# SEEG analysis using Brainstorm http://neuroimage.usc.edu/brainstorm







Francois Tadel Anne-Sophie Dubarry

### Graphic interface





# Scripting environment

- Rapid selection of files and processes to apply
- Automatic generation of Matlab scripts
- Plug-in structure: easy to add custom processes

	By Pipeline editor 1 % Script generated by Brainstorm v3.1 (17-Dec-2010).
	<pre>2 - FileNamesA = ('Subject01\Left\data_average_101213_1558.mat',</pre>
Files to process: Data [235]	Process selection SubjectOl\Right\data_average_101213_1559.mat');
	$ \bigcirc \bullet \bullet \bullet \bullet \bullet \times \land \land \bullet \bullet$
RUN Process1 Process2	Image: Instrume of the second seco
	Import MEG/EEG: Events
	1 & Process: Band-pass filter: 1Hz - 80Hz
	Remove DC offset: [-100ms,0ms]
	Aurora Rutil and (and the aurora)
	Average: by that group (condition average)
	6 'f2', 80,
	Process options 7 'overwrite', 1);
	Channel name: ECG -
	s Files = bst process(
	Time window: 0.000 - 338.998 S V All file 1 (CallProcess', 'process average',
	Event name: cardiac 2 sFiles, [],
	a s 'avgtype', 3,
	4 'isstd', 0);

### Brain*s*torm

- Free and open-source application
- Matlab & Java: Platform-independent
- Designed for Matlab
- Stand-alone version available
- Interface-based: click, drag, drop
- No programming experience required
- Daily updates of the software
- Supports most common file formats





## Multi-modal imaging

ECoG

#### Depth electrodes



#### fNIRS



#### MEG/EEG



### Electrophysiology





Anatomy Link recordings MRI registration

PSD

Filters

Bad channels Artifacts

Correction

Bad segments

Markers Epoching Averaging Sources Time-frequency

### Importing

**Pre-processing** 

Analysis of the experimental data

Loop: all acquisition runs all subjects



## Import

#### Anatomy

Link recordings MRI registration

PSD Filters Bad channels Artifacts Correction Bad segments

Markers Epoching Averaging Sources Time-frequency

- One-click import of the T1 segmentation: FreeSurfer, BrainSuite, BrainVISA, CIVET
- Import and place fiducials in the MRI (N,L,R)



# Database



- Three levels:
  - Protocol
  - Subject
  - Condition

- Popup menus
- All files saved in Matlab .mat
- Same architecture on the disk



# Import

#### Anatomy Link recordings

MRI registration

- PSD
- Filters
- Bad channels
- Artifacts
- Correction
- Bad segments

Markers Epoching Averaging Sources Time-frequency

- Original files linked to the database (no copy)
- Rich data viewer with flexible montage editor
- Optimized reading functions



# Quality control

Anatomy Link recordings MRI registration

### PSD

Filters Bad channels Artifacts Correction Bad segments

Markers Epoching Averaging Sources Time-frequency

### • Power spectrum density for quality control





Anatomy Link recordings MRI registration

**PSD** 

**Filters** 

Artifacts

Correction

**Bad channels** 

**Bad segments** 

### Notch filter: Removes 50Hz/60Hz power line noise (and harmonics)











Anatomy Link recordings MRI registration

### PSD

#### **Filters**

Bad channels Artifacts Correction Bad segments

Markers Epoching Averaging Sources Time-frequency • High-pass filter: Removes slow components (eye movements, breathing, sensor drifts...)



