Brainstorm

USC University of Southern California

Workshop Los Angeles **December 2024**

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OUTLINE OF TOPICS COVERED IN THIS WORKSHOP

- **Morning session: EEG and MEG Analysis**

1. Introduction to Brainstorm Interface
2. Import anatomy
3. Review Raw recordings
4. Import events
5. Frequency filters
6. Artifact detection and correction
7. Sensor level
   - Import recordings
   - Review trials
   - Trial averages
8. Forward model (aka Head model)
9. Noise covariance matrix
10. Computing inverse model and source estimation
11. Optional: Atlases and Scouts
12. Optional: Automatic EEG localization and labeling

- **Afternoon session: SEEG Analysis**

13. Import anatomy
14. Coregister and Normalize images to standard MNI space
15. Contact localization
16. Review Raw recordings
17. SEEG preprocessing
18. Import precomputed Brainstorm protocol
19. Modeling interictal spikes using Min-Norm Imaging
20. Modeling ictal onset with Low Voltage Fast Activity (LVFA) using fingerprint analysis (Sensor Space)
21. Appendix
    - How to run CAT12 segmentation from
    - Remove power line noise

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Brainstorm installation for the workshop:

Please read the following instructions carefully to **prepare your laptop for the training**:

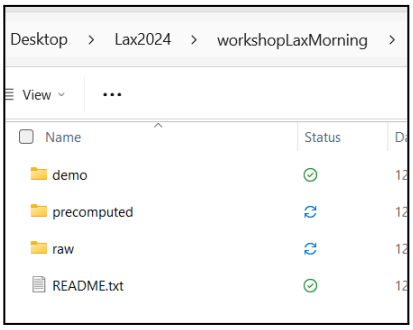
https://neuroimage.usc.edu/brainstorm/WorkshopGeneralInstall

Workshop datasets:

Once you have successfully installed and tested Brainstorm, proceed to download the data to be used in the workshop.

For both AM and PM sessions, we will provide you with the raw data as well as the precomputed Brainstorm protocol. That way, you can either follow this walkthrough and reproduce your results [recommended], or just load the precomputed results and explore the results and other features [not covered in this workshop].

- **Morning session data:**
  - workshopLaxMorning: https://tinyurl.com/2wfwex4s
  - Extract all the folders above to your desktop.
  - This file contains three folders
    - raw: folder with the raw data
    - precomputed: Brainstorm folder with the final results
    - demo: Brainstorm protocol with the EEG 3D scanner demo



This dataset is collected from a simple median nerve stimulation experiment:

- Right median nerves were percutaneously stimulated using monophasic square-wave impulses with a duration of 0.3 ms at 2.8 Hz.
- The stimulus intensity was set at the motor threshold to evoke mild twitches of the thumb.
- The stimulus onsets were recorded as low-to-high TTL with a trigger channel labeled as "Trigger01".
- The total number of stimuli in the dataset was 339.
- The MEG data was recorded with a sampling rate of 2000 Hz and a bandpass filter at 0.16-500 Hz with a Yokogawa 160 axial gradiometer system at Yokogawa Electric Corporation, Kanazawa, Japan.
- The EEG data was recorded with a NIHON KOHDEN system simultaneously with the MEG.

- **Afternoon session data:** please check the page 23

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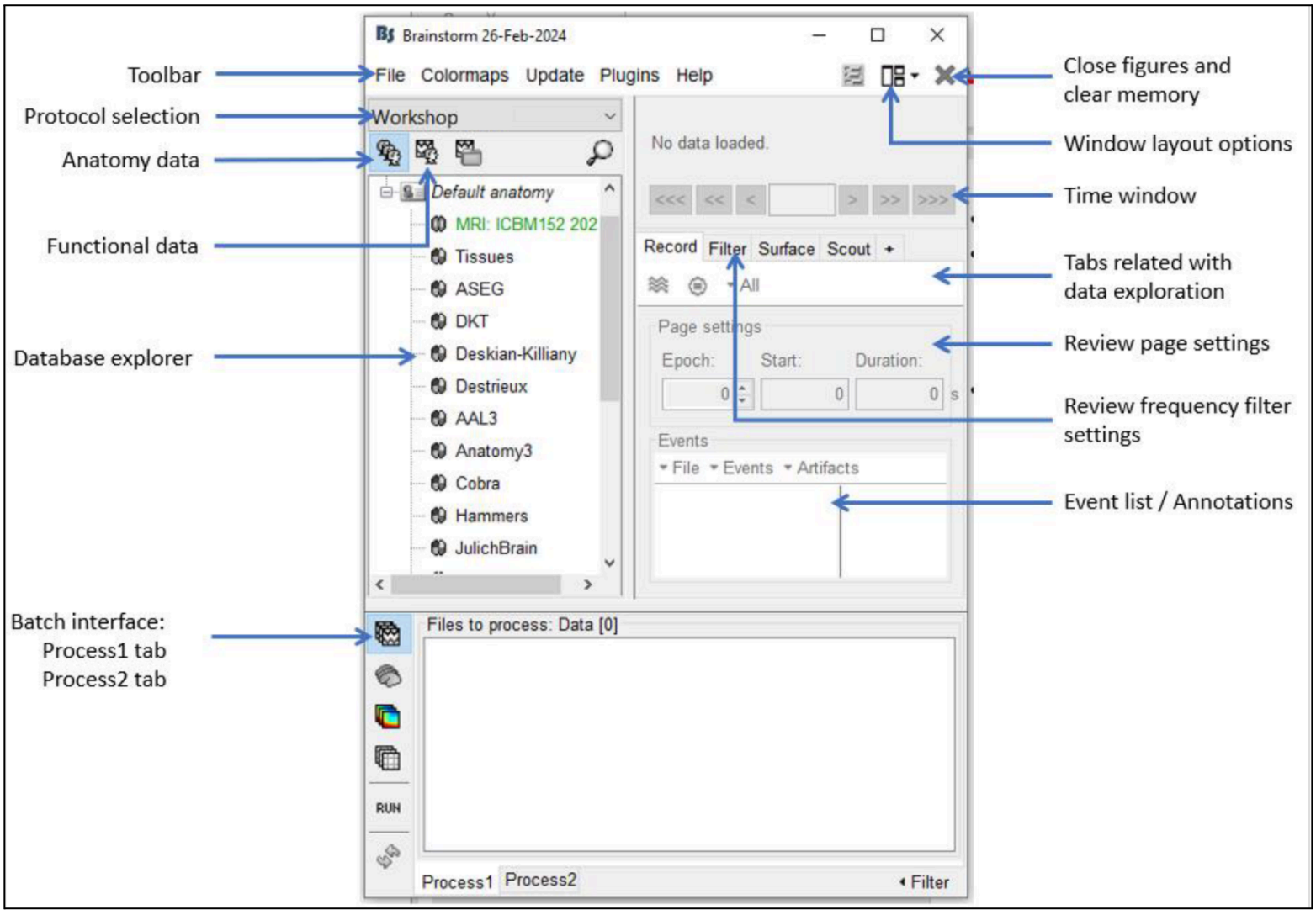
***** red highlighted texts* are processing steps we will be skipping during this workshop to save time**

Morning session: EEG and MEG Analysis

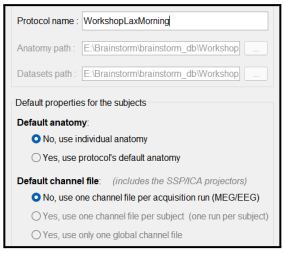
1. Introduction to Brainstorm Interface (Takfarinas)

- CLOSE ALL YOUR APPLICATIONS, INCLUDING WEB BROWSERS
- Start Brainstorm: from MATLAB or using the stand-alone application.
    - Please check here for running Brainstorm for the first time: https://neuroimage.usc.edu/brainstorm/WorkshopGeneralInstall#Running_Brainstorm_for_the_first_time

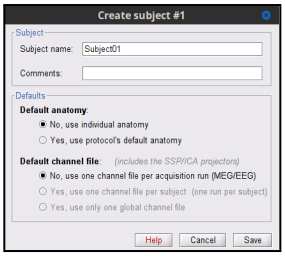


2. Import Anatomy

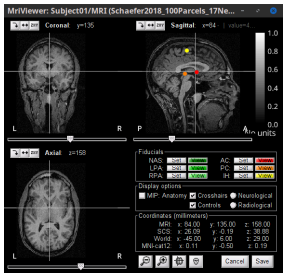
Create new protocol



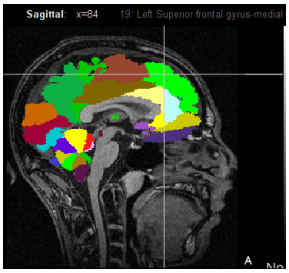
- Select File > New protocol: **WorkshopLaxMorning**
  - **No**, use individual anatomy
  - **No**, use one channel file per acquisition run (MEG/EEG)
- Introduction to database explorer (list of protocols, exploration modes...)
- Switch to anatomy view:  (1st button, on top of the database explorer)



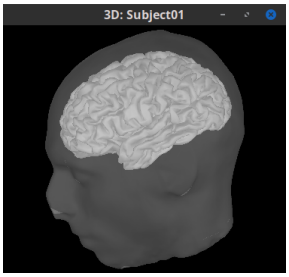
- Right-click on protocol top node > New subject: **Subject01** (use Defaults)
- Right-click on the created subject > Import anatomy folder **(Do not select the (auto) option)**
  - *Files of Type* **CAT12**
  - Select the **anatomy** folder in **/Desktop/workshopLaxMorning/raw/**
  - For the "*Number of vertices*" set to **15000**
  - **You need to have a CAT12**[1] **plugin**



- Once the MRI viewer opens
  - Explain fiducial points and the coordinates (MRI, SCS, MNI)
  - Set coordinates:  , set fiducials, (MRI coords)
  - **NAS [125, 230, 64] LPA [48, 141, 44] RPA [215, 140, 59]**
- Exploring MRI (): double-click or right-click > *Display* > *MRI Viewer*
  - Exploring the volume (click, mouse wheel, sliders)
  - Anatomical atlases, colormaps, colorbar, figure popup menu
- Exploring MRI (): right-click > *Display* > *3D orthogonal slices*



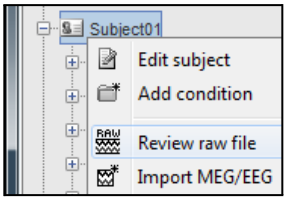
- Display cortex (): double-click or right-click > *Display*
  - 3D figure: rotation, zoom
  - Predefined views and keyboard shortcuts: left, right, top, etc
  - Surface tab: smooth, sulci, edges
  - Scouts tab: atlases and scouts



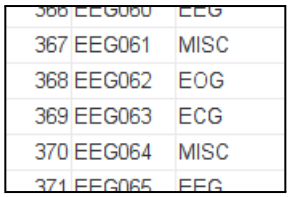
- Close all figures ( button at top-right): close all figures and empty the memory.

