Mapping the brain network dynamics of self-relevant thoughts with EEG microstates & fMRI resting state analysis

Lucie Bréchet

14.2.2019

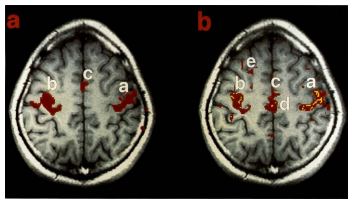
The Functional Brain Mapping Lab (FBM)
Laboratory for Functional and Metabolic Imaging (Lifmet)

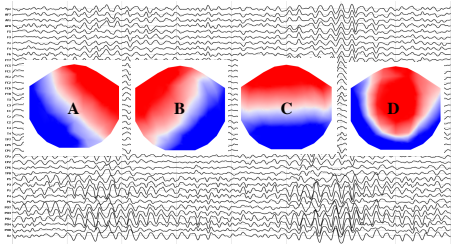
École Polytechnique Fédérale de Lausanne & University of Geneva

The precise functional role of large-scale brain networks at rest is far from clear

fMRI RESTING STATES
(seconds)

EEG MICROSTATES
(sub-seconds)





SPONTANEOUS FLUCTUATIONS

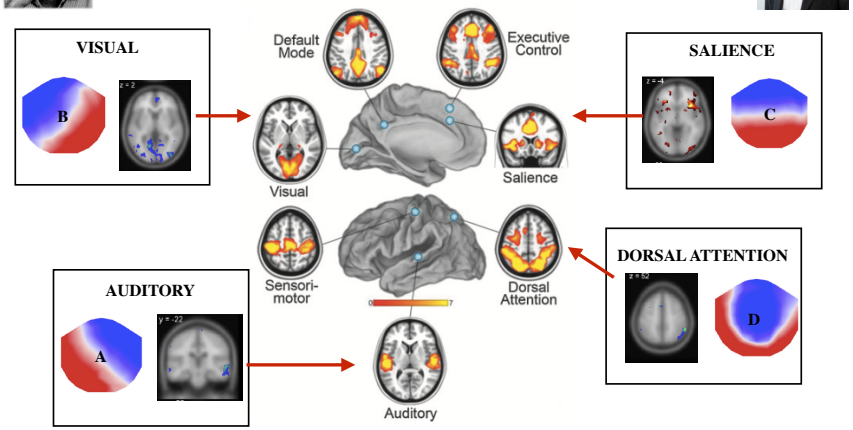
TASK ACTIVATION

How is resting brain activity, whether slow (0.1Hz/10sec) BOLD fluctuations or fast (10Hz/100ms) changes in EEG topographies, functionally related to specific cognitive activity?

Biswal et al., *Mag. Res. Med.*, 1995; Lehmann et al., *Clin. Neurophysio.*, 1987

Functional interpretation of RSNs & EEG microstates based on large-scale cognitive networks in problematic

- functional significance of EEG microstates is based on fMRI RSNs



Spatial similarity between networks at rest and during cognitive tasks suggests similar underlying mental activity.

Britz et al., *NeuroImage*, 2010; Van de Ville et al., *PNAS*, 2011; Smith et al., *PNAS*, 2009

The relationship between states observed at rest & states observed during cognitive tasks

- RSNs cannot explain functions of cognitive networks

RESTING-STATE NETWORKS	COGNITIVE FUNCTION NETWORKS
• CONNECTED	DISCONNECTED
• DISCONNECTED	CONNECTED
• ONE ROLE WITHIN RSN	MULTIPLE ROLES IN CFNs
• ROLE WITHIN RSN	ROLE VARIES ON TASK

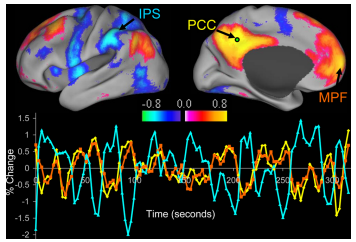
How can we claim that resting brain activity can explain large-scale cognitive networks, if we know that RSNs are spatially different from cognitive networks?

