Effective EEG Connectivity Analysis of Episodic Memory Retrieval

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Talk Outline

- Background
- Research Goals
- Methods
- Experimental Results
- Conclusion & Discussion

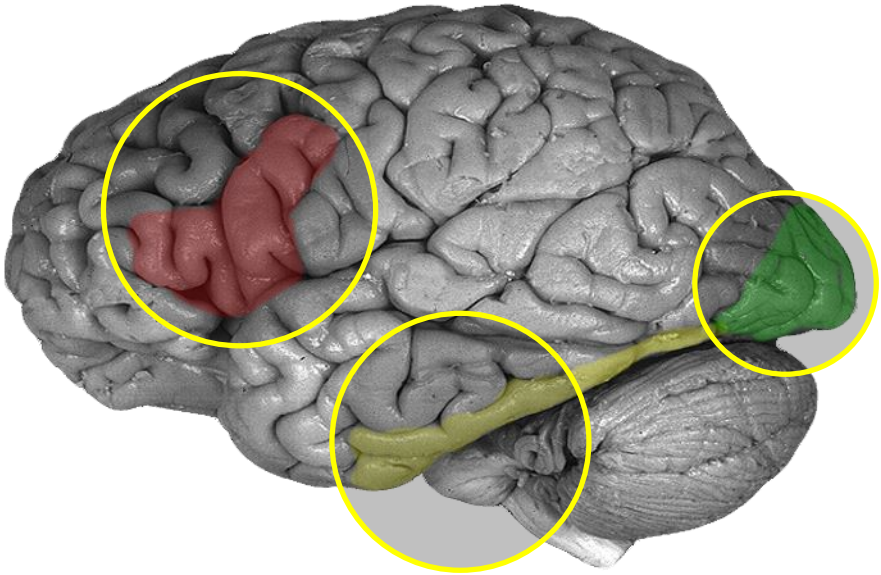
Background

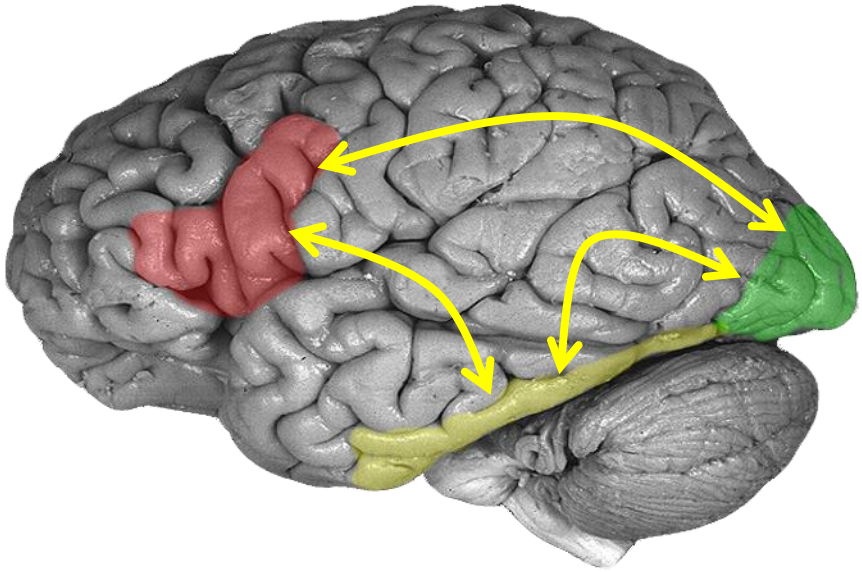
- **Functional Segregation:**

  Different areas of the brain are specialized for different functions

- **Functional Integration:**

  Networks of interactions among specialized areas → **Connectivity**

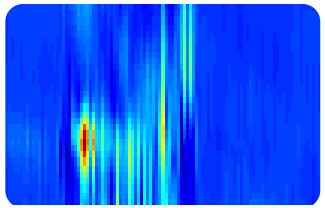


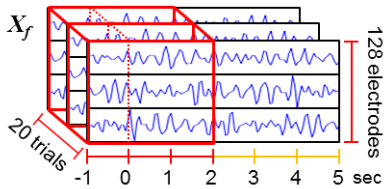


※ Hanneke den Ouden 2009, *SPM Course at Zurich*

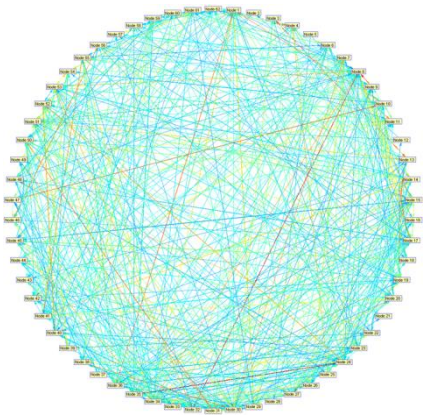
Research Goals

- **To study the information flows of the human brain network**
  - **During episodic memory retrieval**
  - **Partial and direct information within the human brain**





