Effective EEG Connectivity Analysis of Episodic Memory Retrieval

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Talk Outline

- Background
- Research Goals
- Methods
- Experimental Results
- Conclusion & Discussion
• **Functional Segregation:**
  Different areas of the brain are specialized for different functions

• **Functional Integration:**
  Networks of interactions among specialized areas \( \rightarrow \) 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
    \[ \gamma_{ij}^2(f) = \frac{|Y_{ij}(f)|^2}{\sum_{n=1}^{k}|Y_{in}(f)|^2} \]
  - ffDTF
    \[ \eta_{ij}^2(f) = \frac{|Y_{ij}(f)|^2}{\sum_{f} \sum_{n=1}^{k}|Y_{in}(f)|^2} \]
  - Power spectrum
    \[ S(f) = Y(f)VV^*(f), \]
  - 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

Fixation (threshold = 5e-04)

Frequency = 8 Hz; Time = 300 ms

Retrieval (threshold = 5e-04)

Fixation (threshold = 1e-05)

Retrieval (threshold = 1e-05)

(Color of edges are exaggerated for better visualization)
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)*

  - PFC: Prefrontal cortex
  - HYP: Hypothalamus
  - PVC: Primary visual cortex
  - IFG: Inferior frontal gyrus
  - THA: Thalamus
  - MTL: Medial temporal lobes
  - MFG: Middle frontal gyrus
  - SFG: Superior frontal gyrus
  - PCN: Precuneus
  - IPL: Inferior parietal lobes
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
  - $P_{t-test} < 0.05$ (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** (Boisgueneuc 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)
THANK YOU!