Low-pass filter: Remove high-frequencies







FLIP

Anatomy Link recordings MRI registration

PSD Filters Bad channels

Artifacts Correction Bad segments

Markers Epoching Averaging Sources Time-frequency

- Manual inspection of the recordings
- Interactive selection of bad channels
- Re-reference the EEG if necessary (Average ref)

EEG/AvgRef: Sub01/@rawrun_01_sss_notch			- 🗆 🗙			
226.0000 EE G009	₽*	Add / delete event	Ctrl+E	A T A		
EEG010	•	Reject time segment	Ctrl+B	4		
EEG012 have a ha	+	Jump to previous event	Shift+Left			
EEG013	+	Jump to next event	Shift+Right	Į		
EE G015 MAY THE AND	0	View topography	Ctrl+T		View selected	Enter
EE G017	*	Channels	I	•	Mark selected as bad	Delete
EEG018	*	Montage	I	٠	Mark non-selected as bad	Shift+Delete
226 226.5 227 227.5	P	Time selection	I	0	Reset selection	Escape
<<< l>	Ô	Snapshots	I	•	Mark all channels as good	Shift+Escape
9	×	Figure	I	۶	Edit good/bad channels	



Anatomy Link recordings MRI registration

PSD Filters Bad channels Artifacts

Correction Bad segments

Markers Epoching Averaging Sources Time-frequency • Automatic detection of blinks and heartbeats (peak detection, or explicit amplitude threshold)







- Independent component analysis (ICA):
  - Popular in the EEG literature
  - Alternative to SSP for low number of sensors
  - Already implemented: Infomax and JADE (EEGLAB)





#### Anatomy Link recordings MRI registration

PSD

**Filters** 

- **Bad channels**
- Artifacts

Correction

### **Bad segments**

Markers Epoching Averaging Sources Time-frequency

- Automatic detection of artifacts (RMS-based)
- Manual screening of all the recordings is advised (scroll all the sensors by pages of 10-20s)
  - Exclude: Blinks, movements, SQUID jumps

	599.4373	CBADic 1-7HQ-240H2AD c		i l		
}} Pipeline editor — 🛛	MEG0111	man	and a service and a service and	[		
Process selection	MEG0121	my my my	mousinman			
@▼ ↑ ↓ ≫  ≗·	MEG0131	man Manun man Manun	Mat and and the second			
Detect other artifacts	MEG0' 🔺	EG MAG/All: sub002/@rawrun_01_sss	<u>i</u> n – 🗆 🗙	L		
Process options Time window: 226.0000 - 716.9991 s All fi	240 le	0 arditelihizacardia:404240Hzacardiacard	diamr40-240Hardiac	>>		
Sensor types or names (empty=all): MEG, EEG Sensitivity: 0 1 0 2 • 3 0 4 0 5						
☑ 1-7 Hz: Eye movements, subject movements, dental w	ork					
✓ 40-240 Hz: Muscle noise, sensor artifacts				l		
Online tutorial Cancel	Run		AS A			
		232 234 236 238 control   control   control <t< td=""><td>240 242 244 Duration: [1987   &lt;&lt;&lt; &gt;&gt;&gt;</td><td></td></t<>	240 242 244 Duration: [1987   <<< >>>			



Anatomy Link recordings **MRI** registration

#### **PSD**

**Filters** 

- **Bad channels**
- Artifacts
- Correction
- **Bad segments**

Markers Epoching Averaging **Sources** 

**Time-frequency** 



#### Famous faces

![](_page_16_Picture_12.jpeg)

50

fT

uV

0.2

Π4

0.6

n

Anatomy Link recordings MRI registration

PSD Filters Bad channels Artifacts Correction Bad segments

Markers Epoching Averaging Sources Time-frequency

### Morlet wavelets

![](_page_17_Figure_5.jpeg)

#### Hilbert transform + band-pass filter

![](_page_17_Figure_7.jpeg)

![](_page_17_Figure_8.jpeg)

![](_page_17_Picture_9.jpeg)

Anatomy Link recordings MRI registration

#### PSD

- Filters
- Bad channels
- Artifacts
- Correction
- Bad segments

Markers Epoching Averaging Sources Time-frequency **Other measures** 

### Phase-amplitude coupling

![](_page_18_Figure_10.jpeg)

