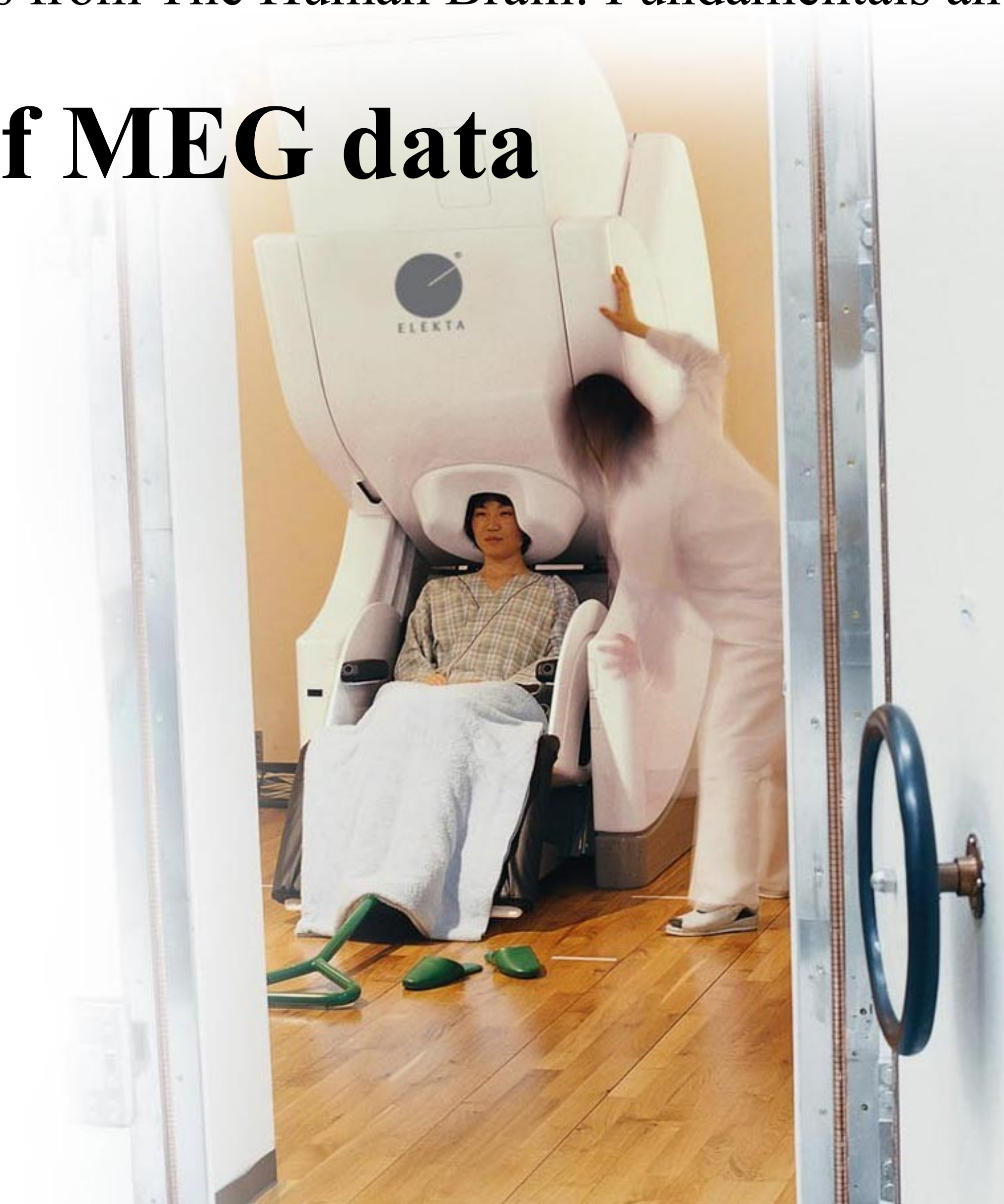
*Jyväskylä Summer School 2013*

COM7: Electromagnetic Signals from The Human Brain: Fundamentals and Analysis (TIEJ659)

