NatMEG

the Swedish National Facility for Magnetoencephalography

Data preprocessing using MaxFilter™

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In collaboration with

ELEKTA

Learning goals

1. To explain what types of **artefacts and interference** exist in MEG data
2. To describe the basics of **signal space separation (SSS)** –based methods for
   a. Artefact and **interference suppression**
   b. **Head position tasks**: transformation and movement correction
3. To **apply these methods** by running MaxFilter™ software
   a. Which **method(s) to select** for what kind of a data set

Outline of the presentation

- Artifact and interference in MEG data
- Introduction to MaxFilter™ software
- Artefact and interference suppression
  - Internal Active Shielding (IAS)
  - Signal Space Separation (SSS)
  - Temporal extension of Signal Space Separation (tSSS)
- Head position tasks
  - Head position tracking
  - Head position transformation
  - Head movement correction
- Guidelines for method selection in MaxFilter™ processing

Structure of the presentation

- Theory - lecture
- Practice using MaxFilter™ – demo
- Example using MEG data – demo

Disclaimer

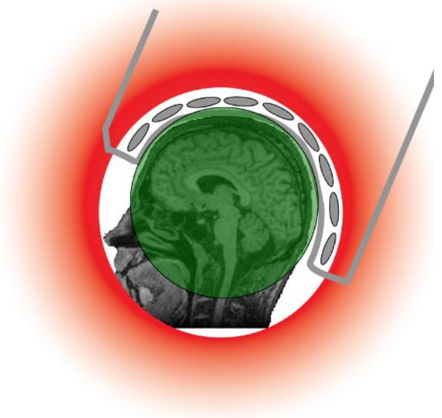
- The section "Head movement tasks" in this module includes information about methods for
  - head position transformation and
  - head movement correction

  that are not available for clinical use in US (MaxFilter-US version)

Artifact and interference in MEG data

Learnign goal 1

Artifacts and interference in the MEG



- External magnetic interference
  - traffic, elevators, ...
- Physiological artifacts
  - blinks, saccades
  - cardiac activity
  - muscular activity
- Non-physiological close-by artifacts
  - movement (typically with breathing, ballistocardiogram) of metallic objects in the body, e.g., dental work, surgical residuals, jewellery
  - stimulators
- Sensor-specific artifacts
  - signal ”jumps” (e.g. due to flux traps)
  - excess sensor noise

Introduction to MaxFilter™ software

Learning goal 3 begins

Introduction to MaxFilter™ software

- MaxFilter™ software (Elekta Oy, Finland) is MEG data preprocessing tool for suppression of external and close-by artifacts, and for head movement compensation
- Current software version MaxFilter™-2.2 (2012)
- GUI & command line tool (for scripting the analysis) available
- As an input, requires continuous FIFF-format MEG data
- Outputs data file in FIFF-format, original file remains untouched
- Head movement compensation not available in MaxFilter™-2.2 US-version
- Note; only parameters and selections relevant for the routine work and that might require change from the default settings are introduced here

Interference suppression

Learning goal 2 a

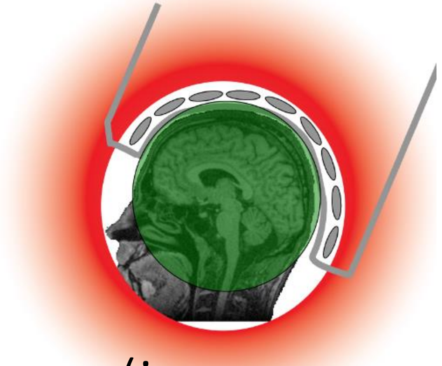
Basics of interference suppression (1/2)

- Hardware shielding
  - Passive shielding; Magnetically shielded room (MSR)
  - Active shielding; External (EAS) and Internal active shielding (IAS)
- Software shielding
  - Signal space projection (SSP)
  - Signal space separation (SSS)
  - Independent component analysis (ICA)
  - ...