Campbell & Schacter, *Lang., Cog. & Neuroscience*, 2016; Davis et al., *Lang., Cog. & Neuroscience*, 2016

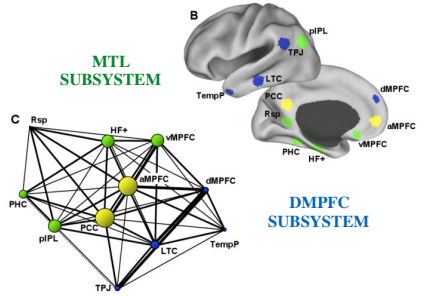
How is the spontaneous mentation functionally related to large-scale networks?

- different networks are linked to different thoughts

"TASK-NEGATIVE NETWORK"



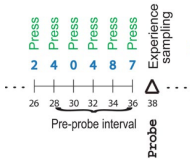
ACTIVE COGNITIVE PROCESSES

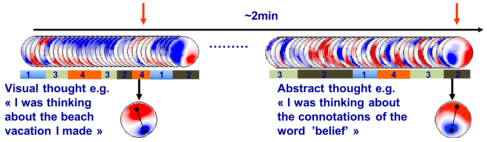


Spontaneous mentation is studied by linking resting-state activity with cognitive processes by using post-scan questionnaires.

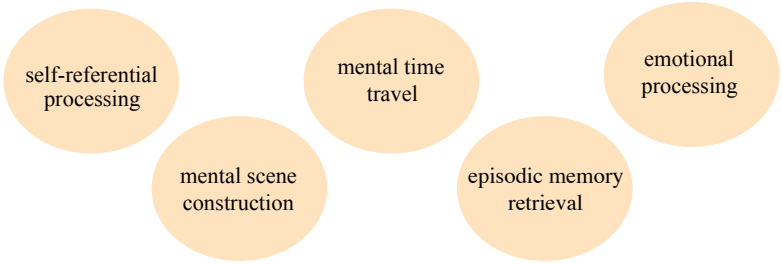
Fox et al., *PNAS*, 2005; Andrews-Hanna et al., *Neuron*, 2010

What are the approaches to study spontaneous mentation?





What is the functional role of default mode network in cognition?



The default mode network is involved in many types of internal processing.

Christoff et al., *PNAS*, 2009; Lehmann et al. 1998

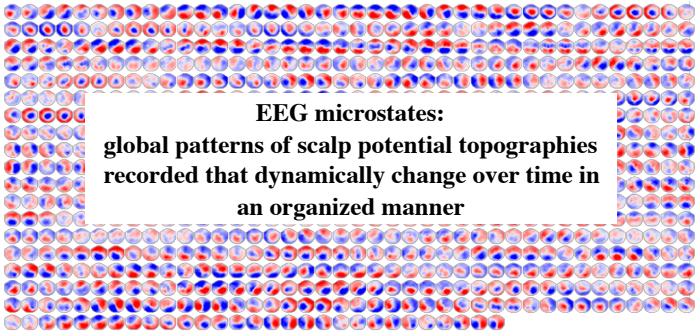
Dynamic fMRI resting state networks

- numerous fMRI studies explored spontaneous fluctuations of ongoing brain dynamics during rest

Large-scale neuronal networks have to change very rapidly and flexibly to adapt to momentary thoughts or to incoming stimuli. They have to reorganize in different spatial patterns on a sub-second time scale.