![](_page_18_Picture_11.jpeg)

Anatomy Link recordings MRI registration

#### PSD

- Filters Bad channels
- Artifacts
- Correction
- Bad segments
- Markers Epoching Averaging Sources Time-frequency **Other measures**

### • Connectivity measures

![](_page_19_Figure_9.jpeg)

- Correlation
- Coherence
- Phase locking value
- Granger causality

![](_page_19_Figure_14.jpeg)

![](_page_19_Picture_15.jpeg)

# Group analysis

Subject averages Low-pass Normalize Project

Group averages
Group statistics

Quality control Workflow

- Contrasts between subjects or conditions
- Parametric or non-parametric t-test
- Cluster-based non-parametric tests
- Export to: **SPM**, R, Excel, SPSS, Matlab...

![](_page_20_Picture_8.jpeg)

![](_page_20_Picture_9.jpeg)

# Group analysis

•

Subject averages Low-pass Normalize Project

Group averages Group statistics

#### **Quality control** Workflow

Tute	orial	iroup	$\sim$	🚣 Report: C:\U:	sers\francois\.brai
R.	8	M		<b>← →</b>   🗁   •	Clear history
	Tuto	rialGroup (subjects)	^	Start: 25-Jan	-2013 17:25:24
÷	8≡	Group analysis		u errors a	na 3 warning
	÷	Common files		process_imp	ort_freesurfer
	<u>.</u>	Intra-subject		process_imp	ort_data_raw
		🐨 🖾 Avg: WAvg: Avg: Faces (16 files)   low(32Hz)   tim	אין	warning [	No input]
		🛛 🖾 Avg: WAvg: Avg: Famous (16 files)   low(32Hz)   t	ii	process_sin_	remove
		Avo: WAvo: Avo: Scrambled (16 files)   low(32Hz		warning S	Subject01/@rawsu
		Avo: WAvo: Avo: Hofamiliar (16 files) How(32Hz)		process_evt	_detect_eog
		Essee Secondad	'	into S	Subject01/@rawsu
		M Faces - Scrambled		process_imp	_eog ort_data_event
		Famous - Unfamiliar		info S	Subject01/@rawsu
		mean( Faces-Scrambled )   MEG		process_bas	eline
		mean( Faces-Scrambled )   EEG		process_time	eoffset
		mean/(Eacael) mean/(Scrambled))   MEG		process_nois	rage
		-		process_sna	pshot
		mean( Faces )-mean( Scrambled )   EEG		process_sna	pshot
		Faces - Scrambled: Cluster t-test EEG		process_hea	dmodel
		M Famous - Unfamiliar: Cluster t-test EEG		warning 2	erse 2 files []
		SIM Faces - Scrambled: Parametric t-test			
				Initial file	5
		Famous - Unfamiliar: Parametric t-test		[No input]	
		Tian Faces-Scrambled = 0: Parametric Chi2 test   MEG		Intermedi	ate files
		Martin Stat Iog( Faces-Scrambled )=0: Parametric Chi2 test   M	E		
		Traces = Scrambled : Parametric t-test   MEG		Subject01/@ Subject01/@	rawsubj001_som rawsubj001_som
		Faces-Scrambled =0: Parametric Chi2 test   EEG		Subject01/le Subject01/le	ft/data_left_trial( ft/data_left_trial)
		Iog( Faces-Scrambled )=0: Parametric Chi2 test   M	E	Subject01/let Subject01/let	tt/data_left_trialC ft/data_left_trialC
		Faces = Scrambled : Parametric t-test   MEG	~	Subject01/le Subject01/le Subject01/le	rt/data_left_trial0 ft/data_left_trial0 ft/data_left_trial0
<		>		Subject01/let	ft/data_left_trialC