Basics of interference suppression (2/2)

- Careful, artefact-free measurement setup recommended
- However, MEG signals are distorted even in ideal environment due to, e.g., hardware inaccuracies
- The signal quality can be enhanced by appropriate signal processing
- The MEG signal is a combination of the pure brain signal and interference => the task is to suppress the interference as much as possible, which requires its accurate measurement
- The signal model should contain the smallest number of parameters that are capable of explaining the data at a given signal-to-noise ratio

Introduction to Signal Space Separation (SSS) –based methods

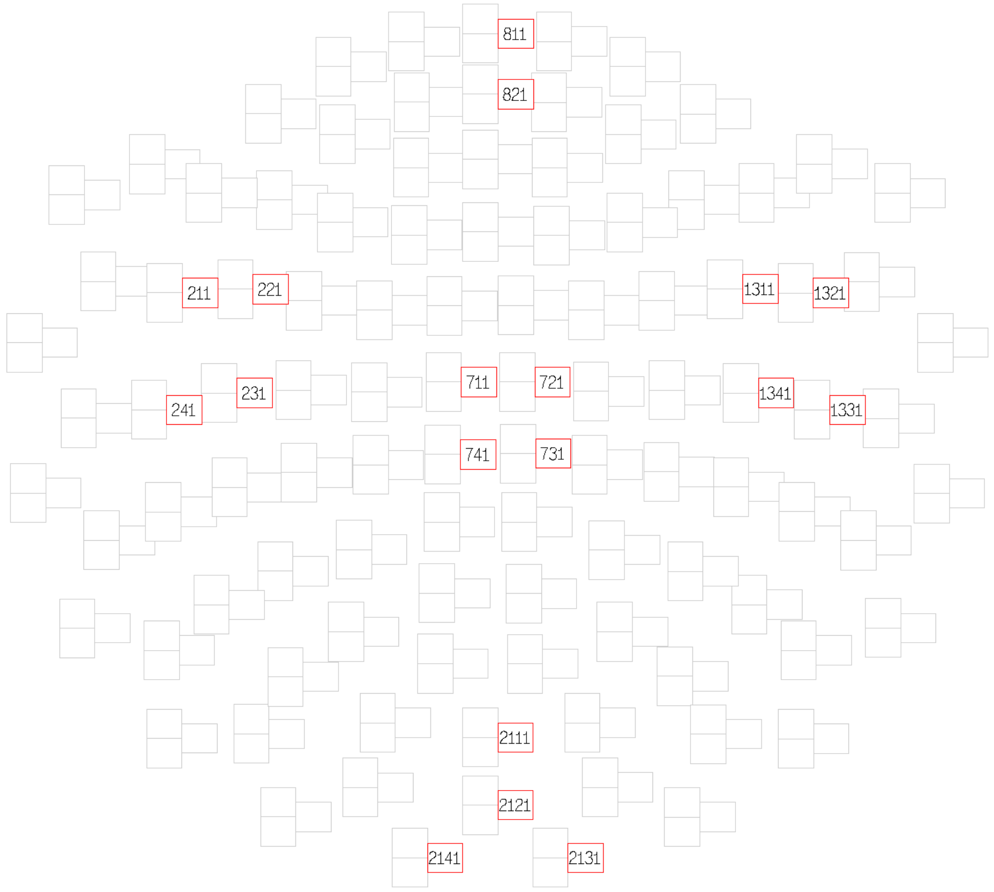


- SSS separates the magnetic field originating from the external sources (i.e. outside of the sensor helmet) from fields originating from inside the sensor helmet
- Suppresses the external magnetic field (Taulu et al. 2004, 2005, 2006)
- In case of patient/subject related (close-by) artifacts, temporal extension of SSS, tSSS, is used to suppress the close-by artifact in addition to external magnetic fields (Taulu and Simola 2006)
- Head position with respect to sensors can be changed, for whole data file (head position transformation) or for each time point separately (movement correction)
- All these SSS- based processing steps require sufficient number of channels measuring magnetic field (i.e., no saturation has happened)

Internal Active Shielding (1/5)

- Internal active shielding can be used to compensate external magnetic fields, especially when single-layer MSR is used
- Aim is to ensure that the channels, especially magnetometers, stay in their dynamic range and measure magnetic fields, i.e, they do not saturate due to the external interference
- Magnetic fields are measured with set of magnetometers

Internal Active Shielding (2/5)