# Pre-processing of MEG data

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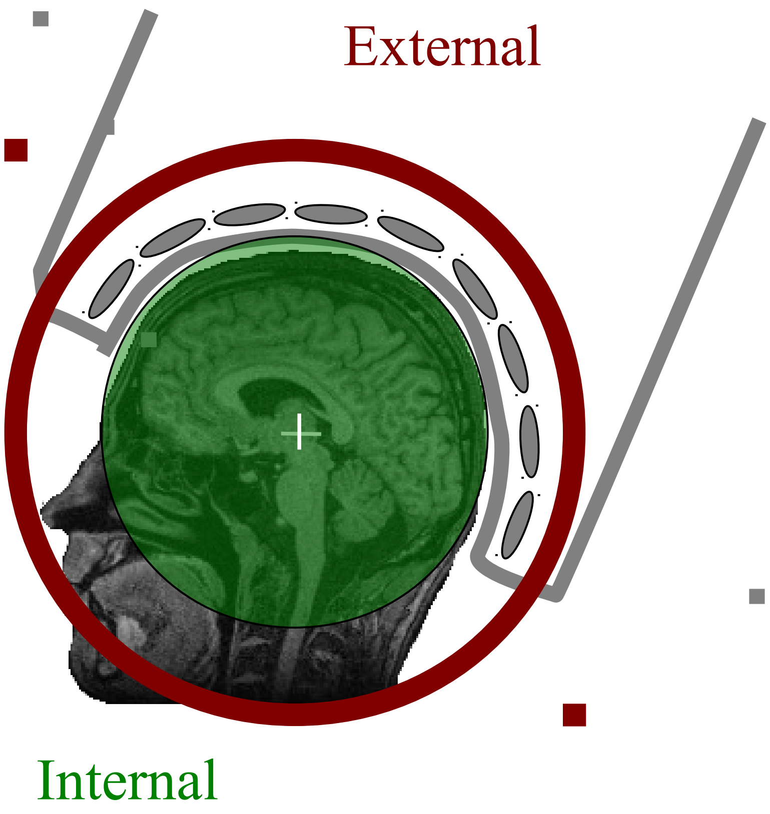
# Why pre-processing?

- Suppression of residual ambient magnetic interference
- Suppression of physiological noise
- Suppression of instrumentation-related noise and artefacts
- Compensation for head movements