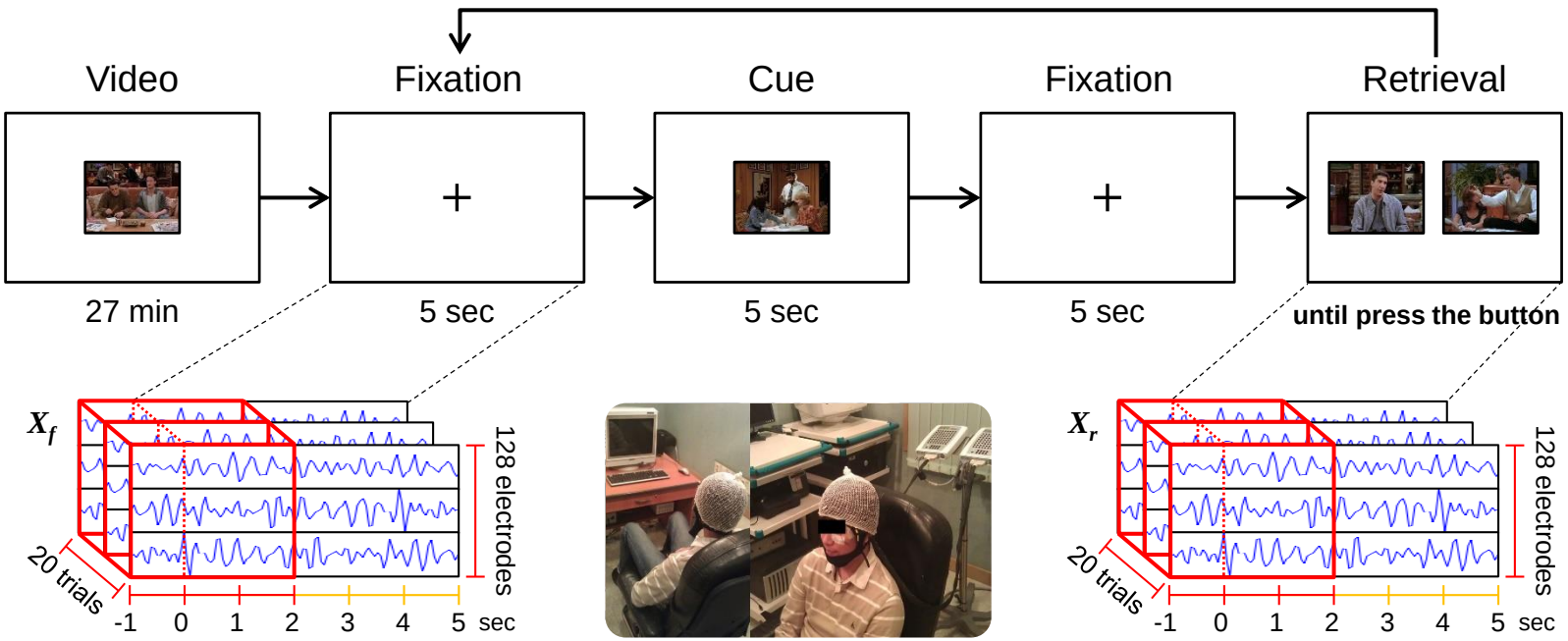
- **Based on effective connectivity measured from EEG**
  - **Source localization technique for estimating the activity of the neuronal sources**
  - **The strength and spectro-anatomical patterns of the inter-areal interactions**
  - **Direct directed transfer function**
  - **Time-varying multivariate autoregressive model**



- **Graph theoretical analysis**
  - **Topological interactions across the brain regions**