[1] https://neuroimage.usc.edu/brainstorm/Tutorials/SegCAT12#Install_CAT12

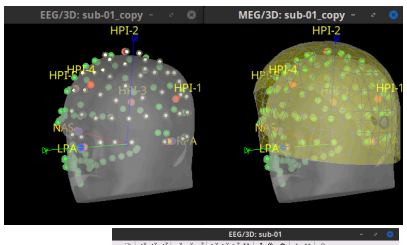
3. Review Raw recordings



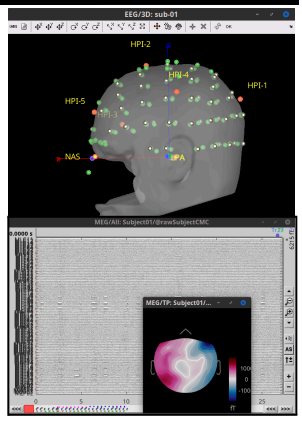
- Switch to functional view: (2nd button, on top of the database explorer)
- Create **Link to raw file**: right-click on *Subject01* > *Review raw file*
  - *Files of Type* **MEG/EEG: Yokogawa/KIT (*.sqd; *.con; *.raw; *.ave; *.mrk)**
  - Select the file **SEF_000-export.con** in the **data** folder in **/Desktop/workshopLaxMorning/raw/**
  - Click on **Open**
- In the popup for **Refining registration**, click on **No**
- The sensor coregistration will show, close it for now



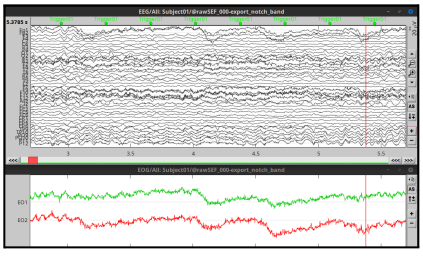
- **Change the type of some channels**: right-click on the channel file > *Edit channel file*:
  - Channel **EO1** (208) and **EO2** (209): Change the type to **EOG**
  - Channel **EKG+** (214): Change the type to **ECG**
  - Channel **E** (231): Change the type to **Misc**
  - Close the figure and accept to save the modifications



- Check sensor coregistration
  - right-click > *MRI registration* > *EEG:Check*
    Some electrodes are above or inside the head surface
  - right-click > *MRI registration* > *EEG: Edit*
    - Select **Project electrodes on the surface**
    - Click **OK** and **Yes** to save
  - right-click > *MRI registration* > *MEG:Check*
  - Close figures

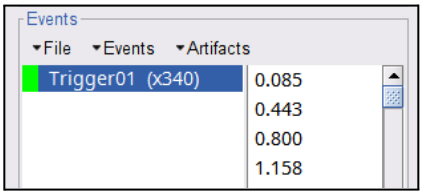


- Review EEG signals: right-click > *EEG* > *Display time series*
  - Display in columns ( ), display windows of 10s
  - Amplitude gain: buttons and shortcuts
  - Add a topography and set the window layout to weighted
- Review MEG signals
- Review EOG signals
- Review EEG and EOG signals simultaneously
- Close all figures



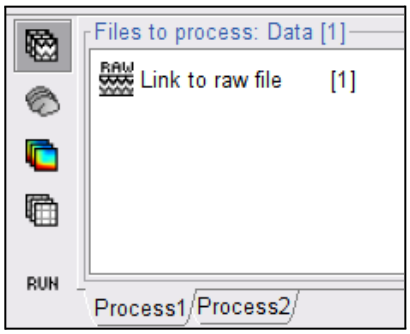
4. Import events

- Different ways of Importing events
- Right-click on *Link to raw file* > *TRIGGER* > *Display time series*
  - Display in columns. Notice that Trigger01 contains information of



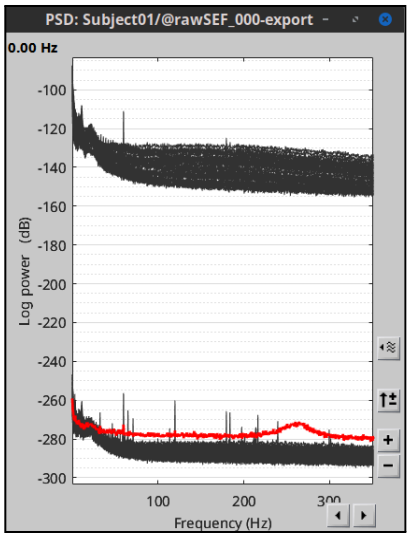
the electric stimuli

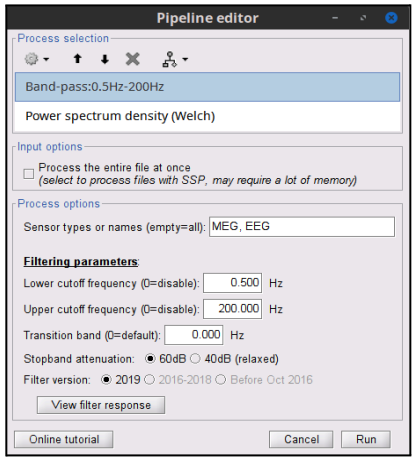
- In the Record tab, menu *File > Read events from channel*
  - Event channels = **Trigger01**
  - Option = **TTL: detect peaks of 5V/12V on an analog channel**
  - Do **NOT** check the option **Accept zeros as trigger values**
- Click **Run**. Close the figure with the time series to save modifications



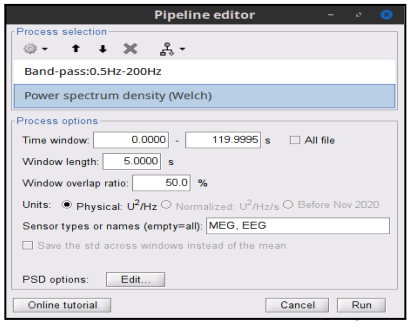
5. Frequency filters

- Process section
  - Tabs **Process1**, **Process2**
  - File types: recordings, sources, time-freq, and matrices
- EEG and MEG: Filter power line artifact
  - Close all the figures
  - Drag-and-drop (RAW) raw file in *Process 1*, click [RUN]
  - Add the process: *Frequency > Power spectrum density (Welch)*
    - *Time window* = **All file**, *Window length* = **5s**, *Overlap* = **50%**
    - *Units* = **Physical**
    - *Sensor types* = **EEG, MEG**
  - PSD Options: **Edit… > OK.** Click on **Run.**
- Open the new ( ) PSD file
  - Two PSD groups, from top to bottom: **EEG** and **MEG** sensors
  - Peak around 11 Hz: alpha waves from the subject's brain
  - Peaks at 60Hz, 120Hz, 180Hz on EEG and MEG: Power lines (60Hz+harmonics)
  - Smaller peaks at 35Hz, 65Hz, 70Hz, 183Hz, 197Hz on MEG only: Unknown source
  - MEG sensor **LC11** appears to have a higher level of noise than all the other MEG sensors.
    Select the channel (it becomes red), right-click, and *Mark the selected as bad.*
    This is often an indication of a bad channel, we can verify this by reviewing MEG signals.

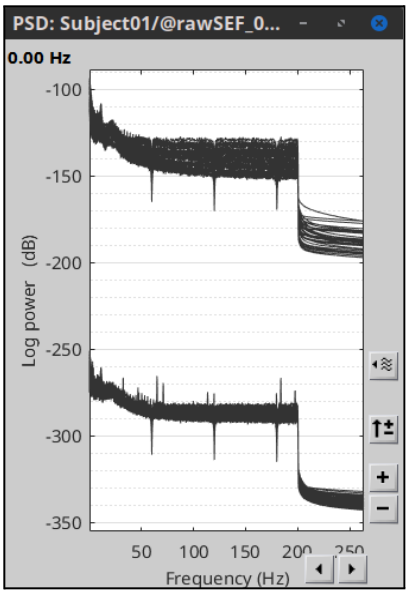




- Notch filter the raw file: click [RUN],
  - Add the process *Pre-process > Notch filter*
    - *Frequencies to remove (Hz)* = **60, 120, 180**
    - *Sensor types* = **EEG, MEG**

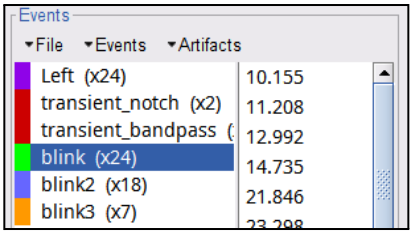


- Click **Run**. Compute the PSD for the notch-filtered raw file, and open the new PSD file



- EEG and MEG: Bandpass filter. First *Clear list* for the Process.
  - Drag-and-drop notch-filtered raw file in Process, click [RUN]
  - Add the process *Pre-process > Band-pass filter*
    - *Sensor types* = **EEG, MEG**, *Lower cutoff freq* = **0.5 Hz**, *Upper cutoff freq* = **200 Hz**
  - Select: **Frequency, Power spectrum density (Welch)**
  - Add the process: *Frequency, Power spectrum density (Welch)*
  - PSD Options: **Edit… > OK. Run** the pipeline.

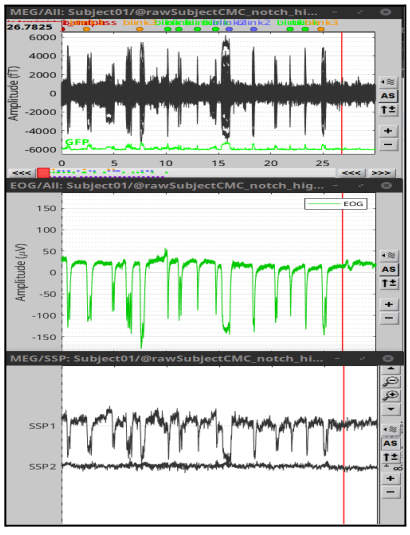
- EEG: re-reference to Average
  - Open the EEG timeseries for the bandpass filtered raw file (in folder **_notch_band**)
- Click on *Artifacts > Re-reference EEG* and use **AVERAGE** as EEG reference channel

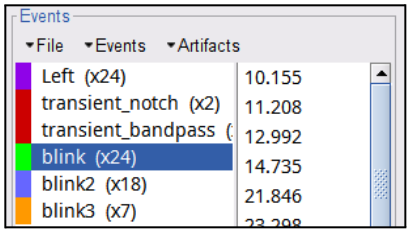


- Delete intermediate files that won't be needed anymore:
  - Select folder **SEF_000-export_notch**
  - Press the Delete key (or right-click > *File* > *Delete*)

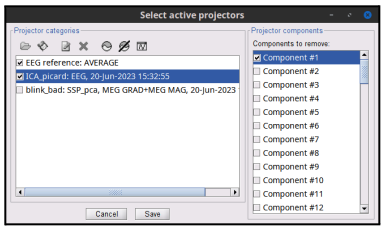
6. Eye-movement-related artifacts and other artifacts

- Detect eye-movement events
  - Open the time series for EEG and EOG
  - In the Record tab, select *Artifacts > Detect eye blinks*, and use the parameters:
    - *Channel name* = **EO2**, *Time window* = **All file**, *Event name* = **blink**
  - Display MEG signals (along EOG) and see some blink occurrences
  - Merge all the **blink** event groups in a **blinks** group
- Detect heartbeat events
  - Open the time series for EEG and ECG
  - In the Record tab, select *Artifacts > Detect heartbeats*, and use the parameters:
    - *Channel name* = **EKG+**, *Time window* = **All file**, *Event name* =
- Handle simultaneous events
  - In the Record tab, select *Artifacts > Remove simultaneous:*
    - Remove events named: **cardiac**