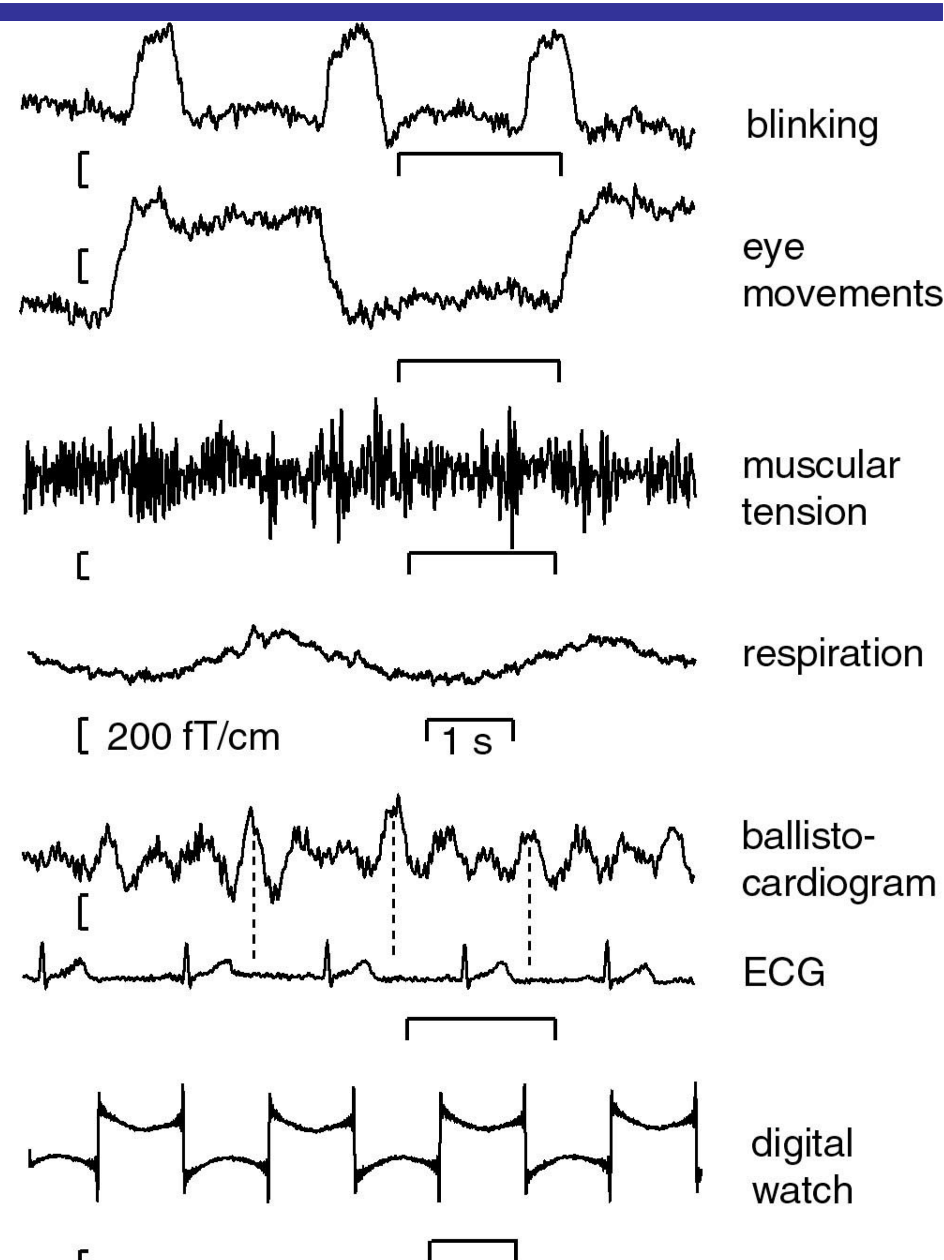
# Sources of magnetic interference

- External = originates outside of the sensor helmet
  - muscular/cardiac
  - magnetic particles in/on limbs etc.
  - traffic
  - power lines
- Internal = originates in/on the head of the subject
  - eyes (blinks, saccades)
  - muscles
  - magnetic “leftovers” from surgery, plates
  - dental work, braces
- Magnetic particles produce signal only when moving (but even very tiny movements can cause problems)