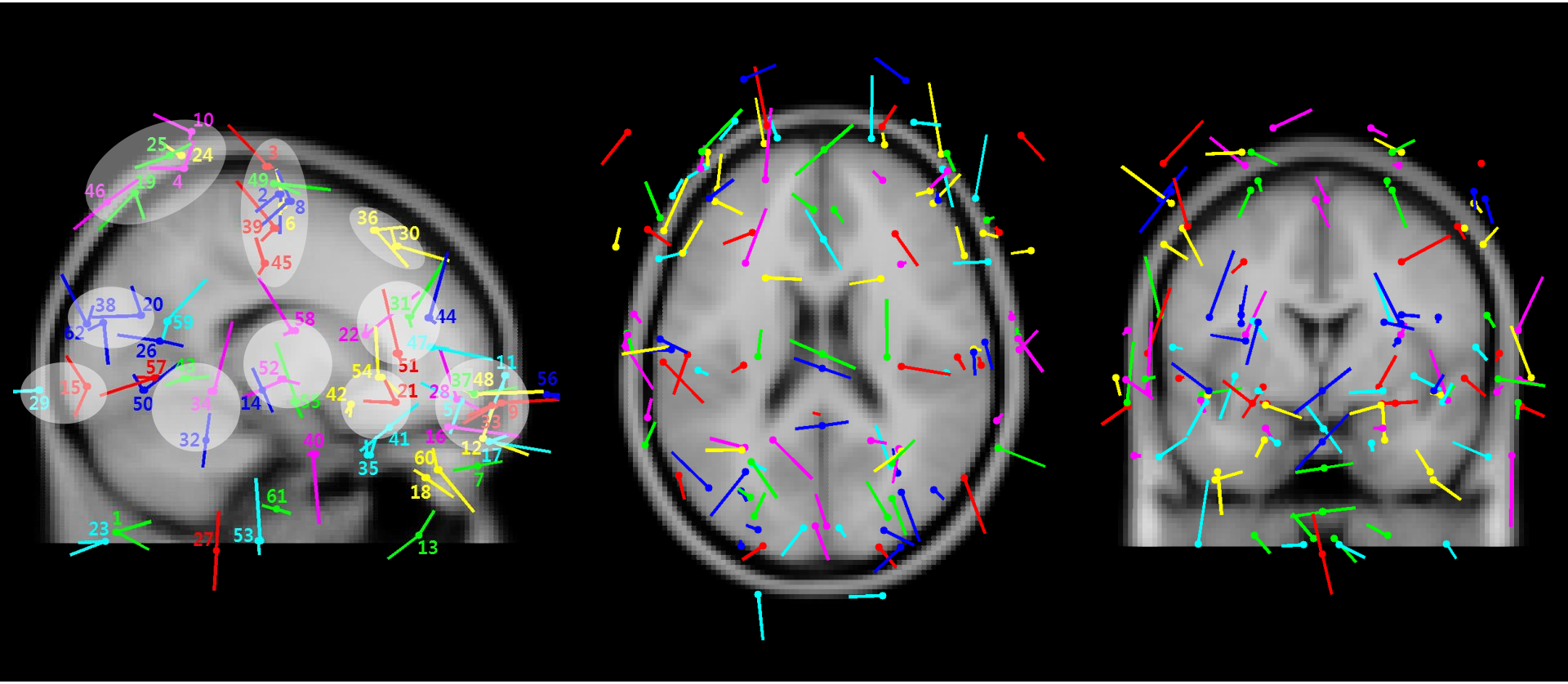
Methods

- **Behavioral Task**
  - The episodic memory retrieval game after watching a video
  - Participants decide whether the order of the two presented images are correct or incorrect.
- **EEG Acquisition**
  - EEG signals were sampled at 1000 Hz using an EEG cap equipped with 128 electrodes
  - Timestamp of all sessions are automatically recorded by the game program



Methods

- **Source Localization**
  - Fitting dual symmetric equivalent dipole model to each source signal (N = 62)
  - Using DIPFIT2 in EEGLAB with a four-shell spherical head model



Methods

- **Direct directed transfer function (dDTF)**
  - A measure based on the transfer function matrix between channels.
    - Transfer function matrix: an SVD of the cross-spectral density matrix
  - A combination of partial coherence and directed transfer function (DTF)

DTF	$\gamma_{ij}^2(f) = \frac{\lvert Y_{ij}(f)\rvert^2}{\sum_{n=1}^{k}\lvert Y_{in}(f)\rvert^2}$
ffDTF	$\eta_{ij}^2(f) = \frac{\lvert Y_{ij}(f)\rvert^2}{\sum_f \sum_{n=1}^{k}\lvert Y_{in}(f)\rvert^2}$
Power spectrum	$S(f) = Y(f)VY^*(f),$
Partial coherence	$\chi_{ij}^2(f) = \frac{R_{ij}^2(f)}{R_{ii}(f)R_{jj}(f)},$
dDTF	$\delta_{ij}(f) = \chi_{ij}(f)\,\eta_{ij}(f)$

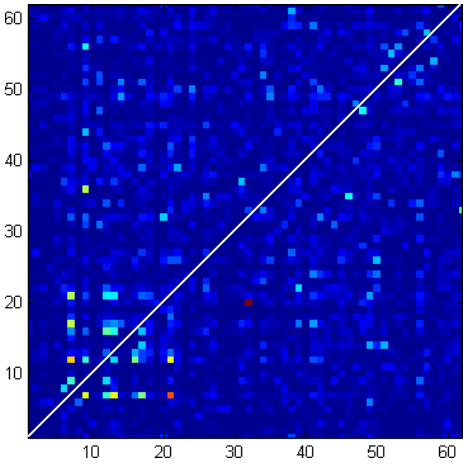
  - Time-varying dDTF can be obtained by using a sliding-window MVAR model
    - Window length: 500 ms, Step size: 10 ms

    → **251 windows** (0-500, 10-510, … , 2500-3000 ms)