Bressler, *Brain Res Rev.*, 1995; Karahanoglu & Van de Ville, *Nature Commun.*, 2015

Spatio-temporal analysis of spontaneous EEG

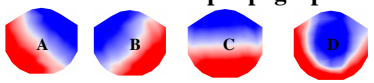


EEG microstates:
global patterns of scalp potential topographies recorded that dynamically change over time in an organized manner

***k*-means cluster analysis:**
groups the topographies with high spatial correlation & defines the descriptive topographies

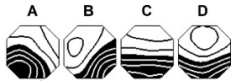
meta-criterion:
defines the number of clusters

most dominant map topographies



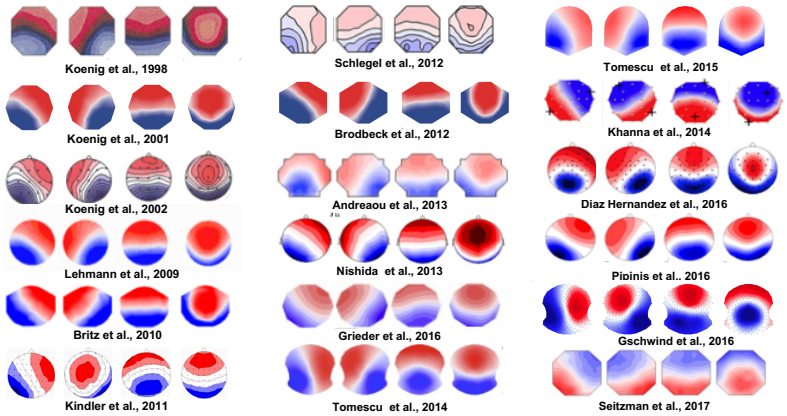
Pacual-Marqui et al., *IEEE*, 1995; Michel & Koenig, *NeuroImage*, 2017

4 most dominant EEG topographical maps



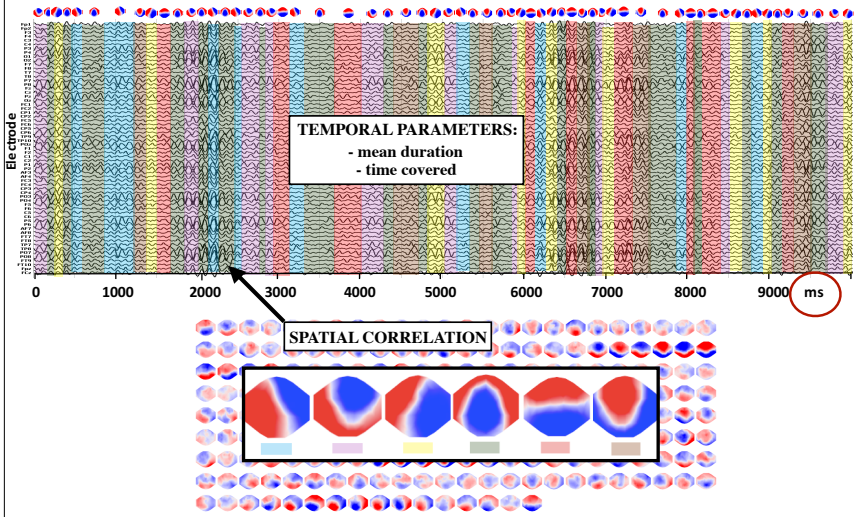
Lehmann et al., 2003

- while the four microstate maps are very distinct from one another, they are highly reproducible across studies



Michel & Koenig, *NeuroImage*, 2017

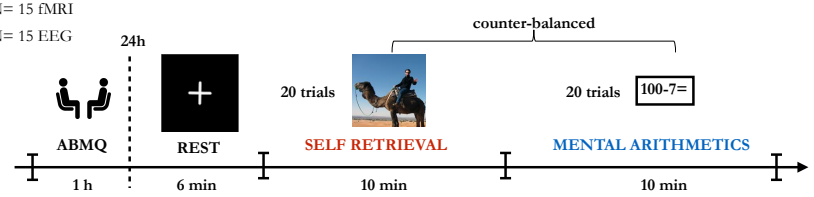
Temporal dynamics of EEG microstates



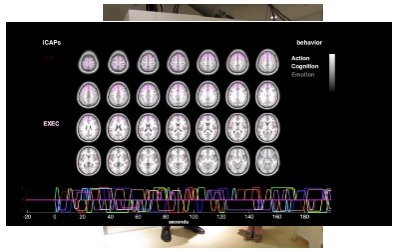
Michel & Koenig, *NeuroImage*, 2017

Are EEG microstates related to specific mental functions & can they be influenced by external or internal manipulation of thoughts?