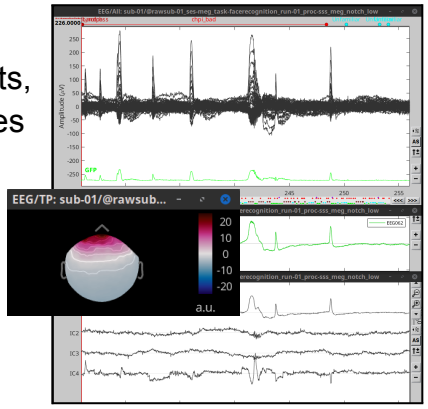




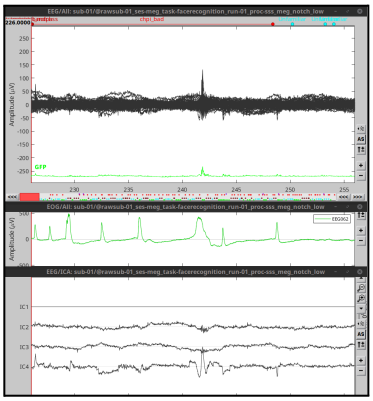
  - When too close to events: **blinks**
  - Minimum delay between events: **250 ms**

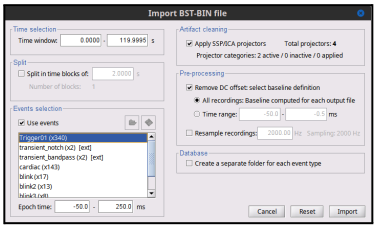


- **Remove blink artifacts from EEG with ICA**[2]
  - Open the time series for EEG
  - In the Record tab, select *Artifacts* > *ICA components*, and use the parameters:
    - *Time window* = **All file**, *Band-pass filter* = **[0, 0]**, *Resample* = **0,** *ICA algorithm* = **Picard**, *Number of ICA components* = **0**
      Sort components based on correlation with = **EOG, ECG**
  - In the *Select active projectors* window, **uncheck** all ICA components, highlight the first eight and plot their time series ( ), and topologies
  - Open ECG and EOG time series and disable **auto scaling** (AS) in the 3 plots
  - Check **Component #1** which is related to the ECG signal and verify the impact of removing it from the EEG signal
  - Check **Component #2** which seem related to the EOG signal and verify the impact of removing it from the EEG signal
  - Click on **Save**, close all figures



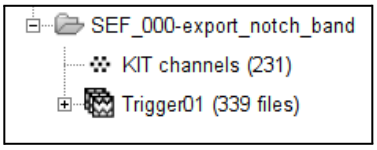
- **Optional: Remove blink artifacts from MEG with SSP**
  - Open the time series for MEG
  - In the Record tab, select *Artifacts* > *SSP: Eye blinks*, and use the parameters:
    - *Event name* = **blinks**, *Sensors* = **MEG**
  - In the *Select active projectors* window, **uncheck** all components, highlight the first two and plot them ( )
  - Open MEG and EOG time series and disable **auto scaling** (AS) in the 3 plots
  - Check **Component #1** to verify the impact of removing it from the MEG signal
  - Click on **Save**, close all figures





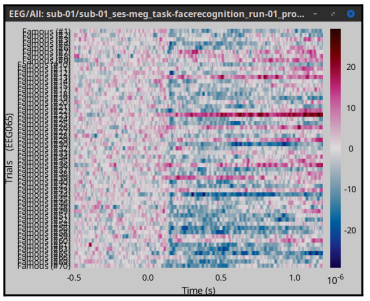
7. Sensor level analysis

- Import recordings in the database
  - Right-click on the pre-processed file > *Import in database*, and use the parameters:



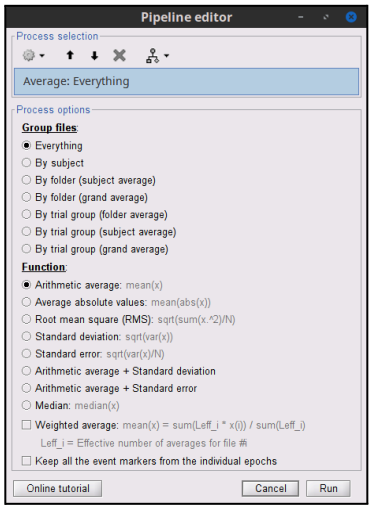
[2] https://neuroimage.usc.edu/brainstorm/Tutorials/Epilepsy#Artifact_cleaning_with_ICA

- *Time window* = **0 - 119.9995 s**
- Do **NOT** check **Split in time blocks**
- Check **Use events** and select **Trigger01 (x340)**
- *Epoch time* = **-50 to 250 ms**
- Check **Apply SSP/ICA projectors**
- Check **Remove DC offset**, select **All recordings**

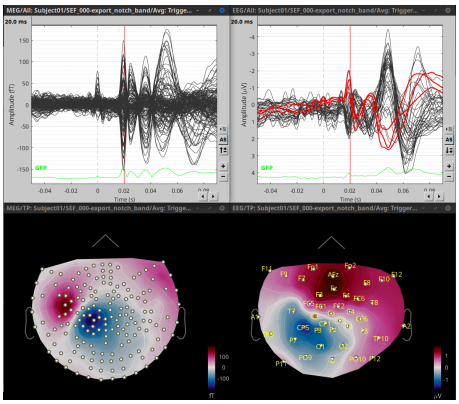


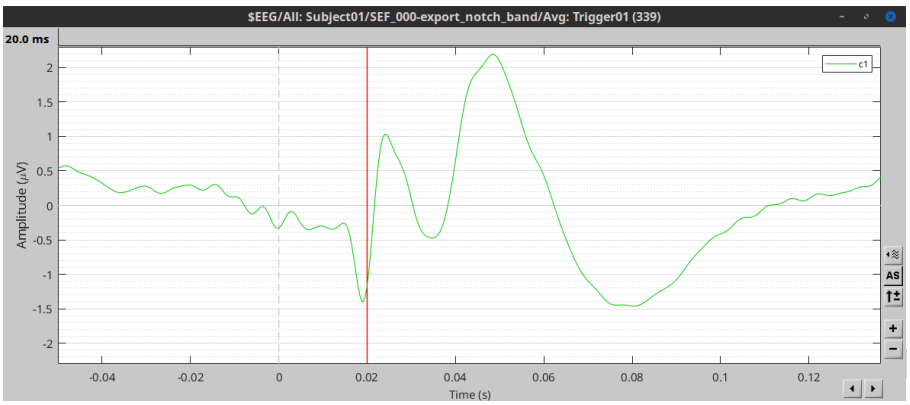
- Answer **Yes** to this question to discard the last epoch.
- A new folder named **SEF_000-export_notch_band** is created (no more **raw** indicator)

- Review trials
  - Trials groups (Trigger01), contain same-name trials (often imported from with the same event)
  - Trials containing an bad event (with **bad** in its name) are labeled as bad ( )
  - Rastre plots: Right-click on trial group > *Display as image* > *EEG* select channel **CP5** in the Display Tab

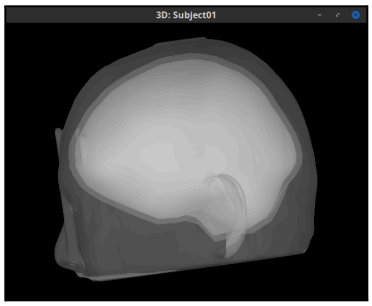


- Average trials
  - Drag and drop all the trial groups in Process1
  - Run process *Average* > *Average files*:
    - *Group files* = **Everything**, *Function* = **Arithmetic average**
- Check different plots for the average somatosensory evoked potential (SEP) in **EEG** signals, and the somatosensory evoked fields (SEF) in **MEG** signals. Plot both topographies
- **Optional: Create a sensor cluster**
  - Open the *Cluster* tab by clicking on the plus sign (**+**) at the right of *Record* tab
  - Click on NEW IND to create a new cluster by indicating the sensor names, use **C3, CP5, P3**
  - Plot the cluster time series with on the plot button ( )
- Observe Components N20, P25, N33 and P45 visible over left somatosensory cortex in EEG and their respective fields in MEG
- Close all figures. Do not save the created cluster

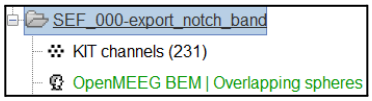




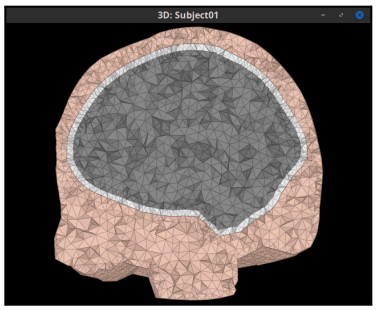
8. Forward model (aka Head model)



- Computing boundary element (BEM) layers
  - Go to the anatomy view
  - Right-click on **Subject01** folder > *MRI segmentation* > *Generate BEM surfaces*
    - Select **Brainstorm**
    - Number of vertices: *Scalp* = **1082**, *Outer skull* = **642** and *Inner skull* = **642**
    - Thickness of layers, Skull (mm) **4**
    - **Note:** This number of vertices is selected to avoid long computations during the workshop. Otherwise, values of **1922 vertices** can be used.
  - Right-click on the default cortex (in green) > *Force inside skull*
  - The **fix** cortex is now selected as default



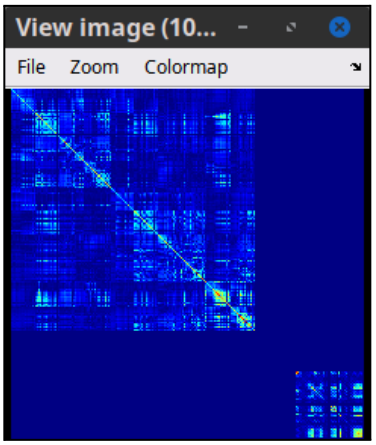
- Compute the head model for EEG and MEG
  - Go back to the functional data view
  - Right-click on the channel file (⁘) in the *SEF_000-export_notch_band* folder > *Compute head model*
    - *Source space* = **Cortex surface**
    - *Forward model* = **MEG: Overlapping spheres** and **EEG: OpenMEEG BEM**
    - Click on **OK**
      - Use default BEM layers and conductivities
      - Use default OpenMEEG options
    - The process may take up to 5 min



- **Optional: FEM Method with Duneuro**

  The forward model can also be computed using the FEM method
  - Computation of FEM meshes from BEM surfaces.
  - They can also be computed from MRI volumes
  - The forward model can be computed with the DUNEuro plugin

9. Noise covariance matrix

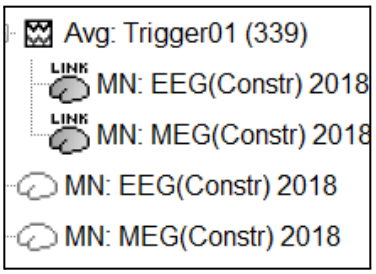


- Compute noise covariance for EEG and MEG from pre-stimulus baselines
  - Select the trial group, right-click > *Noise covariance* > *Compute from recordings:*
    - *Baseline* = **[-50, 0] ms**, *Sensors* = **EEG** and **MEG**
  - Select **Block by block**