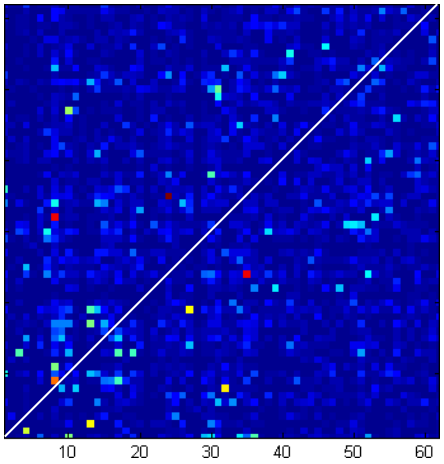
Experimental Results

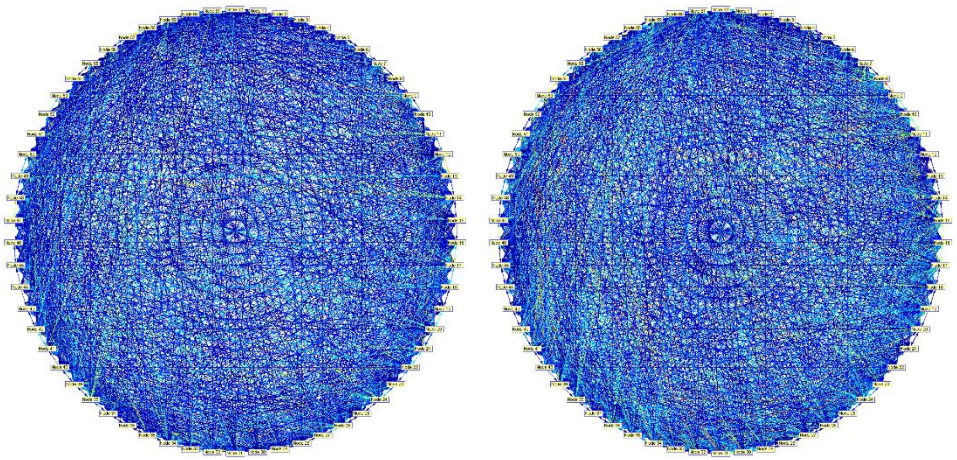
Frequency = 8 Hz; Time = 300 ms

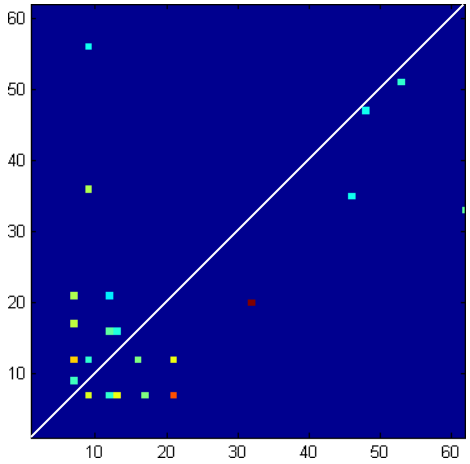
Fixation (threshold = 1e-05)



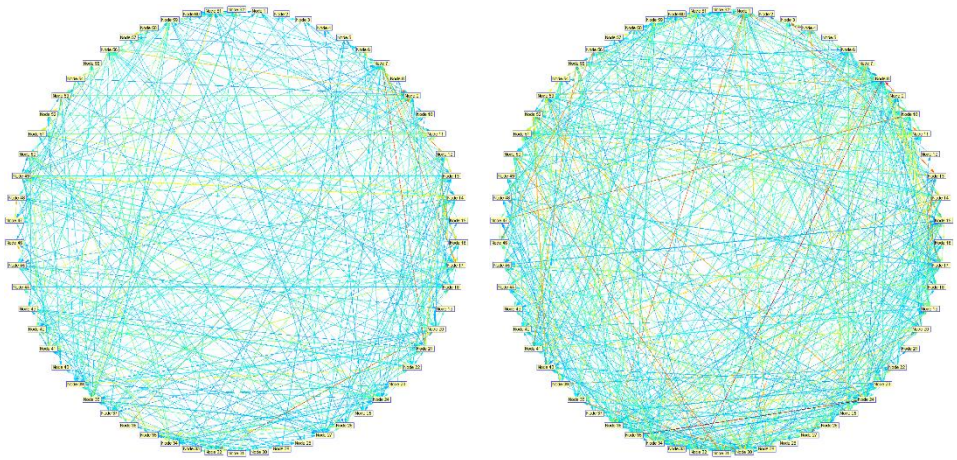
Retrieval (threshold = 1e-05)



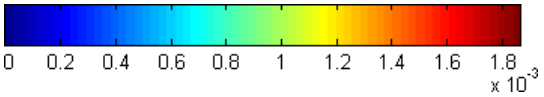


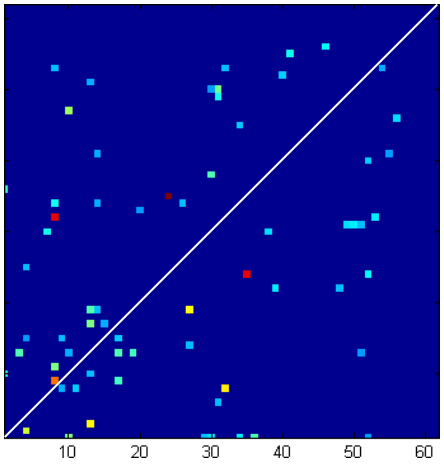


Fixation (threshold = 5e-04)



(Color of edges are exaggerated for better visualization)