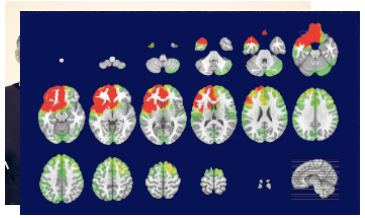
N= 15 fMRI
N= 15 EEG



7T MRI scanner



64-channels EEG



Siemens, Erlangen, Germany

Brain Products, Munich, Germany

Manipulation of resting state networks by instructed mentation

PROPERTIES OF EPISODIC AUTOBIOGRAPHICAL MEMORY

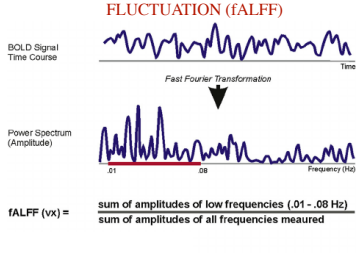
Variable	Brief Description of Rating Scale	Experiments
	Recollection and Belief	
Reliving	I am reliving the original event.	All
Back in time	I travel back to the time when it happened.	All
Remember/know	I remember it rather than just knowing it happened.	All
Real/imagine	I believe the event in my memory really occurred.	All
Persuade	I could be persuaded that my memory was wrong.	3
Accurate	Distorted versus as accurate as a neutral observer.	3
Testify	Would you be confident enough to testify in court?	3
	Component Processes	
See	I can see it in my mind.	All
Setting	I can recall the setting where it occurred.	All
Spatial	I know the spatial layout.	2, 3
Hear	I can hear it in my mind.	All
Talk	I or other people are talking.	All
In words	It comes to me in words.	All
Story	It comes to me as a coherent story.	All
Emotions	I can feel now the emotions that I felt then.	All
	Reported Properties of Events or Memories	
Importance	It is significant for my life.	All
Rehearsal	I have thought or talked about this event.	All
Once/many	It occurred once at one particular time.	All
Merged/extended	A merging of events versus an extended event.	All
Age of memory	Please date the memory (month/day/year).	All

- **directly examine the functional significance of spontaneous mentation by creating a well-controlled task, as close to rest as possible, which would allow us to directly manipulate the inner thoughts**

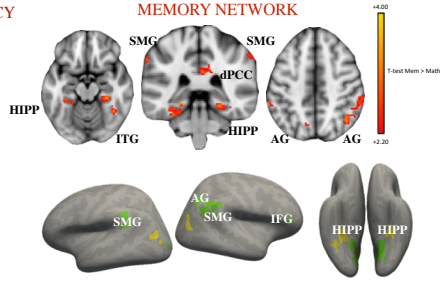
Rubin et al., *Memory & Cognition*, 2003

fMRI: INSTRUCTED MENTATION ACTIVATED NETWORK RELATED TO MEMORIES

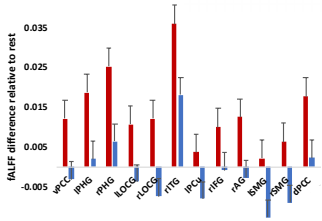
FRACTIONAL AMPLITUDE OF LOW-FREQUENCY FLUCTUATION (fALFF)