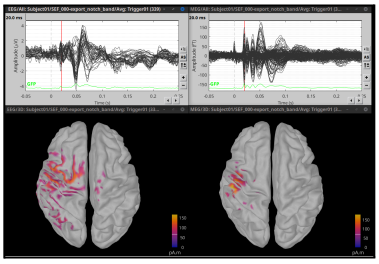
10. Computing inverse models

- Compute inverse model (EEG)

- Right-click on the head model ( ) > *Compute sources [2018]*, use these parameters:
  - Select **Minimum norm imaging,** Select **Current density map**
  - Select **Constrained: Normal to the cortex**
  - *Sensors* = **EEG**

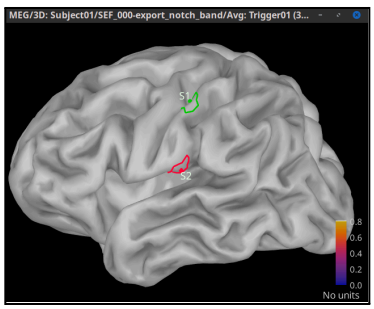


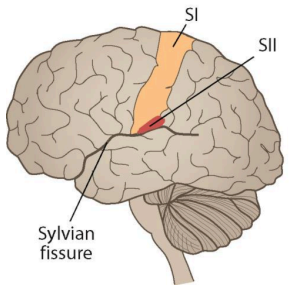
- Compute inverse model (MEG)
  - Right-click on the head model ( ) > *Compute sources [2018]*, use these parameters:
    - Select **Minimum norm imaging,** Select **Current density map**
    - Select **Constrained: Normal to the cortex**
    - *Sensors* = **MEG**
- Explanation of the inversion kernel ( ) and link ( ) files in the database
- Explore the estimated average **Avg: Trigger (339)** at 20ms
  - Display EEG and MEG **time series** (butterfly mode)
  - Display the **sources** derived from EEG and MEG data
  - Set the colormap to local maximum (maximum in that time slice)
    - Right-click on the color bar > Colormap: sources > Maximum Local
  - Set time to **100 ms**
  - Set *Smooth* = **30%** and **Amplitude** threshold to **40%** (both in the Surface tab)
- Explore other times, and the evolution of brain activity



11. Optional: Atlases and Scouts

- Display the **sources** derived from EEG and MEG data
  - In the **Scout** tab, use the dropbox to select different Atlases
  - Operations with Atlases and Scouts
- Create Scouts
  - Open the sources (from MEG) for the average, left view
  - Select the **User Scouts** atlas
  - Create scout **S1** (primary somatosensory cortex) on the left hemisphere
    - Go to Time **20 ms**, Amplitude threshold **60%** Smooth = **30%**
    - Scout tab: Click on *Select point* ( ), then point on activity in the postcentral gyrus
    - Grow Scout to 20 vertices
    - Rename to S1 (double-click on the scout in the list)
    - Review trace: Absolute values

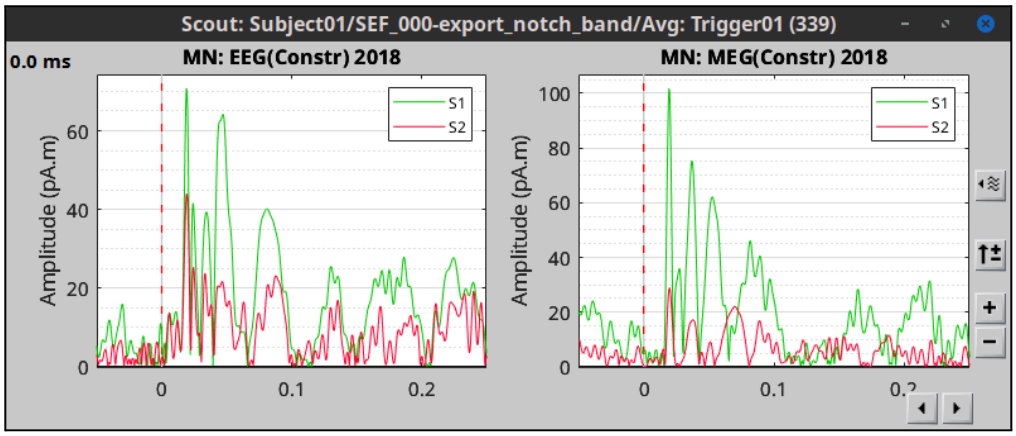




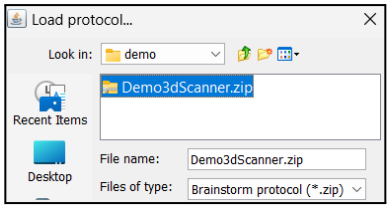
- Create a second scout **S2** (secondary somatosensory cortex) on the left hemisphere
  - Go to Time **50 ms**, Amplitude threshold **20%** Smooth = **30%**

- Scout tab: Click on *Select point* ( ), then point on activity in the bottom part of the post central gyrus, which is the anatomical location of S2.

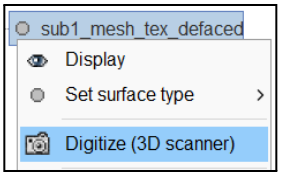
- Review S1 and S2 traces together in absolute values. For sources from EEG and MEG



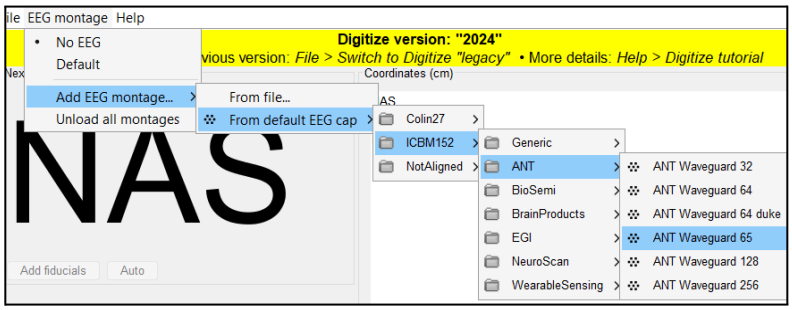
12. Optional: Automatic EEG localization and labeling

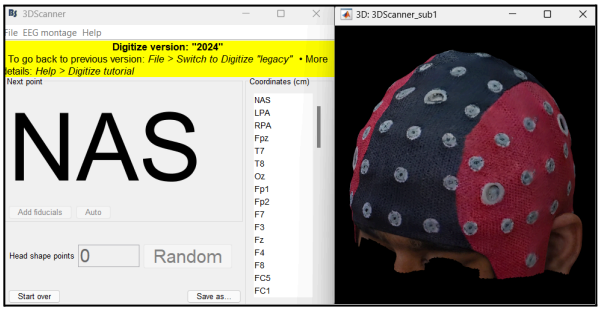


- Load precomputed protocol: **File > Load protocol > Load from zip file** and browse for:
  /Desktop/workshopLaxMorning/demo/Demo3dScanner.zip
- **3DScanner_sub1** subject added.
  - Right-click on **sub1_mesh_tex_defaced** surface.
  - Choose **Digitize (3D scanner)**



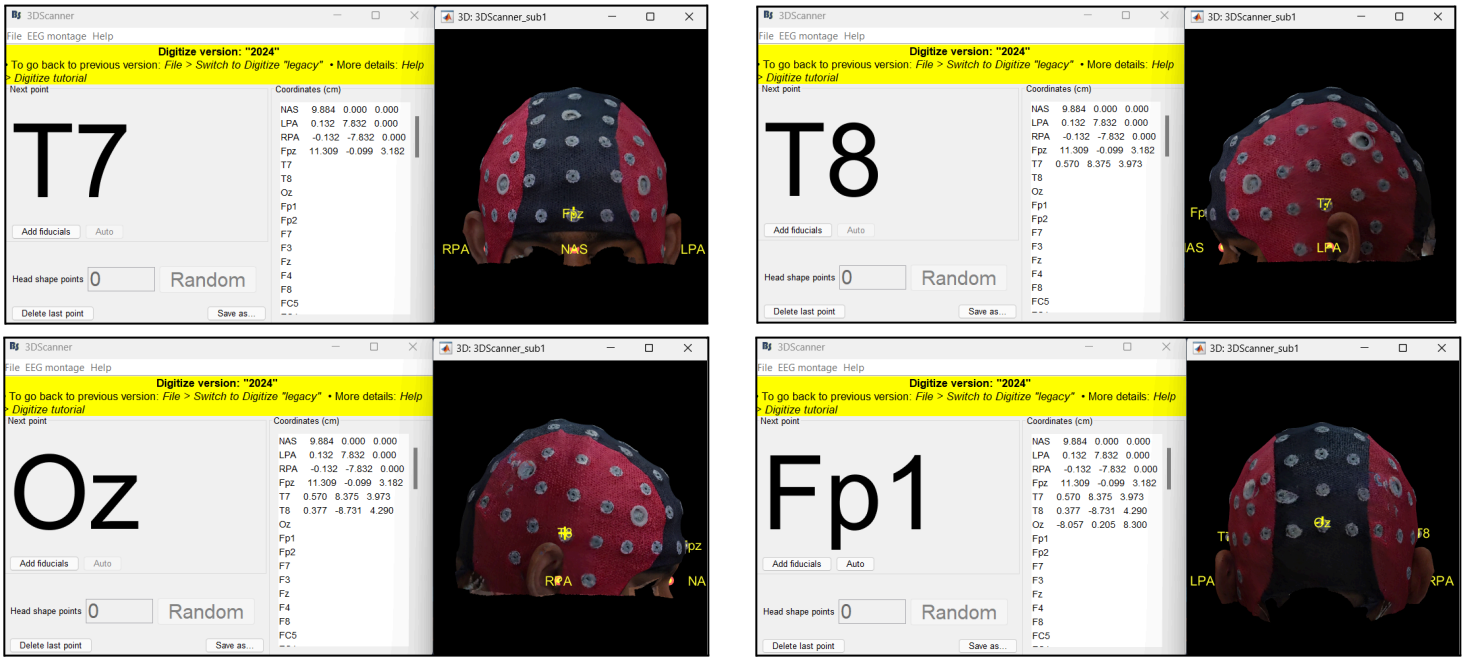
- **Configure EEG cap point collection:** *File > Edit settings…* How many times do you want to localize these fiducial at start: **Set to 1**