# Artefacts and Noise

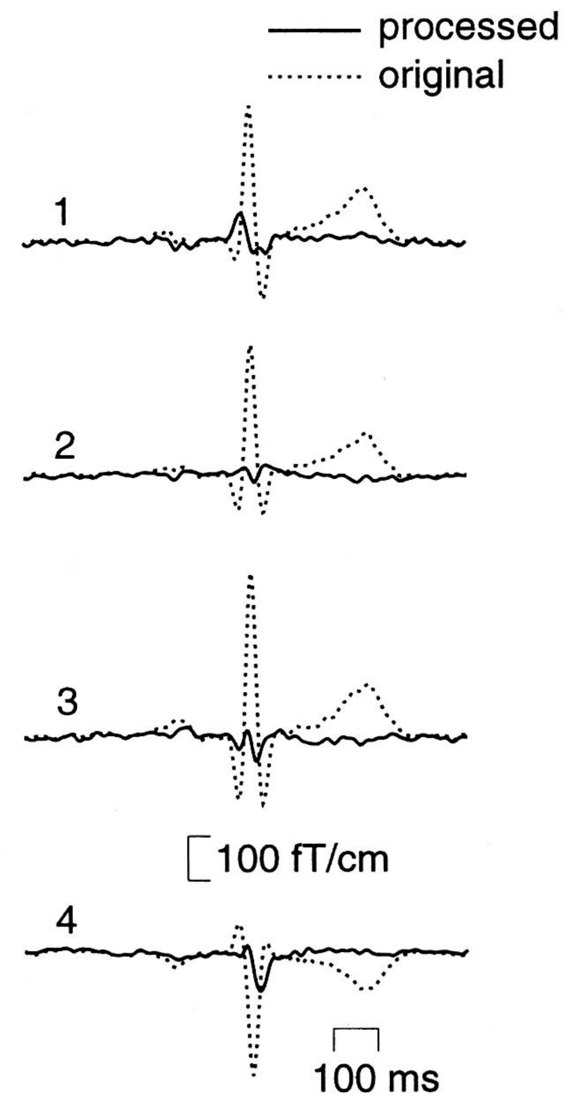
- **Biological noise**
  - muscular (particularly cardiac)
  - ocular (blinks, saccades)
- "Brain noise"
  - background brain activity
- **Moving** magnetic material/particles
  - dental work, braces, surgical plates
- Environmental noise
  - power lines (50/60 Hz + harmonics)
  - traffic
  - elevators
- System noise
  - SQUIDs, electronics and thermal insulation