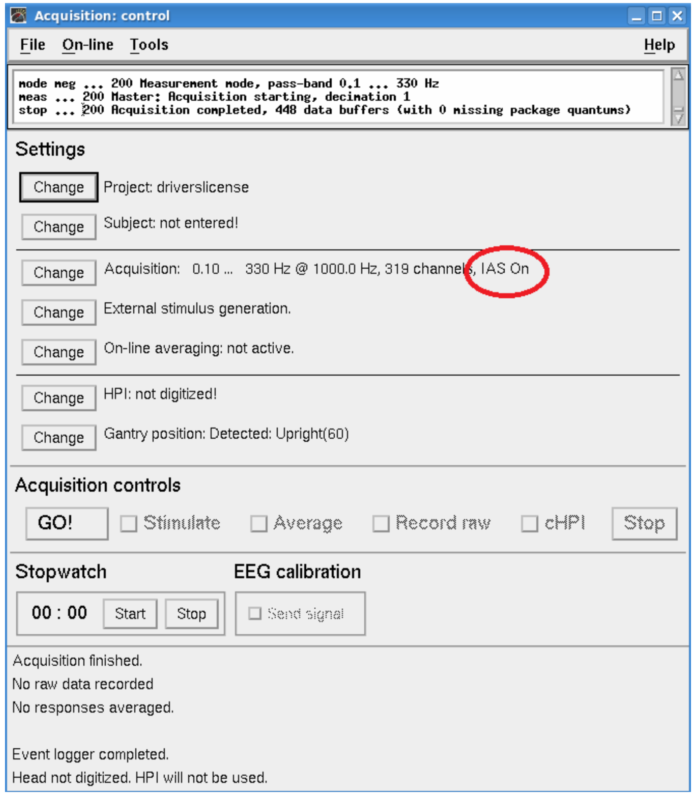


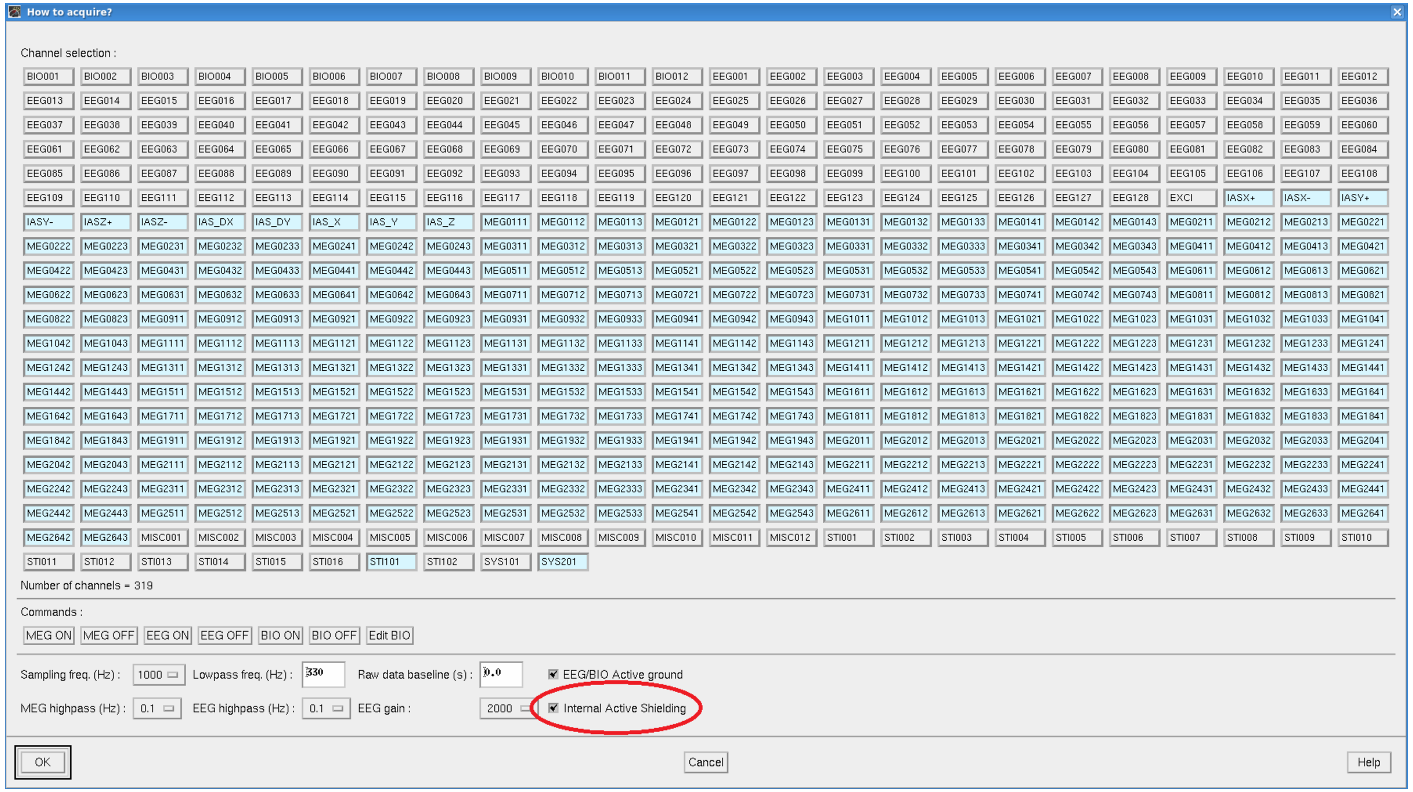
Internal Active Shielding (3/5)