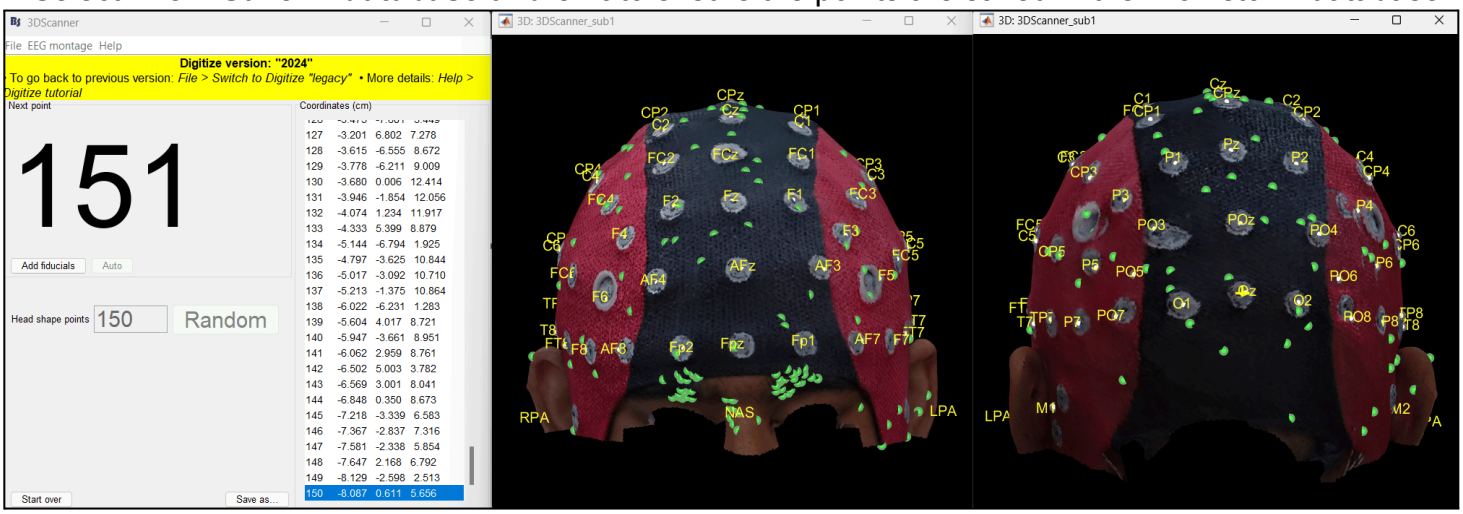


- **Configure EEG Montage:** *EEG montage… > From default EEG cap > ICBM152 > ANT > ANT Waveguard 65*
- **Collect the required number of anatomical fiducials:** Click on the 3D figure, click on ( ) on *Panel iEEG* or use the shortcut **Ctrl+P** to activate collection mode (you will see the mouse cursor change to a crosshair). Click on the desired location on the 3D model and **press key 'C'** to collect the **NAS**, **LPA** and **RPA** fiducials in order. Coordinates list are in **cm**.

- **Collect EEG points:**
  - Collect points in the order **Fpz, T7, T8, Oz.**
  - Press **Auto** to initiate the automatic detection and labeling **.**
  - Click **Yes** on the disclaimer**.**



- **Collect the desired number of head shape points:** To automatically choose 150 random points, click on Random. These can be seen as the green points in the figure and the numbered 001-150 in the Coordinates list on the GUI.
- Select **File > Save in database and exit** to ensure the points are saved in the Brainstorm database.



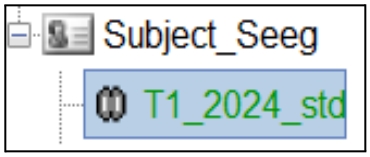
- For a more details please refer to the Brainstorm tutorial: https://neuroimage.usc.edu/brainstorm/Tutorials/TutDigitize3dScanner

** ***red highlighted texts*** ***are processing steps we will be skipping during this workshop to save time***

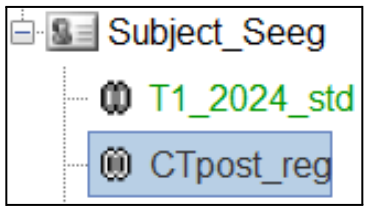
Afternoon session: SEEG Analysis

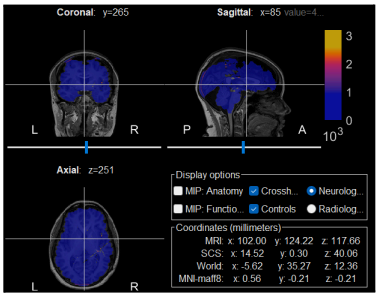
- **Afternoon session data:**
  - workshopLaxAfternoon_raw: https://tinyurl.com/y58yt9wx
  - workshopLaxAfternoon_precomputed: https://tinyurl.com/3pasznau
- Extract all the folders above to your desktop.
- In this workshop session, we will be working on a SEEG dataset recorded at the Epilepsy Monitoring Unit at UTHealth Houston. The data is distributed as **raw** and **pre-processed** data.
  - **raw** data is located in the file **workshopLaxAfternoon_raw.zip** which contains raw SEEG recordings (in EDF format), T1 MRI, and CT scan (both in NIfTI format). The raw SEEG recordings correspond to the following:
    - Two files containing seizure onset:
      - Seizure onset with Low-voltage-fast-activity
      - Seizure with Ictal repetitive spiking
    - One file with interictal spike and
    - One file containing baseline recordings
  - **pre-processed** data is located in the file **workshopLaxAfternoon_precomputed.zip**, which contains a Brainstorm protocol with the raw data already pre-processed.

13. SEEG Analysis: Import Anatomy (Chinmay)



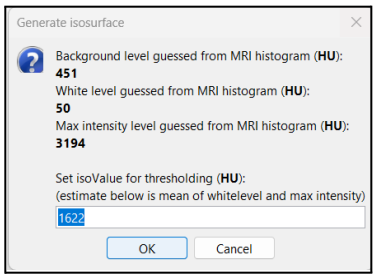
- New protocol: **workshopLaxAfternoon.** New subject: **Subject_Seeg**
- **Import T1 pre-implantation: (5 mins)**
  - Prerequisites: **SPM** plugin
  - Right-click on **Subject_Seeg > Import MRI**
  - Select format: **MRI: NIfTI (*.nii, *.nii.gz)**
  - Select: **/Desktop/workshopLaxAfternoon_raw/T1_2024_std.nii.gz**
  - Introduction to the MRI viewer: Click, mouse wheel, color bar, popup
  - MRI Viewer: **Click here to compute MNI normalization** and select the **maff8** algorithm. This sets default positions for the fiducials Coordinate systems: MRI, SCS, World, MNI and also does MNI normalization
  - Click **Save**





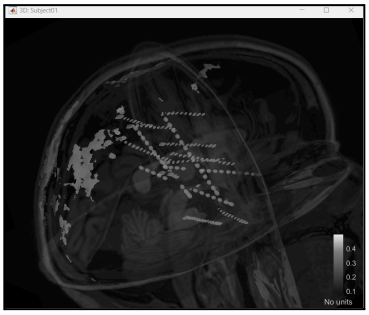
- **Import post-implant CT: (10 mins)**
  - Prerequisites: **SPM** plugin
  - Right-click on the **Subject_Seeg > Import CT**
  - Select format: **MRI: NIfTI (*.nii, *.nii.gz)**
  - Select file: **/Desktop/workshopLaxAfternoon_raw/CTpost_std.nii.gz** (use pre registered: **/Desktop/workshopLaxAfternoon_raw/CTpost_reg.nii.gz**)

14. SEEG Analysis: Coregister and Normalize images to standard MNI space



- Select coregister using **SPM.** Select **Yes** to reslice volume. Select **SPM** for skull stripping.

  (Select **Ignore** and select **No** for reslice volume as the CT is already co-registered and resliced)
  - The MRI viewer opens automatically, showing the post-implantation CT volume as a colored layer on top of the previous volume. Use this display to validate that the co-registration of the two volumes is correct (all the parts of the head must align well).

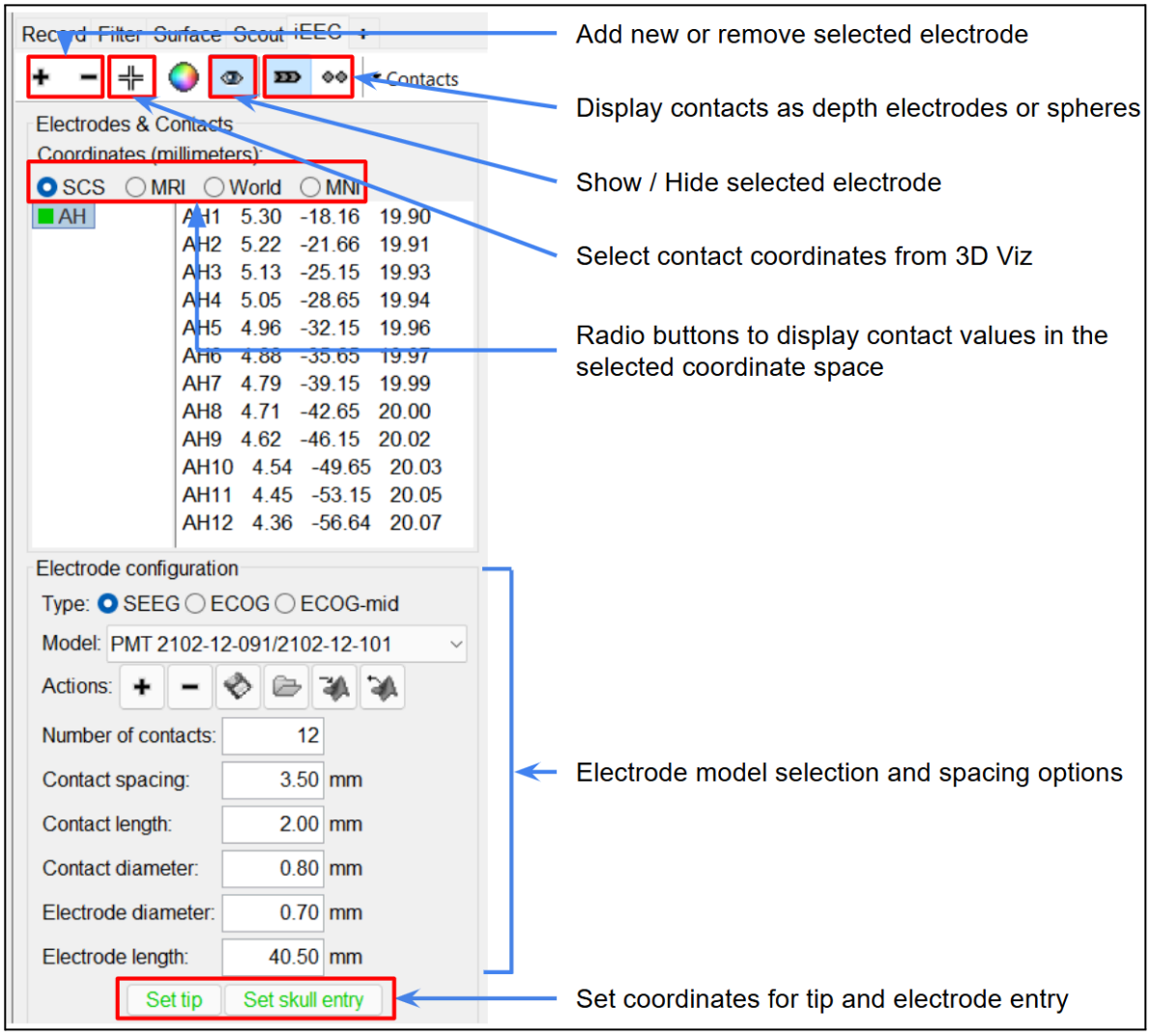


- **Generate isoSurface (2 mins)**
  - This creates a thresholded mesh from the CT to separate the contacts from the rest. This aids the user towards localization of the electrodes and its contacts more accurately.
  - Right click on **CTpost_reg > CT segmentation > Generate**

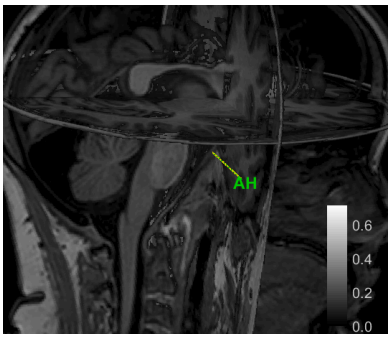
threshold mesh from CT

- Set the isoValue for thresholding, the estimation is from the mean of white level and max intensity of the CT. You can leave it as default, select **OK**.
- An isosurface is generated showing the contact as blobs overlayed on the 3D MRI slices. The **Thresh** slider under **Surface options** can be used to fine tune and regenerate mesh with different isoValues.