*Hari, 1999*

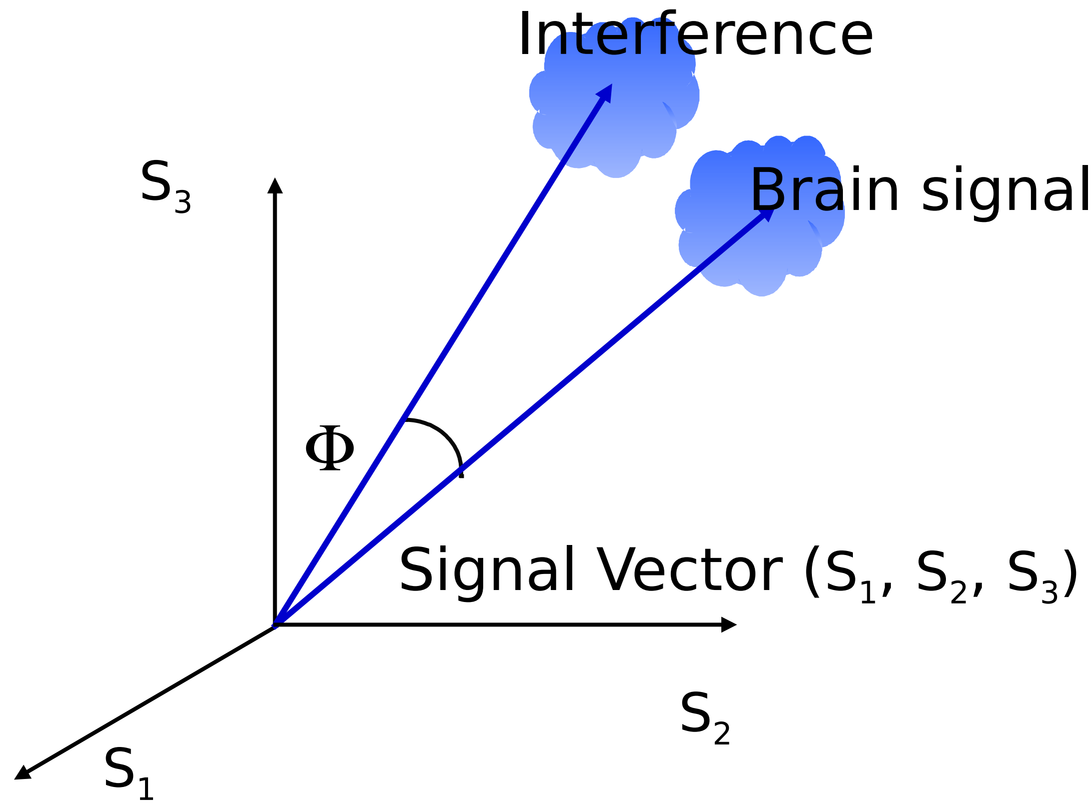
# Pre-processing: Removing artefacts

- Prevent rather than compensate!
- Discard contaminated periods
  - Reject epochs with excessively large signal variation
- Apply temporal low/high-pass filters or “de-trending”
- Remove/model the field pattern of the artefact
  1. Improve the SNR of the artefact by averaging
  2. Remove by projection
- Model the source of the artefact
  1. Dipole at the source (eye, magnetic particle)
  2. Include the artefact model to the brain source model




*Jousmäki and Hari, 1996*

# The concept of signal space




## Example:

3 measurement channels =>
3-dimensional signal space

## Signal vector:

Direction = the shape of the signal pattern
Length = the strength of the pattern

The cloud represents random sensor noise

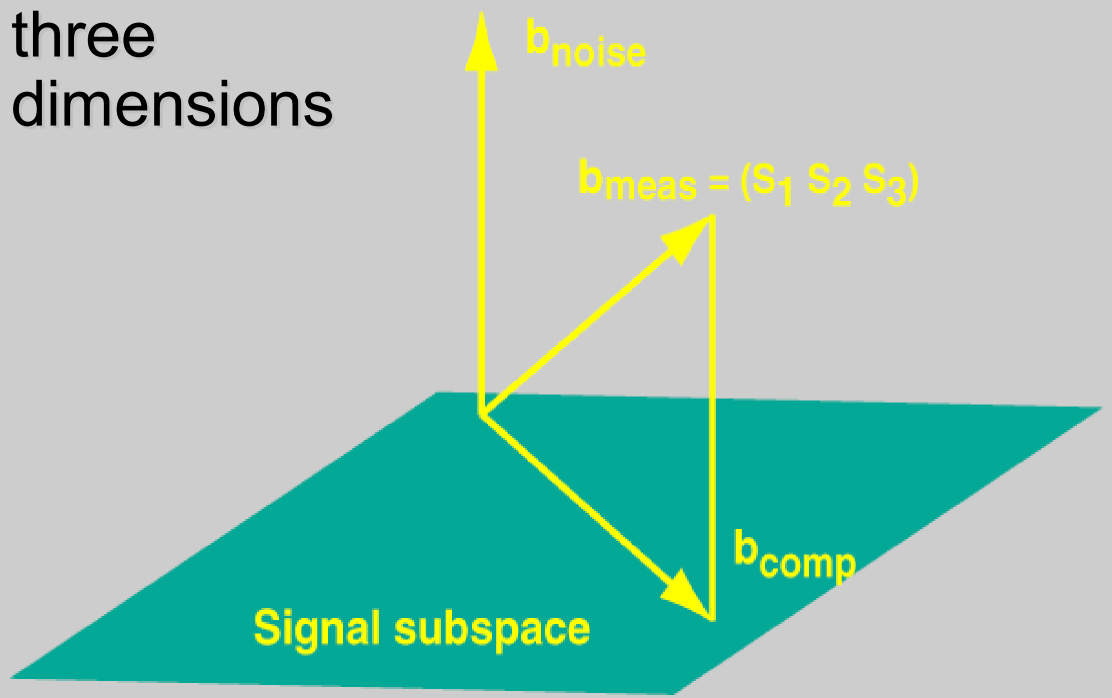
# Signal space projection (SSP)

The measured signals are projected onto a subspace which is orthogonal to all the signal vectors describing the interference