- Feedback coils located at the walls of the MSR are used to produce the compensating magnetic field
- Also some brain-originated might be accidentally suppressed by this procedure
- Thus, the compensating fields need to be cancelled before the data analysis
- SSS suppresses all external magnetic field, also the ones created by the compensation coils, resulting signal where external and compensation fields are suppressed
- It is obligatory to always utilize SSS or tSSS when data have been measured with IAS on

Internal Active Shielding (4/5)

- IAS is turned ON/OFF from the DACQ channel selection window





Internal Active Shielding (5/5)

- How to know the IAS has been ON/OFF? Elekta software will warn you if data has been measured with IAS on but not been SSS-processed

Basics of interference suppression

- Hardware shielding
  - Passive shielding; Magnetically shielded room (MSR)
  - Active shielding; External (EAS) and Internal active shielding (IAS)
- Software shielding
  - Signal space projection (SSP)
  - Signal space separation (SSS)
  - Independent component analysis (ICA)
  - ...

Signal space separation (1/6)

- SSS method [Taulu et al. 2004, 2005, 2006] is based on
  - the quasistatic approximation of Maxwell's equations [see e.g. Hämäläinen 1993]

$$\nabla \cdot \mathbf{B} = 0,$$

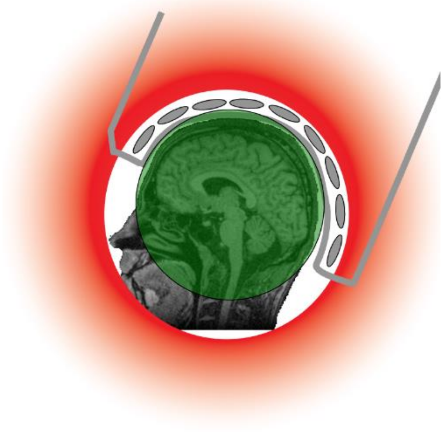
$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J}.$$

  and

  - the fact that there are no sources in the space where the sensors are located, leading to

$$\nabla \times \mathbf{B} = 0.$$

Signal space separation (2/6)



- Magnetic field can be expressed as a gradient of a harmonic scalar potential V: $\mathbf{B} = -\mu_0 \nabla V,$
- V satisfies Laplace's equation $\nabla^2 V = 0$

  which has series-form solution

$$V(\mathbf{r}) = \sum_{l=1}^{\infty} \sum_{m=-l}^{l} \alpha_{lm} \frac{Y_{lm}(\theta, \varphi)}{r^{l+1}} + \sum_{l=1}^{\infty} \sum_{m=-l}^{l} \beta_{lm} r^l Y_{lm}(\theta, \varphi)$$

- Thus, the measured signal vector also has series-form presentation

$$\phi = \sum_{l=1}^{L_{in}} \sum_{m=-l}^{l} \alpha_{lm} \mathbf{a}_{lm} + \sum_{l=1}^{L_{out}} \sum_{m=-l}^{l} \beta_{lm} \mathbf{b}_{lm}$$

Signal space separation (3/6)

- The default model orders L_{in} = 8 and L_{out} = 3, for internal and external expansion, respectively, are known to be sufficient for modeling the spatial frequencies present in the data with currently measured SNR [Ahonen et al. 1993]
- Matrix representation:

$$\phi = \mathbf{S}\mathbf{x} = [\mathbf{S}_{\text{in}}\ \mathbf{S}_{\text{out}}] \begin{bmatrix} \mathbf{x}_{\text{in}} \\ \mathbf{x}_{\text{out}} \end{bmatrix} = \phi_{\text{in}} + \phi_{\text{out}}$$

$$\mathbf{S}_{\text{in}} = [\mathbf{a}_{1,-1} \ldots \mathbf{a}_{L_{\text{in}}L_{\text{in}}}]$$

$$\mathbf{S}_{\text{out}} = [\mathbf{b}_{1,-1} \ldots \mathbf{b}_{L_{\text{out}}L_{\text{out}}}]$$

$$\mathbf{x}_{\text{in}} = [\alpha_{1,-1} \ldots \alpha_{L_{\text{in}}L_{\text{in}}}]^{\text{T}}$$

$$\mathbf{x}_{\text{out}} = [\beta_{1,-1} \ldots \beta_{L_{\text{out}}L_{\text{out}}}]^{\text{T}}.$$