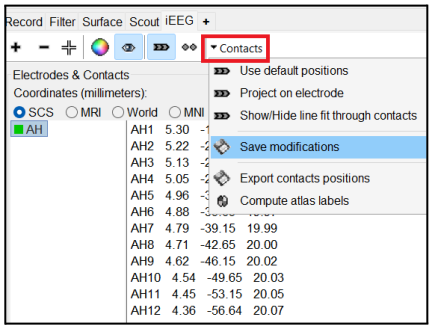
15. SEEG Analysis: Contact localization



- **Manual contact localization (30 mins)**
  - Right click on **Subject_Seeg > SEEG/ECOG implantation**. Choose **MRI+CT+IsoSurf**. This takes you to the functional tab and **Subject_Seeg > Implantation > SEEG/ECOG (0)** channel gets created. The MRI Viewer (CT overlayed MRI) and 3D Viz (isoSurface+3D MRI Slices) load up as well along with the **Panel iEEG**.
  - On **Panel iEEG** Click on the **+ (Add new electrode)**. This opens up the **Add electrode** window. Enter anything under the **Electrode label** based on your convention. For now, enter **AH** and press **OK**.

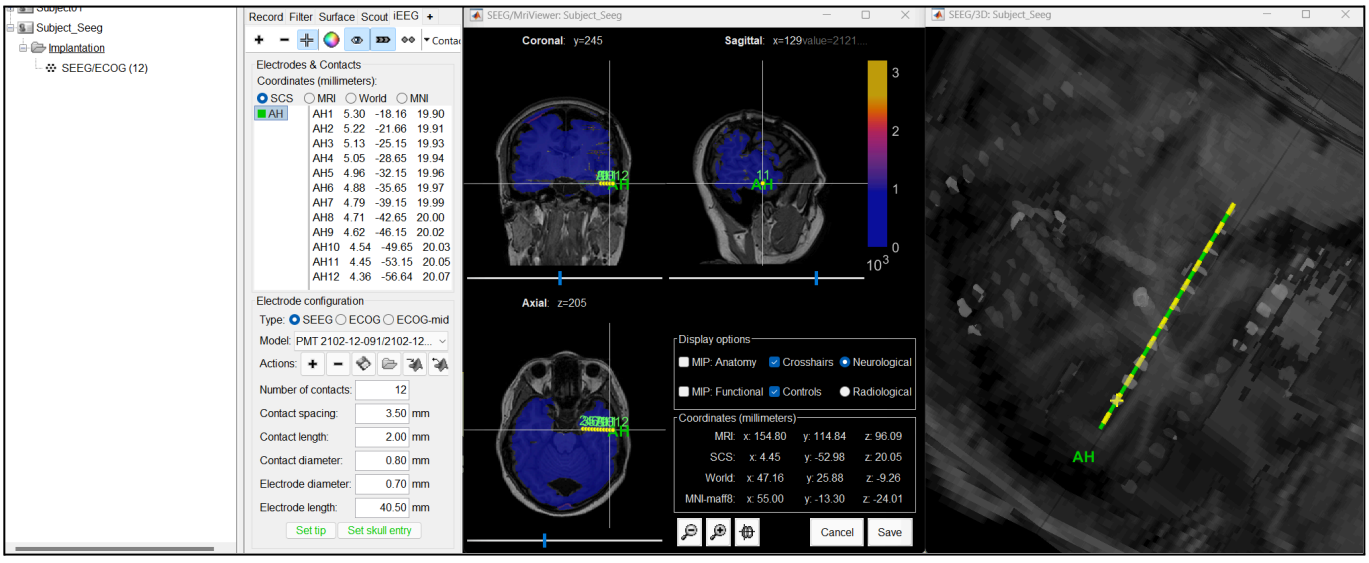


  - Select **SEEG**, and choose the electrode model (**PMT 2102-14-091/2102-12-101**) which is a 12 contact electrode.
  - On **Panel iEEG**, click the ( ) button (shortcut: Ctrl+P) to activate coordinate selection in 3D and choose the deepest contact from the isosurface in 3DViz. This should plot a yellow crosshair marker point on the contact blob and also update the crosshair in the MRI Viewer.



***Note:** You can play around with the **Thresh** slider under **Surface** tab to get better visibility of the contacts in 3D as required*

  - Click **Set tip** and the button turns green, indicating that the tip has been set. This point in 3D is at the centroid of the blob, which gives a more accurate location of the contact.
  - With coordinate selection active, repeat the steps above and choose a contact closer to the skull for the skull entry. Now click **Set skull entry** and the button turns green indicating that the entry point has been set. The MRI Viewer gets updated with the electrode.



- Click on **Save** in the MRI Viewer. This saves the new channel file and updates the number of channels in the database explorer. Click **Yes** for any other **Save** windows that pop up.
- Right click on **Subject_Seeg** and choose **SEEG/ECOG implantation** in the Functional tab to get an updated 3D Viz and MRI Viewer with all the electrodes.
- Repeat these steps for each SEEG electrode except the last step of saving.
- To save all the further electrodes, click on **Contacts > Save Modifications** to update the channel information and also save the changes to the database.
- For more details please refer to the Brainstorm tutorial: https://neuroimage.usc.edu/brainstorm/Tutorials/IeegContactLocalization

- **Anatomical labeling (5 mins)**
  - Switch to the Anatomy view.
  - Right-click on **Subject_Seeg > Add MNI parcellation > AAL3**.
  - Close all the figures. Switch back to the Functional view.
  - Right-click on the channel file **> iEEG atlas labels**
  - Create **Subject_Seeg.tsv** and click **OK**. **Select all the available options: coordinates in various coordinate systems, volume parcellations, surface parcellations**.
  - The output is a table, one row per sensor contact in the channel file, for each sensor: coordinate location in the parcellation atlas and probability of the label .

SEEG contact labels

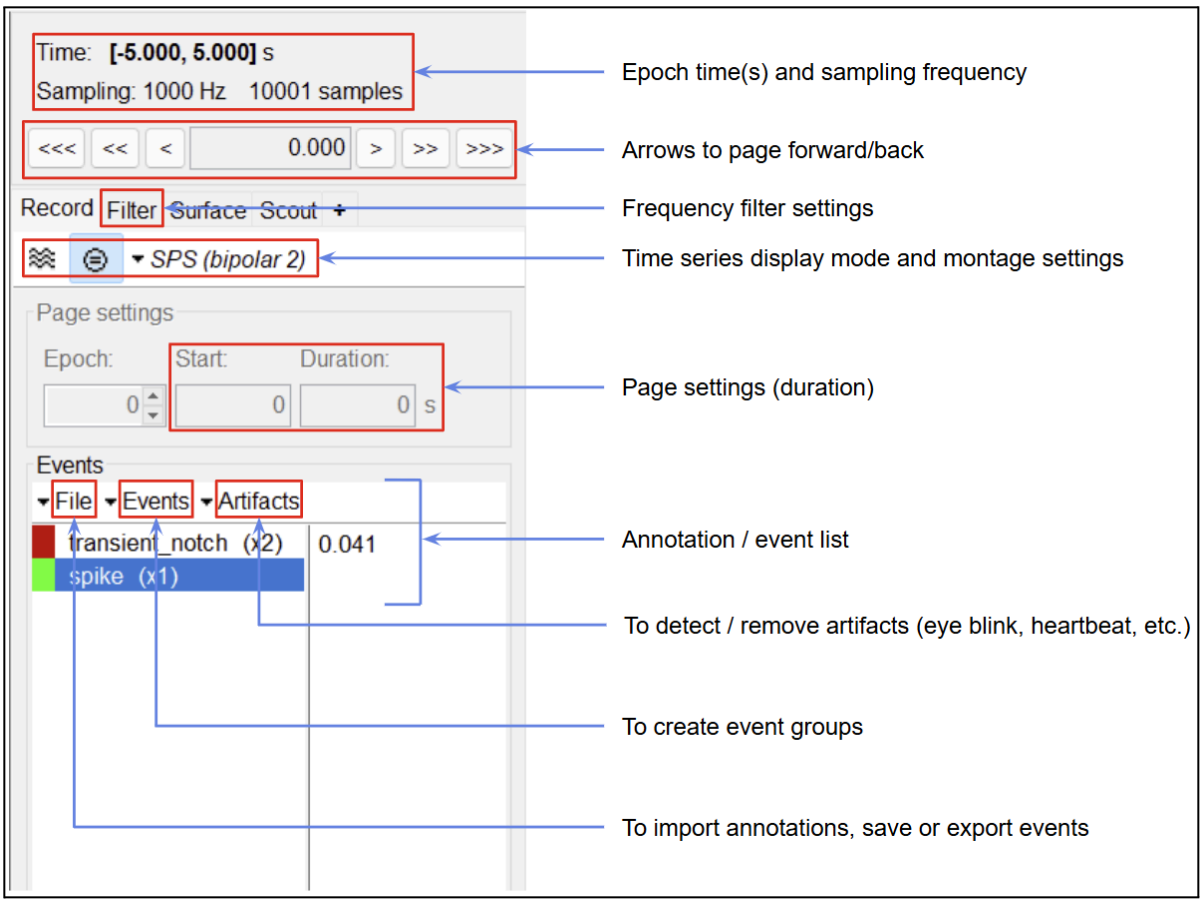
Channel	SCS	MNI	World	AAL3 (MNI-linear)	AAL3 (MNI-linear)_prob
AH1	[5.305,-18.157,19.895]	[19.135,-11.912,-24.224]	[12.360,27.284,-8.751]	ParaHippocampal R	88%
AH2	[5.219,-21.656,19.911]	[22.739,-12.052,-24.203]	[15.857,27.143,-8.802]	ParaHippocampal R	84%
AH3	[5.134,-25.155,19.926]	[26.343,-12.191,-24.182]	[19.353,27.002,-8.854]	ParaHippocampal R	55%
AH4	[5.048,-28.653,19.942]	[29.947,-12.331,-24.161]	[22.850,26.861,-8.905]	Hippocampus R	81%
AH5	[4.963,-32.152,19.957]	[33.551,-12.471,-24.139]	[26.347,26.720,-8.956]	Hippocampus R	100%
AH6	[4.877,-35.651,19.972]	[37.156,-12.610,-24.118]	[29.844,26.579,-9.007]	Hippocampus R	98%
AH7	[4.792,-39.150,19.988]	[40.760,-12.750,-24.097]	[33.341,26.438,-9.058]	Hippocampus R	75%
AH8	[4.706,-42.649,20.003]	[44.364,-12.890,-24.076]	[36.837,26.297,-9.109]	Fusiform R	23%
AH9	[4.621,-46.148,20.019]	[47.968,-13.030,-24.054]	[40.334,26.156,-9.160]	Temporal_Inf R	6%
AH10	[4.535,-49.647,20.034]	[51.572,-13.169,-24.033]	[43.831,26.015,-9.211]	Temporal_Mid R	29%
AH11	[4.450,-53.146,20.050]	[55.176,-13.309,-24.012]	[47.328,25.874,-9.262]	Temporal_Mid R	70%
AH12	[4.364,-56.645,20.065]	[58.781,-13.449,-23.991]	[50.825,25.733,-9.313]	Temporal_Mid R	87%