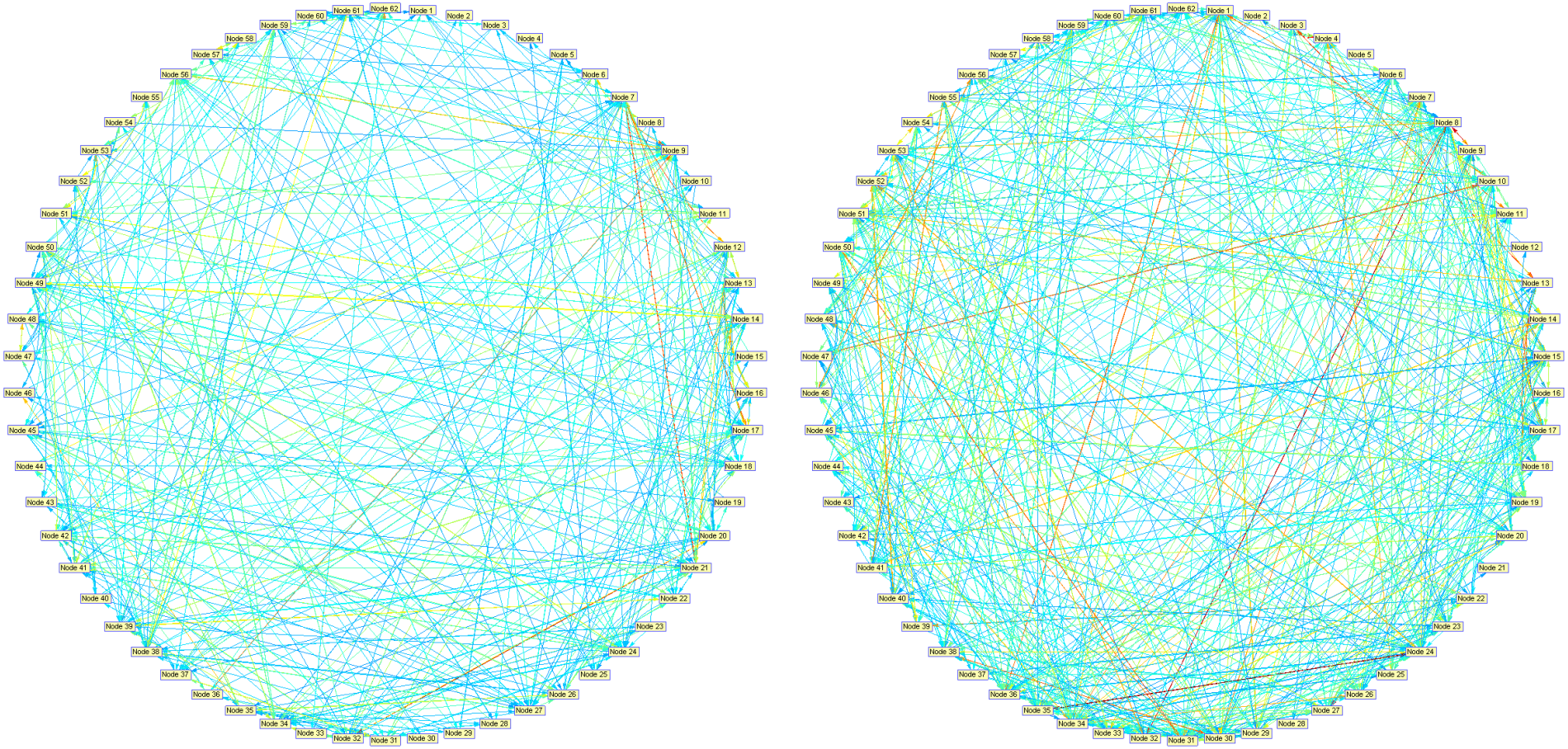




Retrieval (threshold = 5e-04)

Experimental Results

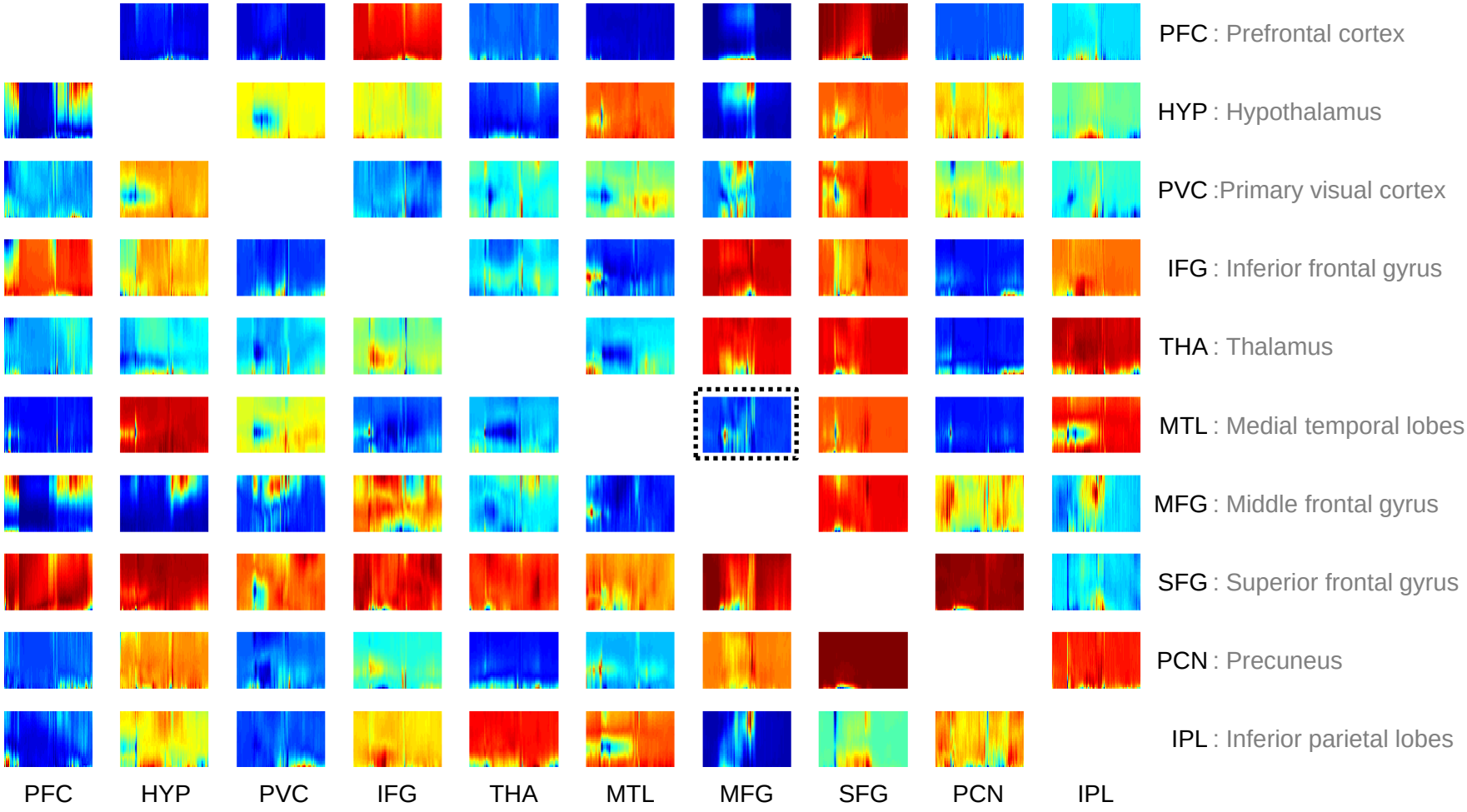
- **Mean dDTF Network Graph** (threshold = 5e-4)