Signal space separation (4/6)

- Dimension of the SSS basis $n = (L_{in} + 1)^2 + (L_{out} + 1)^2 - 2$ is smaller than the number of channels in modern multichannel devices -> unique decomposition into internal biomagnetic and external interference components:

$$\hat{\mathbf{x}} = \begin{bmatrix} \hat{\mathbf{x}}_{\text{in}} \\ \hat{\mathbf{x}}_{\text{out}} \end{bmatrix} = \mathbf{S}^{\dagger}\boldsymbol{\phi}$$

- Number of degrees of freedom using default L_{in} and L_{out} parameters is 95
- SSS is purely spatial operation, no dependence on time

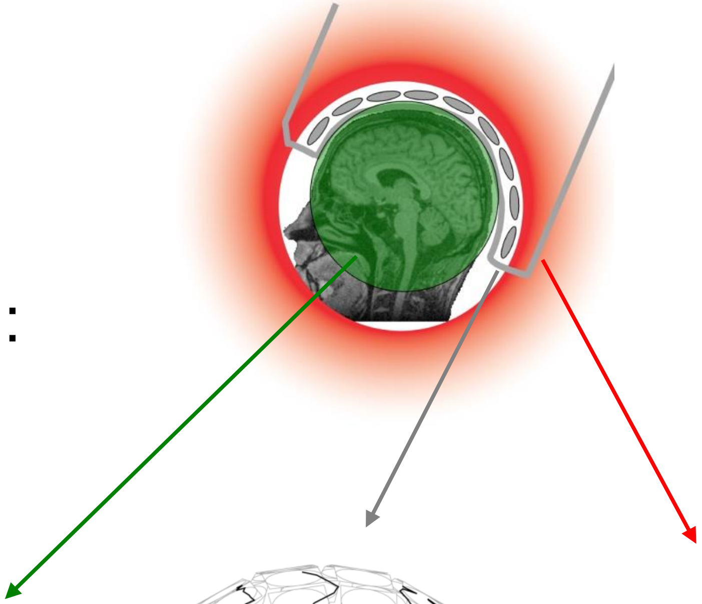
Signal space separation (5/6)

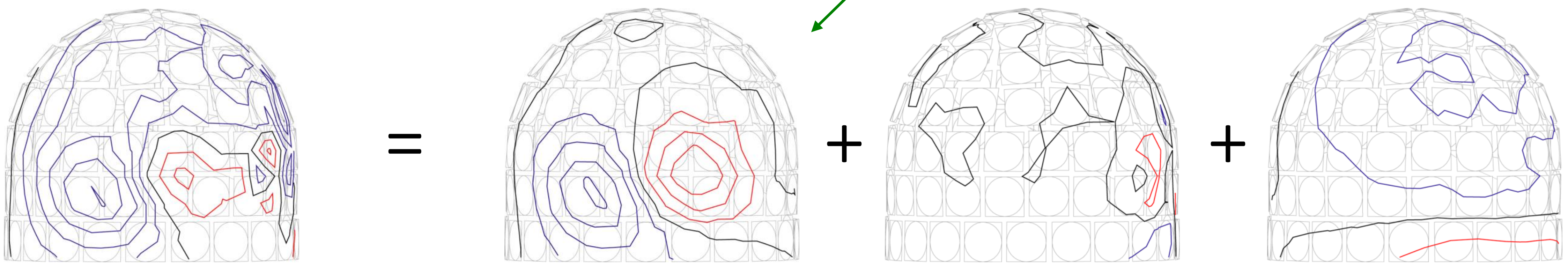
- SSS requires accurate knowledge of the sensor array and its geometry, sensor calibration
- Model is created using all magnetometers and gradiometers, only excluding the channels where the signal does not present magnetic fields, e.g., very noisy or artefact-contaminated channels
- Channels excluded from the model are estimated in the location of original sensors in the processing. Thus, there are always 306 MEG channels in the resulting data

Signal space separation (6/6)

Measurement:

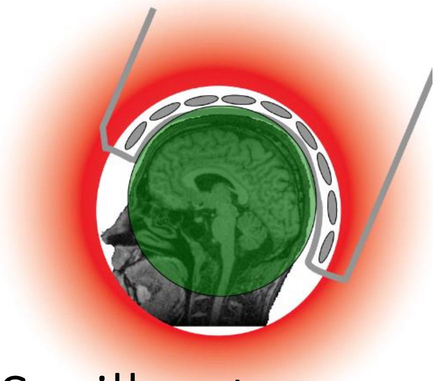
Signal space separation:





Contaminated magnetic field = internal magnetic field + residual + external magnetic field

tSSS Basics (1/2)



- In case of close-by artifacts, sources are not purely external and SSS will not suppress them
- Close-by artifacts leak in to both basis, internal and external, and are visible also in signal that is not explained by the model, i.e., residual signal
- Temporal extension of SSS (tSSS):
  1. Basic SSS
  2. Estimation of the internal, external and residual signals
  3. Correlation between internal multiple moments and residual signal
  4. If similar temporal waveform found, i.e., correlation stronger than preset threshold, signal is regarded as external origin
  5. Correlated temporal waveforms projected out from the SSS-processed data

tSSS Basics (2/2)

- tSSS requires certain time window and cannot be performed for a single time point only
- tSSS works in temporal segments; the number of projected components is data-dependent and can changes over time from window to window
- When no close-by artifacts are present in the data, tSSS reduces to SSS

Head position tasks

Learning goal: 2 b

Head position tracking (1/1)

- The relation between the head and the sensor array is determined with the help of HPI coils
- If continuous HPI (cHPI) is **not** measured, head position is assumed to be stationary
- In cHPI measurement, HPI coils are activated continuously, at coil-specific high-frequency signals (typ. 290–330 Hz)
- Signals reflecting the coil locations, and therefore the head location, are thus embedded in the raw MEG data

Head position transformation (1/1)

- In basic SSS processing, sensor-level signals are presented as multipole moments that are not dependent on the sensor locations.
- The internal part of the magnetic field is transformed back to the sensor level. However, the transformation to the sensor space doesn't need to be the same, but other head position with respect the sensor can be used
- Typically head position transformation is performed to
  - Default (standard) head position (to compare sensor-level data between subjects or patients)
  - Head position of another recording (to compare different measurement sessions of the same subject or patient)
- Reconstruction noise can occur in large head-position transformations. Thus, large transformations are typically not recommended
- If source modelling is performed on individual recordings, there is no need to do head position transformation

Head movement correction (1/2)

- Head movement correction can be used if continuous HPI (cHPI) is **on** during the measurement
- The head movement correction works the same way as the head position transformation; however, the transformation is performed to each data sample separately, taking into account the estimated head position at that time point
- After estimation of the head position, the HPI coil signals are subtracted from the data. If a residual still remains, low-pass filtering can be applied

Head movement correction (2/2)

- The position where the head is transformed in the movement compensation can be selected to be
  - initial head position from the file
  - standard head position
  - head position from a separate fiff-file
  - average head position of a fiff-file (requires 2 steps to produce this)
- As reconstruction noise can be introduced in large transformation, the initial head position or the average head position are typically recommended options

Guidelines for method selection in MaxFilter™ processing

Learning goal 3 a

Recommendations on how to select parameters for MaxFilter™ processing (1/2)

- Choosing weather to apply (t)SSS?
  - IAS ON during recording?
    - YES -> SSS or tSSS required
    - NO -> SSS or tSSS not required but recommended
- Choosing between SSS and tSSS?
  - external artifacts only?
    - YES -> use SSS (tSSS also possible)
  - also close-by artifacts or artifacts originating inside the sensor helmet?
    - YES -> use tSSS

Recommendations on how to select parameters for MaxFilter™ processing (2/2)

- Selecting between head position tasks?
  - cHPI ON during recording?
    - YES -> use head movement compensatation
    - NO -> not possible to use head movement compensation
  - If movement compensation selected, does the initial head position represent well the overall head position in the data file?
    - YES -> head position transformation to the initial head position
    - NO -> head position transformation to the average head position
  - sensor-level comparison of different data sets planned?
    - YES –> use head position transformation to align the data sets
    - NO –> no head position transformation needed

Summary

- To explain what types of **artefacts and interference** exist in MEG data
- To describe the basics of **signal space separation (SSS)** –based methods for
  - Artefact and **interference suppression**
  - **Head position tasks**: transformation and movement correction
- To **apply these methods** by running MaxFilter™ software
  - Which **method(s) to select** for what kind of a data set