### Execution reports with snapshots saved in HTML

<ul> <li>→   ▷→   Clear history</li> </ul>		
Start: 25-Jan-2013 17:25:24 Elapsed: 9m 56s		
0 errors and 3 warnings		
process import freesurfer		
process_import_data_raw		
warning [No input]	Errors detected in the events of the AUX file (markers at the beginning of a trial): Removed 1 × "left": 82.500 Removed 1 × "left": 62.500	25-Jan-2013 17:26:36
process_sin_remove		
warning Subject01/@rawsubj001_somatosensory_201	11109 Cannot overwrite native files.	25-Jan-2013 17:33:29
process_evt_detect_eog		
info Subject01/@rawsubj001_somatosensory_201	11109 EEG058: 30 events detected in 2 categories	25-Jan-2013 17:33:31
process_ssp_eog	· · · · · · · · · · · · · · · · · · ·	
process_import_data_event	Report: C:\Users\francois\brainstorm\reports\report_TutorialScript_130125_1335.mat	
info Subject01/@rawsubj001_somatosensory_201	• • Clear history	
process baseline	Shupshots	
process timeoffset	Subject01/right/data_average_130125_1254.mat	
process noisecov		
process average		
process snapshot		
process snapshot		
process beadmodel		
process_inverse		
process_interse		
warning 2 files []		
Initial files	Subject01/left/data_average_130125_1254.mat	
	-104.20	
[No input]	400-	
	€ 200 ·	
Intermediate files	200 -	
	- SOO GFP	
Subject01/@rawsubj001_somatosensory_20111109_01_/ Subject01/@rawsubj001_somatosensory_20111109_01_/	01 005 0 0.05 0.1 0.15 0.2 0.25	
Subject01/left/data_average_130125_1734.mat	Time (0 🔍 🗵	
Subject01/left/data_left_trial001.mat [deleted]	Subject01/right/data_average_130125_1254.mat	
Subject01/left/data_left_trial001_bl_timeoffset.mat		
Subject01/left/data_left_trial002.mat [deleted]	-104.20	
Subject01/left/data_left_trial002_bl.mat [deleted]	500 ·	
Subject01/left/data_left_trial002_bl_timeoffSet.mat	E	
Subject01/left/data_left_trial003_bl.mat [deleted]		
	-500 · WWW/FC*/	

![](_page_21_Picture_7.jpeg)

## Add your code to Brainstorm

- Direct manipulation of the files in Matlab
- Use the menu "Run Matlab command"
- Write a plugin:
  - Well documented API
  - Lots of example (200 functions written as plugins)
- Examples of recent external contributions:
  - MVPA decoding (Oliva, MIT)
  - Microstate segmentation (Cacioppo, UChicago)
  - Eyetracker/EEG synchronization (Uni Freiburg)

![](_page_22_Picture_10.jpeg)

### User community

• 19,900 users registered on the website

![](_page_23_Figure_2.jpeg)

![](_page_23_Picture_3.jpeg)

### User support

- Online tutorials:
- Active user forum: 300 posts/month
- Daily updates:

30-hour self-training program

800 downloads/month

👹 Brainstorm		Search Q	👹 Brain <i>s</i> torm		🔒 Log in	Q ≡
	Get started		3-sphere shell gives near-identical results to	1	14	11d
Software	Starting a new study	Epoching and averaging				
Introduction	1. Create a new protocol [9]	15. Import epochs [9]	Reference and channel types   Discussions   S	2	8	11d
Gallerv	2. Import the subject anatomy [8]	16. Average response [7]	How to add missing atlas	6	36	11d
Developed	3. Explore the anatomy [13]	17. Visual exploration [10]				
Download	Reviewing	18. Colormaps [5]	Canonical Correlation Analysis	2	15	12d
Installation	4. Channel file / MRI registration [11]	19. Clusters of sensors [4]		0	10	104
llcove	5. Continuous recordings [9]	Source modeling		2	15	120
Users	6. Multiple windows [5]	20. Head model [9]	Correspondence EEG signals / electrode labels 🔳 Discussions (S) 🔞	3	17	12d
Tutorials	7. Event markers [10]	21. Noise/data covariance	Eventing source levelized time series directly			
Forum	Pre-processing	22. Source estimation [28]	to matlab?	1	13	12d
Courses	8. Stimulation delays [9]	23. Scouts [17]	Importing ECOG electrodes from Curry			
	9. Select files / Run processes [11]	Advanced processing	seeg, ecog	16	210	13d
Community	10. Power spectrum / Frequency filters [15]	24. Time-frequency [33]				
Publications	11. Bad channels [6]	25. Difference [13]		_		
Development	12. Artifact detection [8]	26. Statistics [30]	Find us on			
	13. Artifact cleaning with SSP [16]	27. Workflows [10]				
What's new	14. Additional bad segments [7]	28. Scripting [31]	le tacebook.			

