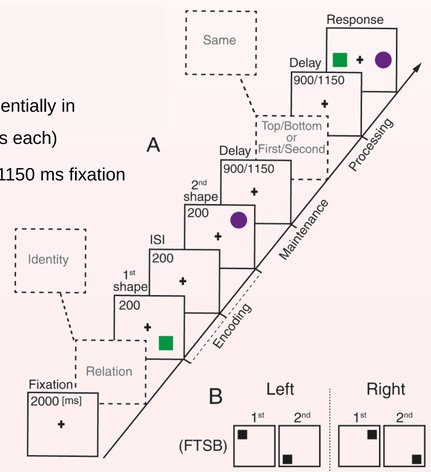


- **Question: from perception to memory**
  - **How does the human brain integrate the constant influx of spatial and temporal information into unified mnemonic representations?**
- **Aims**
  - Define oscillatory signatures of spatiotemporal integration in working memory
  - Investigate role of prefrontal cortex (PFC) in spatiotemporal integration

Task and behavior

A) Working memory task

1. **Pretrial**: 2000 ms fixation
2. **Encoding**: 2 shapes presented sequentially in top/bottom spatial orientation (200 ms each)
3. **Maintenance (analyzed here)**: 900/1150 ms fixation
   → Test cue presented mid-delay
4. **Processing**: 900/1150 ms fixation
5. **Response**: self-paced

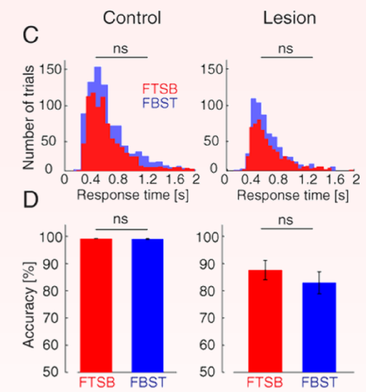


B) Spatiotemporal conditions

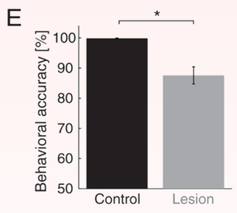
- **FTSB**: 1st stimulus in top position, 2nd stimulus in bottom position
- **FBST**: the reverse

C, D) Conditions equal in difficulty

- No differences in RT (p > 0.5) or accuracy (p > 0.3)`

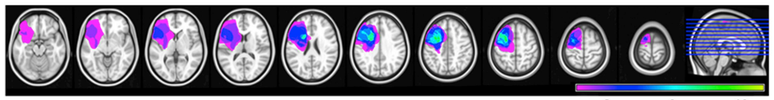


E) PFC lesions impair accuracy ($p < 10^{-9}$)



EEG Methods

- **Participants**: 14 PFC lesion patients, 20 healthy controls [3]



Color bar: number of patients with lesions at specified site

- **Power** computed in 5 frequency bands: delta (δ; 2-4 Hz), theta (θ; 4-7 Hz), alpha (α; 8-12 Hz), beta (β; 13-30 Hz), gamma (γ; 30-50 Hz)
- **Functional connectivity** computed using phase lag index (PLI) [4]
- **Phase-amplitude coupling (PAC)** computed using oscillation-triggered coupling [5]

Results

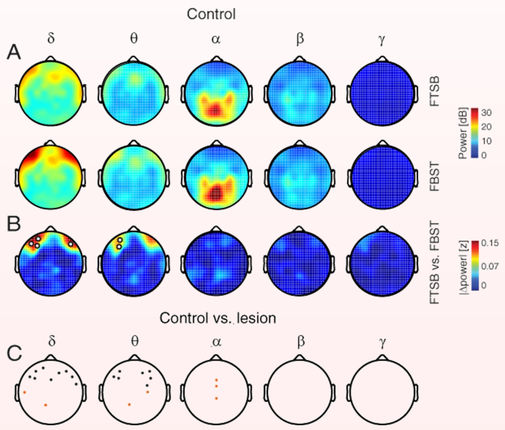
PFC lesions diminish frontal δθ signatures of spatiotemporal integration