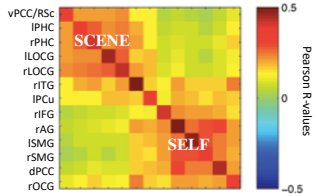
MEMORY NETWORK



fALFF DIFFERENCES RELATIVE TO REST

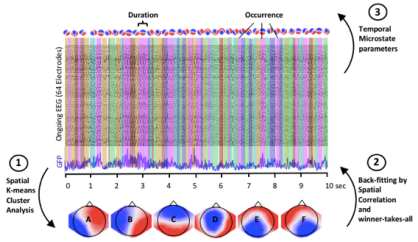


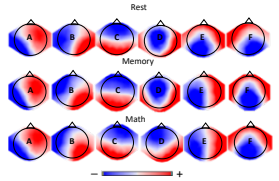
CONNECTIVITY ACROSS fALFF DERIVED ROIs



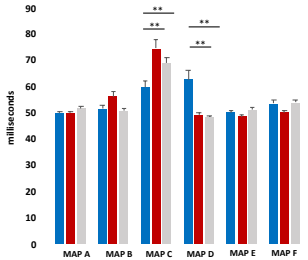
Bréchet et al., NeuroImage *(in revision)*, 2019

EEG: TEMPORAL DYNAMICS OF SPECIFIC MICROSTATES WERE MANIPULATED ON SUB-SECOND SCALE

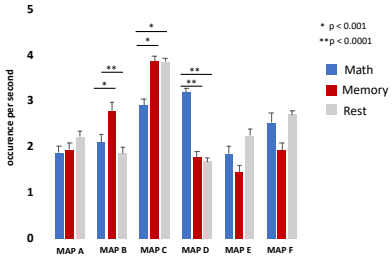




DURATION

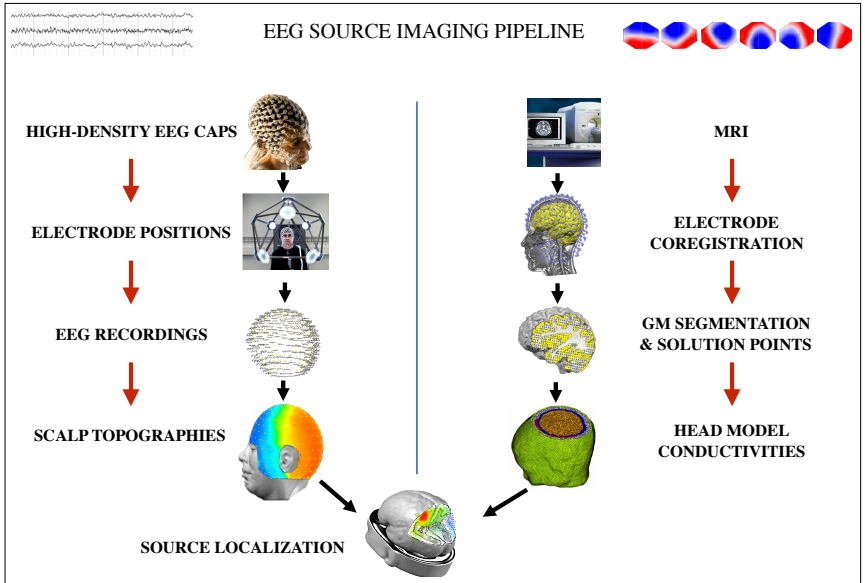


OCCURRENCE



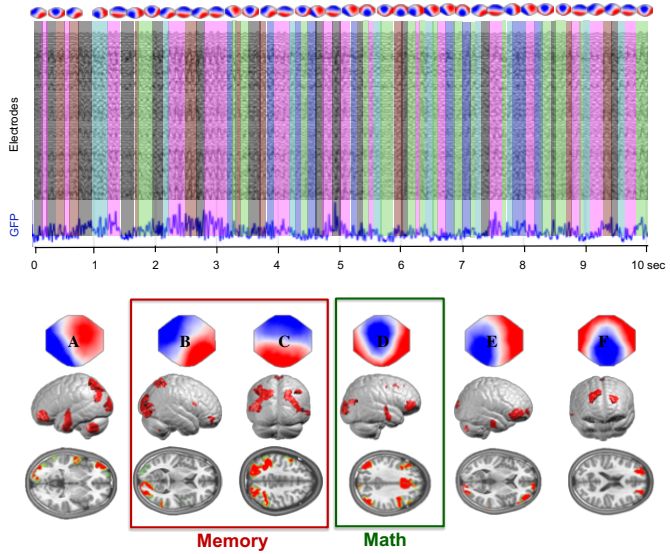
Bréchet et al., NeuroImage *(in revision)*, 2019