![](_page_24_Picture_7.jpeg)

# Contributors

![](_page_25_Picture_1.jpeg)

Sylvain Baillet MNI

![](_page_25_Picture_3.jpeg)

**Richard Leahy** USC

![](_page_25_Picture_5.jpeg)

John Mosher **Cleveland Clinic** 

![](_page_25_Picture_7.jpeg)

François Tadel Univ Grenoble-Alpes

![](_page_25_Picture_9.jpeg)

Martin Cousineau MNI

Matti Hamalainen Antoine Ducorps **Denis Schwartz** 

![](_page_25_Picture_13.jpeg)

![](_page_25_Picture_14.jpeg)

8

MEG

Soheila Samiee PhD student

Elizabeth Bock

MEG engineer

![](_page_25_Picture_16.jpeg)

Jeremy Moreau PhD student

![](_page_25_Picture_18.jpeg)

Peter Donhauser PhD student

![](_page_25_Picture_20.jpeg)

K. Nasiotis PhD student

![](_page_25_Picture_22.jpeg)

**Dimitrios Pantazis** MIT

**Guiomar Niso** Politécnica Madrid

![](_page_25_Picture_25.jpeg)

collaborators

Anand Joshi USC

![](_page_25_Picture_27.jpeg)

Hossein Shahabi USC

![](_page_25_Picture_29.jpeg)

**Esther Florin** Univ Hosp Cologne

![](_page_25_Picture_31.jpeg)

Anne-Sophie Dubarry Aix-Marseille Univ

![](_page_25_Picture_33.jpeg)

# TODAY

![](_page_26_Picture_2.jpeg)

### Sample data

### **Epilepsy recordings:**

- Patient recorded at the Grenoble University Hospital
- Focal epilepsy of the left temporo-occipital junction, MRI-negative, implanted in the surrounding areas
- Depth electrodes: DIXI D08-\*\*AM Microdeep (8-18 contacts)
- Recorded with a Micromed system at 512Hz
- 4 minutes of recordings with one short seizure (no propagation)

![](_page_27_Figure_7.jpeg)

### **Patient anatomy:**

- T1 MRI pre-implantation, processed with BrainVISA 4.5
- T1 MRI post-implantation
  - Registered on the pre-implantation image with SPM
  - Used to get 3D positions for the SEEG contacts
- Volumes were de-identified with FreeSurfer's mri\_deface

![](_page_28_Picture_7.jpeg)

![](_page_28_Picture_8.jpeg)

![](_page_28_Picture_9.jpeg)

![](_page_28_Picture_10.jpeg)

![](_page_28_Picture_11.jpeg)

### Sample data

### **SEEG electrodes marked in the T1post:**

![](_page_29_Picture_2.jpeg)

![](_page_29_Picture_3.jpeg)

### Sample data

### **Epileptogenicity maps:**

- Comparison of HFO power ictal vs. baseline
- Identification of the seizure onset zone
- Estimation of the seizure propagation

![](_page_30_Picture_5.jpeg)

![](_page_30_Picture_6.jpeg)