Fixation Frequency = 8 Hz; Time = 300 ms Retrieval

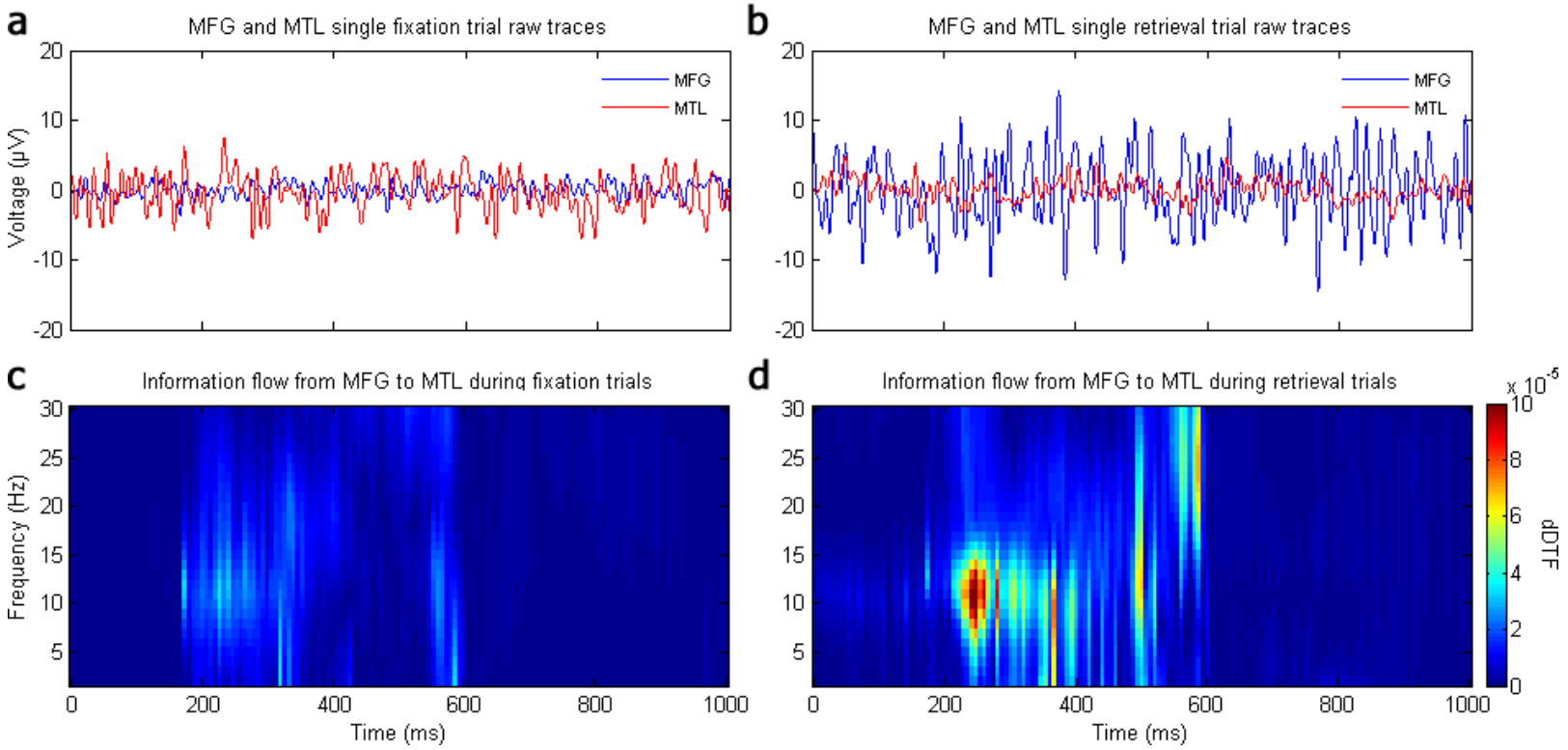
Experimental Results

- **Active Brain Regions during Retrieval Tasks (Retrieval – Fixation)**



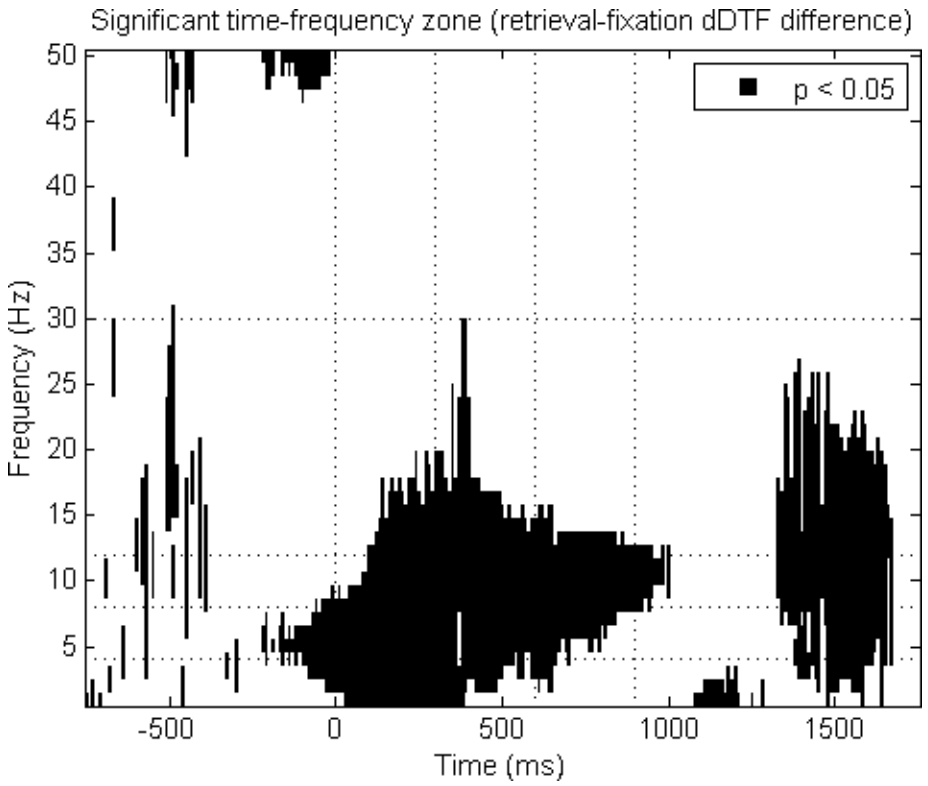
Experimental Results

- **Example of the Increased Information Flow**
  - Information flow from MFG to MTL in retrieval task is higher than in fixation
  - Oscillatory powers of MFG in retrieval task is also increased but has no direction
  - Which frequency and time bands are significant?