  - For more details please refer to the Brainstorm tutorial: https://neuroimage.usc.edu/brainstorm/Tutorials/Epileptogenicity#Anatomical_labelling

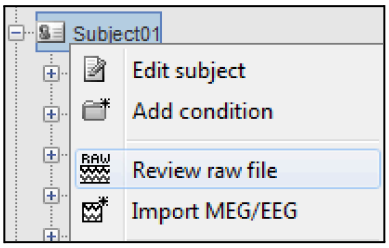
OPTIONAL DEMO: Automatic SEEG contact localization and labeling

Details: https://www.researchgate.net/publication/386140762

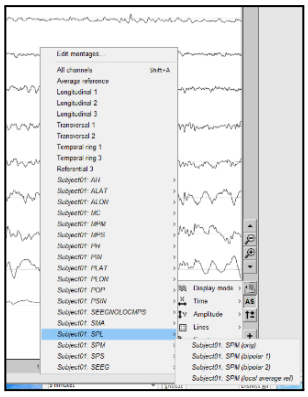
16. SEEG Analysis: Review Raw recordings (15 mins) (Yash)



- In the functional view:  (2nd button, on top of the database explorer)
- Create Link to raw file: right-click on **Subject01 > Review raw file**
- Files of Type **EEG: EDF/EDF+**
  - Select the file **Baseline.edf** in the data folder
  - Click on **Open**

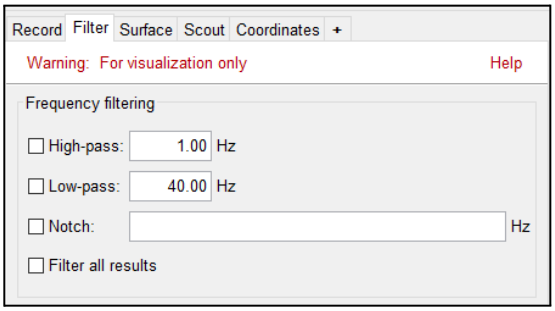


- Review SEEG: Right-click on **Link to raw file > SEEG > Display time series**
  - Display in columns: Button  in the Record tab **> Display mode > Column**
    - **Amplitude**: Buttons and shortcuts, Display menu
    - **Time**: Display windows of 15 seconds, Scroll with F3, Auto-Scale button

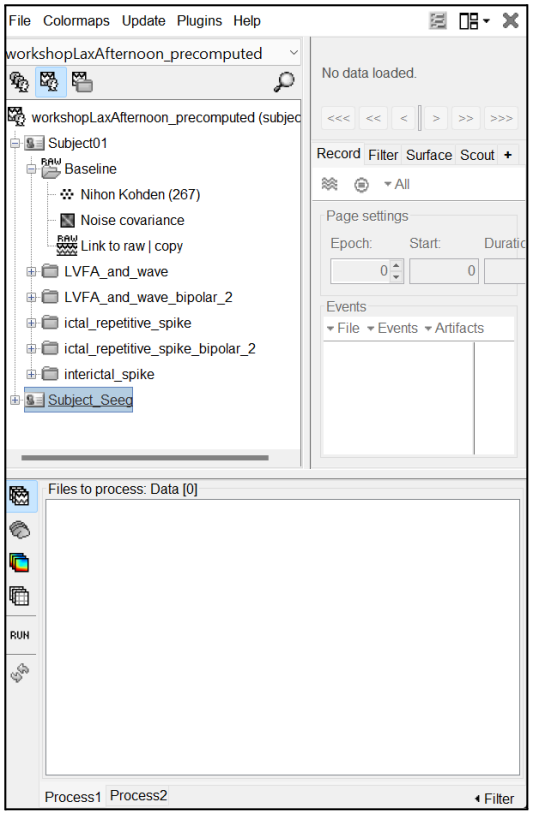


- Select bad channels + right click **> Channels > Mark selected as bad** (if needed)
- Montages: click **Display configuration**  **> Montage > Subject01: SEEG > Subject01 SEEG: (bipolar 2)**
    - Select the montage for the dataset
      (Average, Referential, Transversal or longitudinal)
    - For the SEEG dataset, select **bipolar 2** montage for continuous chain.

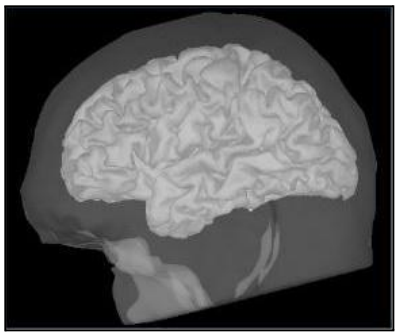
- Filter settings for review are set under the **Filter** tab in the panel
    - this is only for visualization
    - Select the checkbox to turn ON the high or low frequency filter.



- Add annotations:
    - Got to record view **> Events > Add Group > Event A**
    - Select 2 peaks and press **E**
    - Got to record view **> Events > Add Group > Extended**
    - Drag across the window
    - Press **E**
    - Save annotation: **File** > **Save modifications**

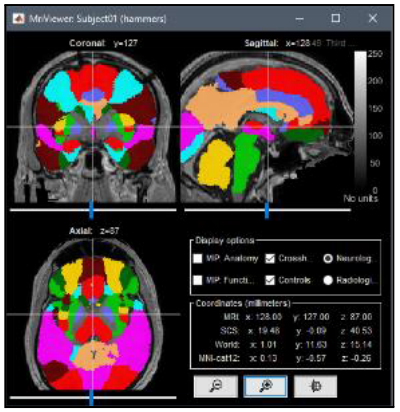


17. SEEG Preprocessing:

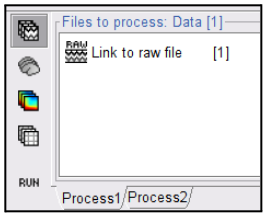


Run CAT12 segmentation:

- Prerequisite: CAT12 plugin
- Right click on **MRI > MRI segmentation > CAT12**
- Display cortex.
- Close figure, double-click on **cortex_15002V** (low-resolution pial surface)
- 3D figure: **Rotation, zoom, predefined views**
- Surface tab: **Smooth slider, sulci, edges**
- Scout tab: **Parcellations of the surface vertices**
- Volume parcellations: **AAL3, Hammers, tissues**
- Adjust transparency, change the atlas, non-linear MNI transformation
- Add MNI parcellation: **Schaefer2018_100_7net**
- Close all: Big cross (✖) on the top-right, close all the figures and empty memory.



For more details refer to the Brainstorm tutorial:
https://neuroimage.usc.edu/brainstorm/Tutorials/SegCAT12#Install_CAT12

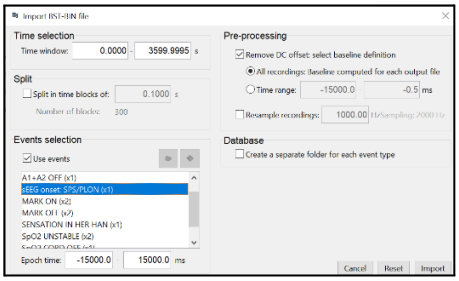


Remove power line noise:

- Compute Periodogram
  - Close all the figures
  - Drag-and-drop (RAW) raw file in **Process 1, click [RUN]**
  - Add the process: Frequency, Power spectrum density (Welch)
  - Time window = **All file**, Window length = **_ s**, Overlap = **50%**
  - Units = **Physical**
  - Sensor types = **SEEG**
  - Click on **Run**
- Review Periodogram
  - Peaks at 60Hz, 120Hz, 180Hz on EEG and MEG: Power lines (60Hz+harmonics)
- Process Notch filter
  - Select: **Pre-process > Notch filter**
  - Frequencies to remove (Hz) = **180, 300, 420, 540, 660, 780, 900Hz**
  - Sensor types = **SEEG**

Import recordings:

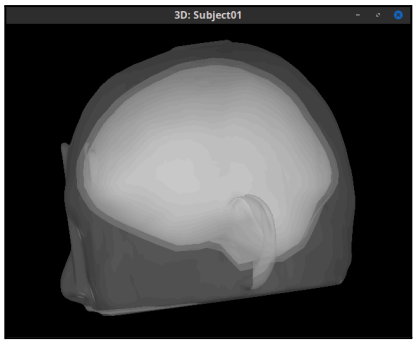
- Import in database
  - Right-click on the pre-processed file > Import in database, and use the parameters:
    - Time window = **0 - 119.9995 s**
    - Do NOT check Split in time blocks
    - Check **Use events** and select **s**EEG onset
    - Epoch time = **-15000 to 15000 ms**
    - Check Remove DC offset, select **All recordings**
  - A new folder named _ is created (no more **raw** indicator)



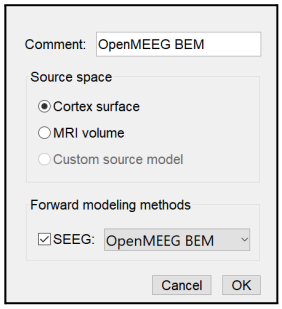
18. SEEG Analysis: Import precomputed Brainstorm protocol (5 mins)

- Prerequisite: Download from the zip file from url: https://tinyurl.com/3pasznau
- Open Brainstorm
- Click **File > Load Protocol > Load from zip file**
- Click on ... , and point to the downloaded zipped file: **workshopLaxAfternoon_precomputed.zip**
- Protocol called **workshopLaxAfternoon_precomputed** should appear

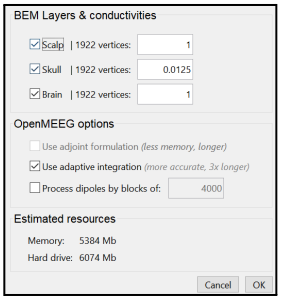
19. SEEG Analysis: Modeling interictal spikes using Min-Norm Imaging



- **Compute Forward Model (aka Head Model) (10 mins)**
  - Computing boundary element (BEM) layers
    - Prerequisite: **OpenMEEG** plugin
    - Go to the anatomy view
    - Right-click on **Subject01 folder > MRI segmentation > Generate BEM surfaces**
      - Select Brainstorm
      - Number of vertices: Scalp = **1922**, Outer skull = **1922** and Inner skull = **1922**
      - Thickness of layers, Skull (mm)= **4**
      - **DON'T CLICK [OK]**
    - Double-click on **mid_15002V** to make it as the default cortex (in green). If already green, no need to double-click.