EEG SOURCE IMAGING PIPELINE



to estimate the current density distribution that best explains the maps recorded at any moment in time

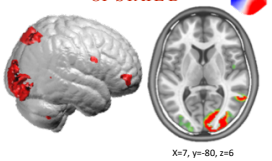
EEG source localization of microstates



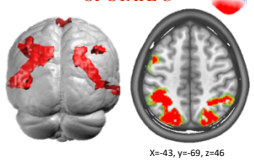
Bréchet et al., NeuroImage *(in revision)*, 2019

EEG: SOURCE LOCALIZATION CONFIRMED ACTIVATION OF NETWORKS RELATED TO EPISODIC MEMORIES & MATH CALCULATION

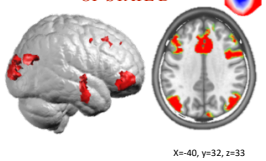
SOURCE LOCALIZATION OF STATE B



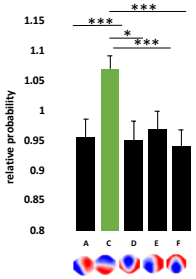
SOURCE LOCALIZATION OF STATE C



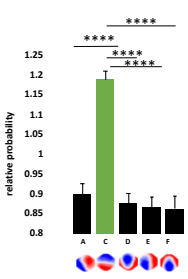
SOURCE LOCALIZATION OF STATE D



TRANSITION TO STATE B

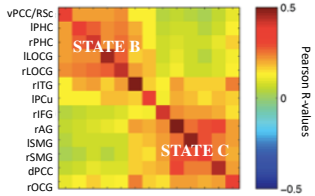


TRANSITION FROM STATE B



* p <.05
** p<.01
*** p<.001
**** p<.0001

2 MEMORY SUB-NETWORKS OF CONNECTIVITY ANALYSIS



Bréchet et al., NeuroImage *(in revision)*, 2019

Concluding remarks & future direction

- When at rest, our minds wander from thought to thought in distinct mental states
- To capture & relate these states to specific cognitive contents is challenging

- ☑ We capture the spatiotemporal dynamics of large-scale networks associated with DMN
- ☑ We used fMRI & EEG to study the inner thoughts by instructing participants

- ☑ BOLD activity mapping revealed enhanced activity in memory retrieval network
- ☑ Functional connectivity showed 2 sub-parts (scene-reconstruction & self-reliving)

- ☑ EEG analysis revealed modulation of duration & occurrence of microstates
- ☑ EEG source analysis showed similar spatial distribution of microstates & fMRI regions

Concluding remarks & future direction

We can gain a better understanding about how thoughts evolve in the minds of patients diagnosed with mental illnesses & we may be able to provide an early diagnosis of neurodegenerative disorders such as Alzheimer's disease

THANK YOU

UNIVERSITÉ DE GENÈVE
FACULTÉ DE MÉDECINE

The Functional Brain Mapping Laboratory

CIBM

Lifmet

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

EEG PREPROCESSING & PIPELINE

DOWN-SAMPLED: 125HZ

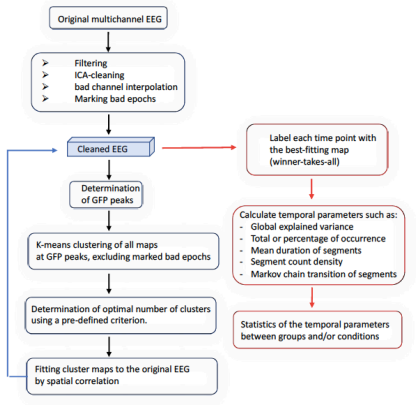
BAND-PASS FILTERING: 1-40Hz

ICA

INTERPOLATION

AVERAGE-REFERENCE

GFP PEAKS



64-CHANNEL SYSTEM (Brain Products, Munich, Germany) Bréchet et al., NeuroImage *(in revision)*, 2019