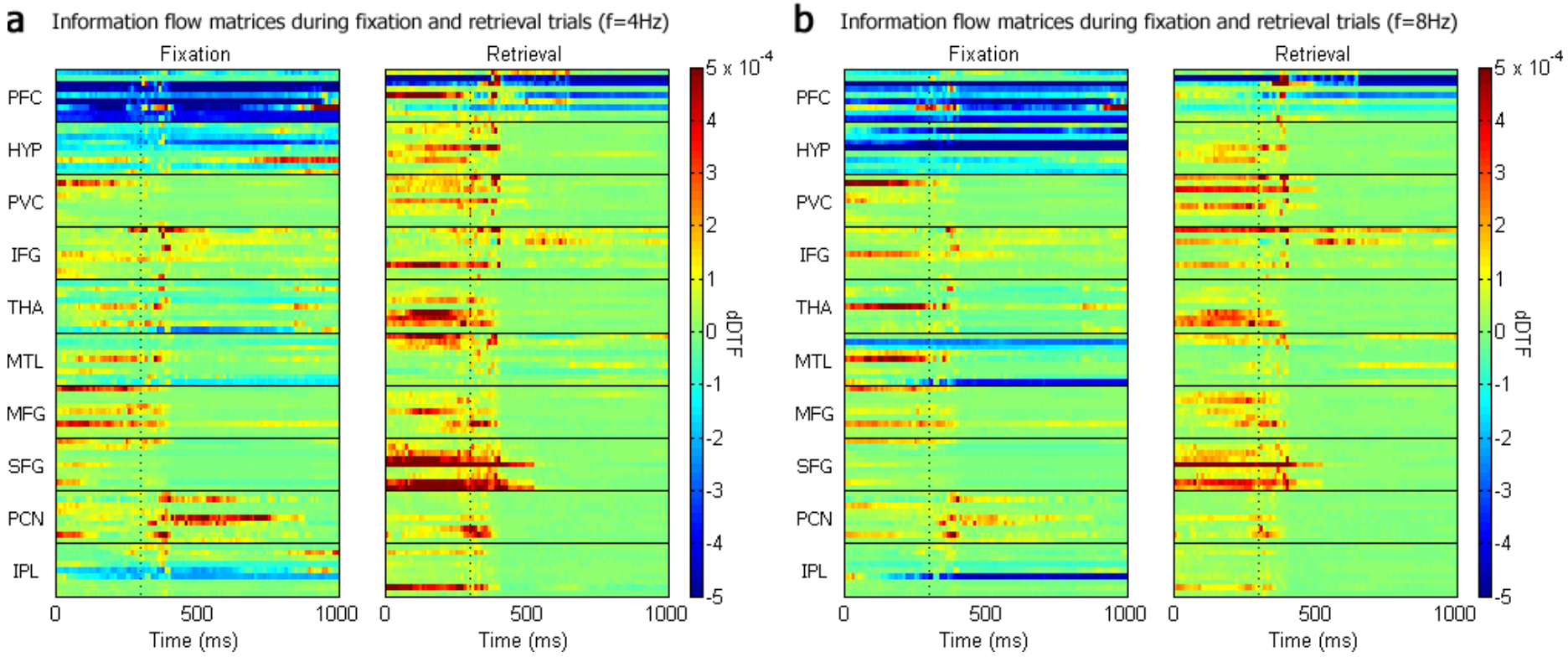
Experimental Results

- **Significant Time-Frequency Zone**
  - Significantly different dDTF between fixation and retrieval tasks
    - Two-sample *t*-test → $p < 0.05$
  - Time band: 0 ~ 1000 ms
  - Frequency band: 2-30 Hz
  - Differences around 1500 ms were not considered
    - Too delayed from the onset of stimuli
    - Irrelative facts



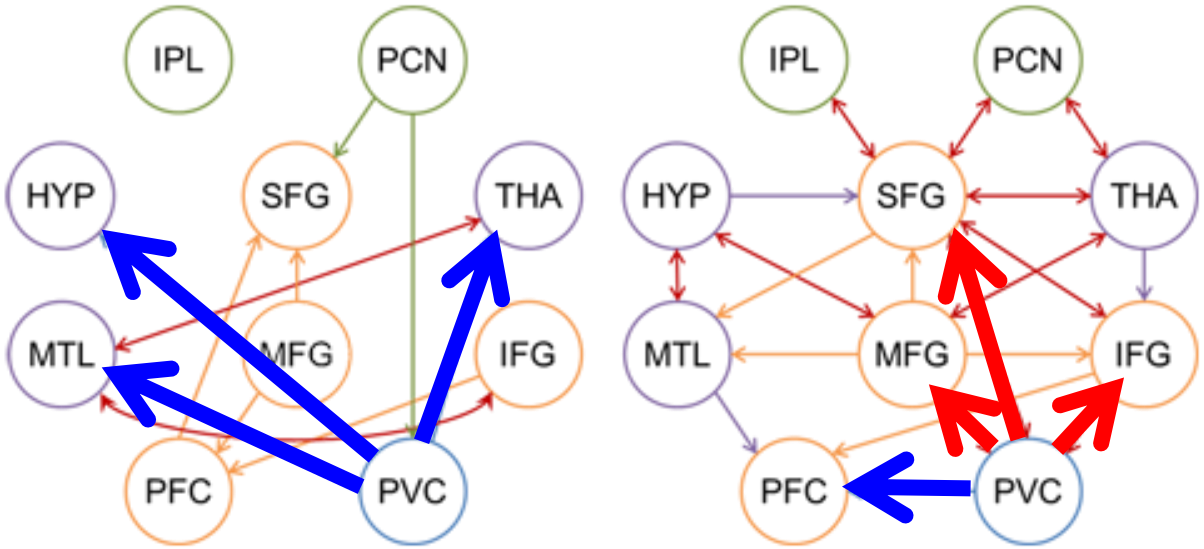
Experimental Results

- **Information Flows are Increased in Active Brain Regions**
  - Statistically meaningful increases in most of the 90 pairs during retrieval tasks
  - $p_{t\text{-}test} < 0.05$ (76 pairs in 4 Hz and 80 pairs in 8 Hz)



Experimental Results

- **Networks of the Effective Connectivity Shows:**
  - **Topological interactions across the brain regions**
    - **Fixation: sparse local networks** in the frontal and occipital-medial temporal area
    - **Retrieval: densely interconnected network**
  - **Asymmetrical features**
    - **PVC-temporal/occipital regions vs PVC-frontal regions**