  - Compute the head model for SEEG
    - Go back to the functional data view, navigate to the **interictal_spike** folder and expand it
    - Right-click on the **Nihon Kohden channel file** (⁘)**> Compute head model**
      - Source space = **Cortex surface**, Forward model = **SEEG: OpenMEEG BEM**, click **OK**
      - Use default BEM layers and conductivities.
      - Use default OpenMEEG options.

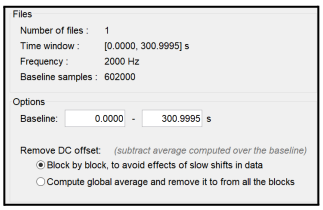


- **DON'T CLICK [OK]**

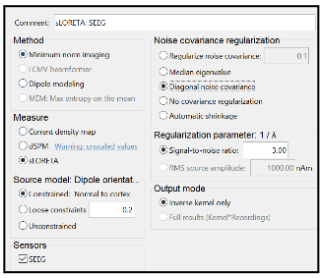
- Copy the head model files to the other folders
  - Right-click on the head-model file (**OpenMEEG BEM | mid 15k**)**> Copy to other folders**

- View Leadfield vectors
  - Right-click on head-model file ( ) **> View SEEG leadfield vectors**
  - Select reference=**MC2**, click **OK**
  - Make sure scouts are unselected
    - Go to the Scout tab, and make sure **ALL** and **SEL** are unselected
    - Go back to the **Surface** tab
  - Select Transparency = **90**, and **Press Shift+Up arrow** till the arrows are visible
  - Press E to show the electrode
  - Press **Up/down** to change the Reference electrode, **right/left** to change the Target
  - Press to close all figures

- **Compute Noise Covariance Matrix (for SEEG) (15 mins)**
  - Explain Process section
    - Tabs Process1, Process2
    - File types: recordings, sources, time-freq, and matrices

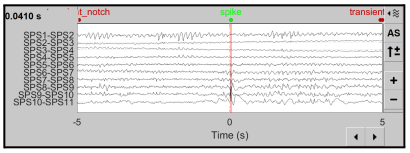


  - Switch to **Baseline folder**
  - Compute **Link to raw file | copy** ( ) for sEEG from Baseline recording
    - Select the trial group, right-click **> Noise covariance > Compute from recordings**:
      - Baseline = **[0, 301] s**
      - Select **Block by block**
      - **DON'T CLICK [OK]**
      - Copy the Noise Covariance ( )across other folder
        - Right-click noise covariance file > **Copy to other folders**



- **Compute Inverse Model (5 mins)**
  - Switch to the **interictal_spike folder,**
  - Right-click on the head model ( ) **> Compute sources**, use these parameters:

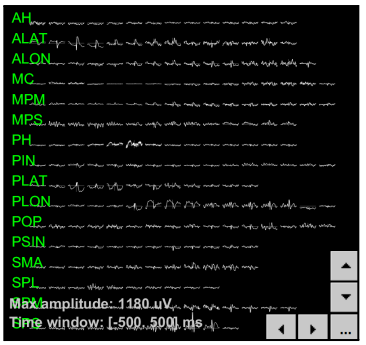
- Click on **Show Details**
- Select **Minimum norm imaging**, Select Measure: **sLORETA**
- Select **Constrained: Normal to Cortex**
- Select Noise covariance regularization: **Diagonal noise covariance**
- Sensors = **SEEG**
- **DON'T CLICK [OK]**



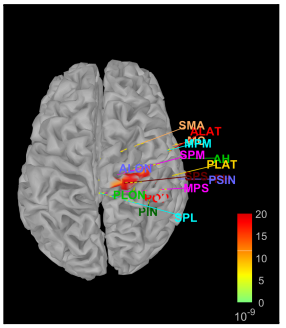
- Explanation of the **inversion kernel** ( ) and **link** ( ) files in the database

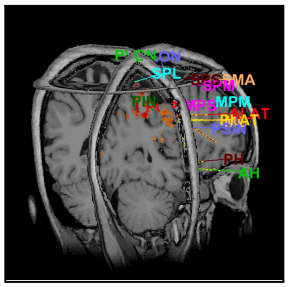
- **Display sensor time series (5 mins)**
  - Display time series
    - Right-click on **Recording** (**Spike (#1) …)> SEEG> Display time series**
    - On the right side of the figure,

    Select ( ) **> Montage > Subject01: SPS >Subject01: SPS (bipolar 2)**
    - Select the first peak of **SPS10-SPS11 (Time 0.041s)**
  - Display 2D Layout of the spike
    - Right-click on **Recording** ( )**> SEEG> 2D Layout**
    - Click ... on the corner and select **[-500, 500]**



- **View Inverse Modeling results (10 mins)**
  - Display on Cortex
    - Right-click on link (**sLORETA …**) **> Cortical activations > Display on cortex**
    - Show sensors:
      - **Ctrl+L** – SEEG contacts, **Ctrl+E** – for sensors
    - Show colormap Bar: Right Click on **Colorbar > Colormap: Sources > Permanent menu**
      - Select **Maximum: Custom [0, 2]**
      - **Contrast: -18, Brightness: 99**
      - Switch to Surface tab, Select **Amplitude: 56%**
  - Display on 3D MRI Viewer
    - Right Click on link ( ) **> Cortical activations > Display on MRI**

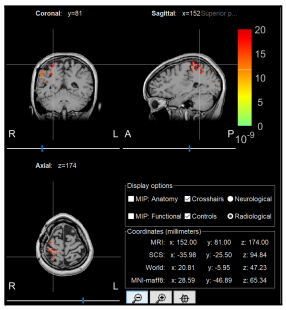




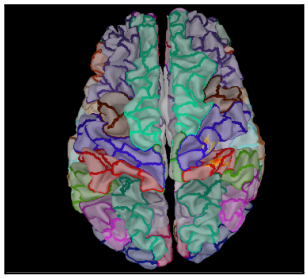
(3D)

- Right Click and drag to select Axial, Coronal, and Sagittal slices
- Press **M** to go to voxel with Maximum Intensity

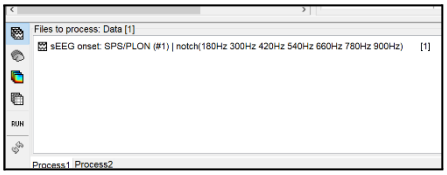
- Display on MRI viewer
  - Right Click on link (LINK) **> Cortical activations > Display on MRI (MRI Viewer)**
  - Right Click on **Colorbar > Electrodes > SEEG contacts**
  - Show colormap Bar: Right Click on **Colorbar > Colormap : Sources > Permanent menu**
  - Explain Radiological and Neurological view
  - Explain MIP function and MIP anatomical



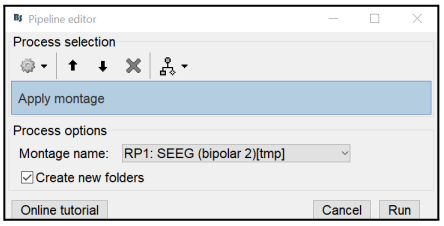
- **Atlases and Scouts (5 mins)**
  - Display sources on the Cortical surface
    - Right-click on link (LINK) **> Cortical activations > Display on cortex**
    - In the **Scout** tab, use the dropbox to select different Atlases
    - Display **Desikan-Killiany** and **Destrieux**
    - Subdivided Desikan-Killiany
      - **Atlas > Subdivide atlas> Area > Area of the sub-regions (cm^2): 5**
      - **DON'T CLICK [OK]**
    - Press ✖ to close all figures



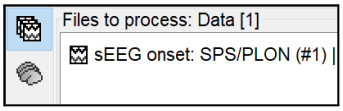
20. SEEG Analysis: Modeling ictal onset with Low Voltage Fast Activity (LVFA) using fingerprint analysis (Sensor Space) (Yash Vakilna)

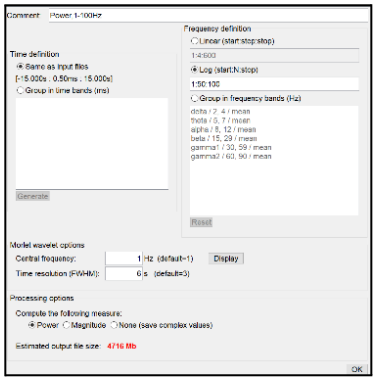


- **Compute Bipolar Montage (5 mins)**
  - Navigate and expand **LVFA_and_wave** folder
  - Press ✖ to close all figures
  - Drag-and-drop ( ) recording file in **Process 1, click [RUN]**
  - Add the process: **Standardize>Apply Montage**
    - Montage name: **Subject01: SEEG (bipolar 2)[tmp]**
    - Select **Create new folders**
    - **DON'T CLICK [RUN]**
  - A new folder with **bipolar_2** suffix will appear

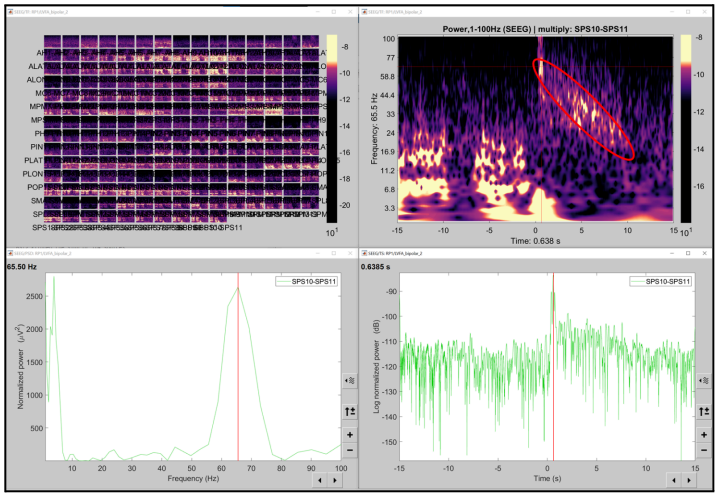


- **Compute Time-Frequency decomposition (5 mins)**
  - Navigate and expand **LVFA_and_wave_bipolar_2** folder
  - Delete any previous recordings in the Process 1 tab below
  - Drag-and-drop ( ) recording file in **Process 1, click [RUN]**
  - Add the process: **Frequency>Time-Frequency (Morlet wavelets)**
    - Sensor type: **SEEG**
    - Select **Spectral flattening: Multiply output power values by frequency**
    - Click **Edit …**
      - Frequency definition: **Log (start:N:stop)**, **1:25:100**
      - Central Frequency: **1 Hz**, Time resolution (FWHM): **6s**
      - Click **[OK]**
      - **DON'T CLICK [RUN]**





- **View Time-frequency maps (10 mins)**
  - Expand (sEEG onset …) recording file, right-click on **Power ( )**, and select **All channels**
  - Click on **Smooth display, Log(Power)**
  - Click on **SPS8-SPS9**
  - Right-click on **Colorbar>Colormap**: **Timefreq >Permanent menu**
  - Set Turn-off **[Absolute Value]**(if on), **Maximum: Local**, **Contrast: 49**, **Brightness: -65**
  - Demonstrate Left-click and Drag on colorbar to select appropriate Brightness and Contrast



  - Right-click on the colored time-frequency plot > **Power Spectrum, Time Series**
  - Click to ✖ close all figures