A) Power during maintenance of FTSB and FBST conditions in controls

B) Integration (|FTSB-FBST|) in controls

C) PFC lesions diminish integration

- Black, control > lesion
- Orange, lesion > control



PFC lesions selectively diminish δθ connectivity signatures of spatio-temporal integration

A) Computation of PLI

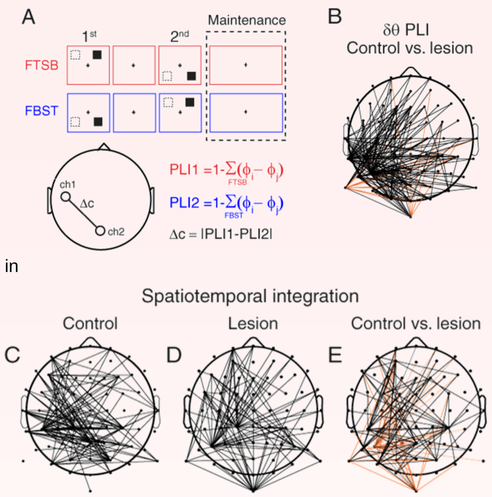
B) PFC lesions diminish PLI independent of feature binding

- Black, control > lesion
- Orange, lesion > control

C, D) Integration (|FTSB-FBST|) in controls and lesion patients

E) PFC lesions diminish PFC-posterior integration, but not lateral-mesial posterior integration

- Black, control > lesion
- Orange, lesion > control



PFC lesions diminish mesial posterior α-γ PAC signatures of spatiotemporal integration

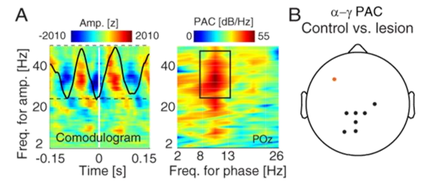
A) Posterior α-γ PAC in controls

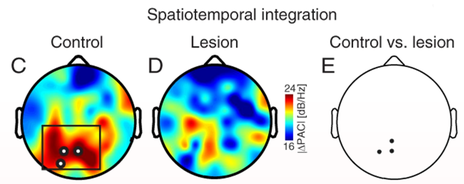
B) PFC lesions diminish PAC independent of feature binding

- Black, control > lesion
- Orange, lesion > control

C, D) Integration (|FTSB-FBST|) in controls and lesion patients

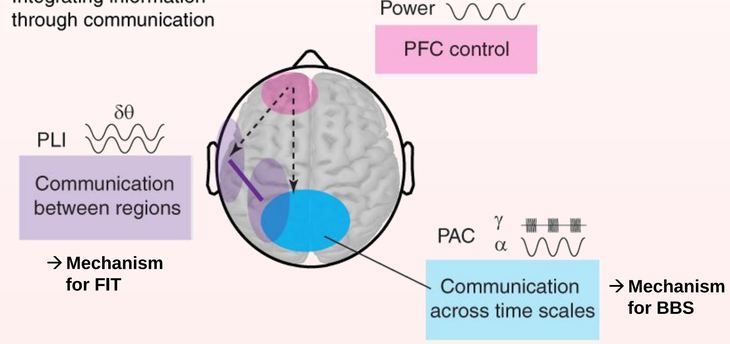
E) PFC lesions diminish integration





Conclusions

Oscillatory synchrony supports spatiotemporal integration with PFC input



References

1. **Treisman AM, Gelade G** (1980). A feature-integration theory of attention. *Cogn. Psychol.* 12
2. **Gray CM, König P, Engel AK, Singer W** (1989). Oscillatory responses in cat visual cortex exhibit inter-columnar synchronization which reflects global stimulus properties. *Nature* 338
3. **Johnson, EL, Dewar, CD, Solbakk, A-K, Endestad, T, Meling, TR, & Knight, RT** (2017). Bidirectional frontoparietal oscillatory systems support working memory. *Current Biology* 27
4. **Aydore S, Pantazis D, Leahy RM** (2013). A note on the phase locking value and its properties. *NeuroImage* 74
5. **Dvorak D, Fenton AA** (2014). Toward a proper estimation of phase–amplitude coupling in neural oscillations. *J. Neurosci. Methods* 225

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