    - **PCN→SFG vs PCN←SFG**
  - **Hub node: SFG** (globally connected with overall brain regions)

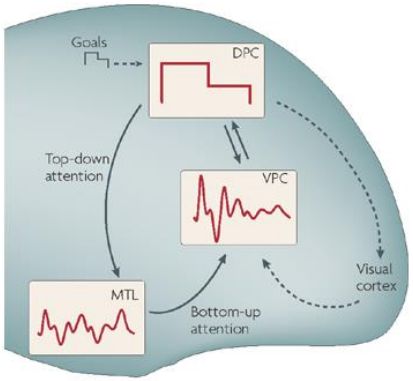


Conclusion & Discussion

- **Information flows during episodic memory retrieval**
  - Between frontal cortex, medial temporal, parietal and occipital lobes
  - Globally interconnected effective connectivity network
  - Across 2~30 Hz frequency band and 0~1000 ms time band

- **Graph theoretical analysis**
  - SFG acted as a hub in the network during memory retrieval
  - SFG is a key component of the neural network of memory process
  - **Participation of SFG is triggered by the highest level of executive processing** (Boisgueheneuc et al., 2006)

- **Asymmetric information flows between brain regions**
  - PVC-temporal/occipital regions vs PVC-frontal regions
  - PCN→SFG: non-retrieval; PCN←SFG: retrieval
  - **The dual process model of attention to memory** (Cabeza, 2008)



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THANK YOU!