Structure of the cortical network during successful memory encoding of TV commercials

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Experimental Question

The events we experience in the course of our lives fall into general categories:

• **Those we remember**

• **Those we do not**

Can we predict those events that are likely to initiate the later formation of a memory trace?
Memory structure (Squire & Knowlton, 1994)

Declarative memory (explicit)
- Episodic (events)
  - Experiences particular to time/place
  - MTL, PFC
- Semantic (facts)
  - World/word, language knowledge,
  - MTL, PFC

Non-declarative memory (implicit)
- Procedural
  - Motor, cognitive skills
  - Basal ganglia, Cerebellum
- Perceptual
  - Perceptual priming
  - Association cortex

[Brain diagrams showing MTL, PFC, Cerebellum, Association cortex]

Brain-imaging methods with a high temporal resolution are needed to shed light on the time course of encoding-relevant brain dynamics.
Reading Brain Activity

Portable

[Diagram showing the relationship between EEG, ERP/MEG, PET, and FMRI in terms of space (mm) and temporal resolution (ms).]
Cortical Activity

- High-resolution EEG means a body of techniques that provide for a higher spatial resolution (mm)

1) Large number of sensors

64-128 electrodes disposed according to an extension of the 10-20 international system

2) Realistic Models of Head Structures

Scalp, skull, dura mater and cortex compartments were segmented from MRIs and tessellated with about 5000 triangles. Lead Field matrix $A$ takes in account the different conduction effects of the structures between Scalp and Cortex

3) Linear Inverse Problem

$$\xi = \arg \min_x \left( \|Ax - b\|_M^2 + \lambda^2 \|x\|_N^2 \right)$$

Babiloni et al., *Neuroimage*, 2005
Cortical Activity Propagation

Functional neuroimaging brain maps reveal *where* the cortical activations appear.

The central question is *how* the activity propagates among different cortical regions.

How to define the information flow between two cortical signals?

**Granger causality (1969):** an observed time series $x(n)$ causes another series $y(n)$ if knowledge of $x(n)$’s past significantly improves prediction of $y(n)$: $x(t) \rightarrow y(t)$;

$$y(n) = a_1x(n-1) + a_2x(n-2) + a_3x(n-3)+...+...$$

$$\text{Err ( } y \rightarrow x \text{ ) } >> \text{Err ( } x \rightarrow y \text{ )}$$
Partial Directed Coherence is a spectral measure, used to determine the directed influences between any given pair of channels in a multivariate data set (Baccalà and Sameshima, 2001).

It is computed on a Multivariate Autoregressive model (MVAR) that simultaneously models the whole set of signals $X$

$$\sum_{k=0}^{p} A(k)X(t-k) = E(t)$$

Time domain

$$A(f)X(f) = E(f)$$

Frequency domain

$PDC_{ij}(f) = \frac{|A_{ij}(f)|}{\sum_{m=1}^{L} |A_{im}(f)|^2}$

$PDC_{ij}$ estimates the DIRECT influence of the channel $j$ toward the channel $i$
Graph Theory

A graph is a mathematical model that represents the interactions within a network. It is composed of nodes and connections.

- Nodes: electrodes, cortical areas, single neurons
- Edges: synchronous activities, causal relationships, chemical interactions

Brain networks can also be conceptualized as graphs:
- Nodes: electrodes, cortical areas, single neurons
- Edges: synchronous activities, causal relationships, chemical interactions

Typical Brain Networks Estimated

COHERENCE
COHERENCE PHASE DIFF.

MVAR METHODS (PDC)
Measures of Global Interaction

Path: a sequence of edges linking two vertices in the graph

Efficiency

The “Efficiency” is a quantity recently introduced in (Latora and Marchiori, 2001) to measure how efficiently the nodes of the network communicate if they exchange information in parallel.

The efficiency $e_{ij}$ in the communication between vertices i and j is defined to be inversely proportional to their shortest path: $e_{ij} = 1/d_{ij}$

- Global Efficiency is defined as the average efficiency of the graph on global scale (analogous of Characteristic Path Length, Watts and Strogatz, 1998)

$$E_{glob} = \frac{1}{N(N-1)} \sum_{i\neq j} e_{ij}$$

It represents a measure for the presence of wide-scope interactions

Random networks have generally high values of global efficiency
Measures of Local Clustering

Sub-graph: the model obtained by removing a node and its connections from the original graph

- Local Efficiency is the average of all the sub-graphs’ global efficiencies (analogous of Cluster Index. Watts and Strogatz, 1998)

\[ E_{loc} = \frac{1}{N} \sum_i E_{glob}(A_i) \]

It represents the tendency of the graph to form clusters of nodes highly connected

Regular networks have generally high values of local efficiency
Hi-Res EEG

Functional Connectivity Graph Theory

Processing EEG Data

Raw EEG signals

Artefacts

Detrending

Filtering

Pre-Elaboration

Features Extraction

Directed Graphs

Graph Theory

Features Extraction

Statistical Validation

Activity estimation on segmented cortical areas

Connectivity estimation among different regions of interest
Each commercial break consists of six different spots

A lifelike experiment!

Experimental Design

Neutral Documentary (~40 min)
Day Memory test for commercials
1 2 3 4 5 7 6 8 9 10 11 12 13 14 15

Film showing

Memory test for commercials
(Retrieval)

Classification based on behavioural measures of memory

EEG recording during video commercials
(Encoding)

Day 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Remembered Commercials (RMB)

Forgotten Commercials (FRG)
Results

De Vico Fallani et al., *Clinical Neurophysiology*, in press

PDC

FRG

Alpha frequency band
(EEG oscillations between 8 and 12 Hz)

RMB
Results

- Distance was inversely proportional to the link weight: \( d_{ij} = \frac{1}{w_{ij}} \)
- Efficiency indexes were scaled by the mean value from 100 random graphs
- ANOVA statistics was performed with a test-level equals to 0.05

The evident decrease of local-efficiency in the Alpha band during encoding activity reflects a significant drop of clustering connections within the functional brain network.

De Vico Fallani et al., *Clinical Neurophysiology*, in press
Conclusions

The obtained results indicate that during the time of encoding it is possible to extract from the brain significant features that are predictive of accurate recall.

In the Alpha band, the significant decrease of local clustering connections during encoding activity probably reflects the presence of attentional and semantic processes. These processes are known to decrease the synchronicity of the Alpha oscillations of the EEG signals.

Other graph measures could be applied in order to characterize concisely the functional network dynamics in the human brain.