fMRI PREPROCESSING

MOTION CORRECTION

BRAIN SEGMENTATION

SLICE TIMING CORRECTION

SPATIAL SMOOTHING

DE-TRENDING

GLM CONFOUND REGRESSION

CO-REGISTRATION ESTIMATION (fALFF to MNI space)

fMRI ACQUISITION

SMS/EPI SEQUENCE

SAGITTAL SLICES

TR: 1sec

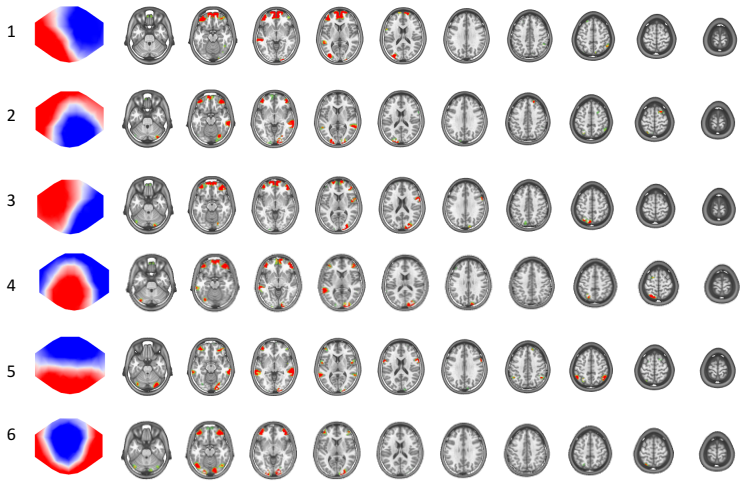
TE: 22ms

SPATIAL RESOLUTION: 2mm isotropic

8 CHANNEL HEAD COIL

Bréchet et al., NeuroImage *(in revision)*, 2019

SOURCE LOCALIZATION OF 6 MOST DOMINANT MICROSTATES ACROSS THREE CONDITIONS: MATH & MEMORY



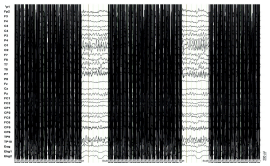
5000 Solution points

Bréchet et al., NeuroImage *(in revision)*, 2019

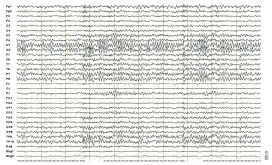
BOLD CORRELATES OF EEG TOPOGRAPHY REVEAL RAPID RESTING-STATE NETWORK DYNAMICS

EEG MICROSTATES & fMRI RSNs MEASURE COMMON PROCESSES

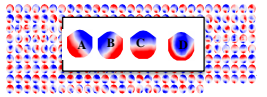
RECORDING OF EEG in the MR



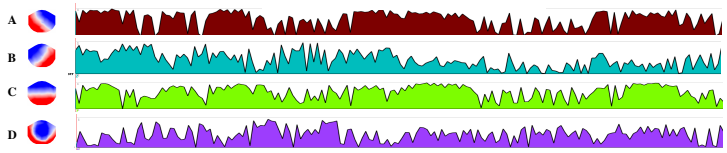
CLEANING OF THE ARTEFACTS

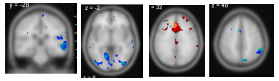


SPATIAL CLUSTER ANALYSIS



TIME COURSE OF EEG MICROSTATES





EEG MICROSTATES CORRELATED WITH ICA-DERIVED RSNs

Britz et al., *NeuroImage*, 2010