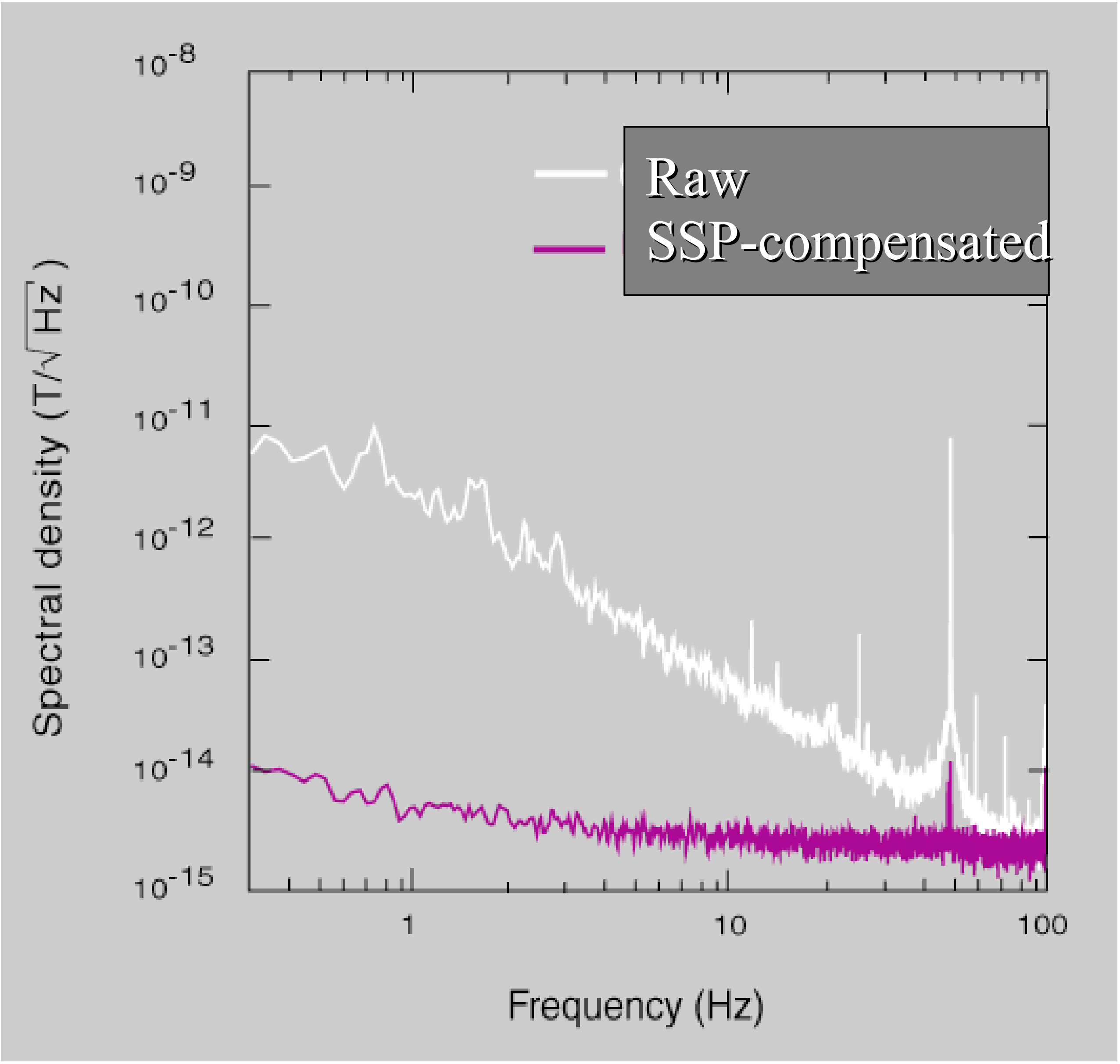
The interference subspace is often determined by principal component analysis (PCA). Typically 1–8 PC's with the highest eigenvalues selected.

For ambient noise suppression, PCA is applied on an “empty-room” recording.

Illustration in three dimensions



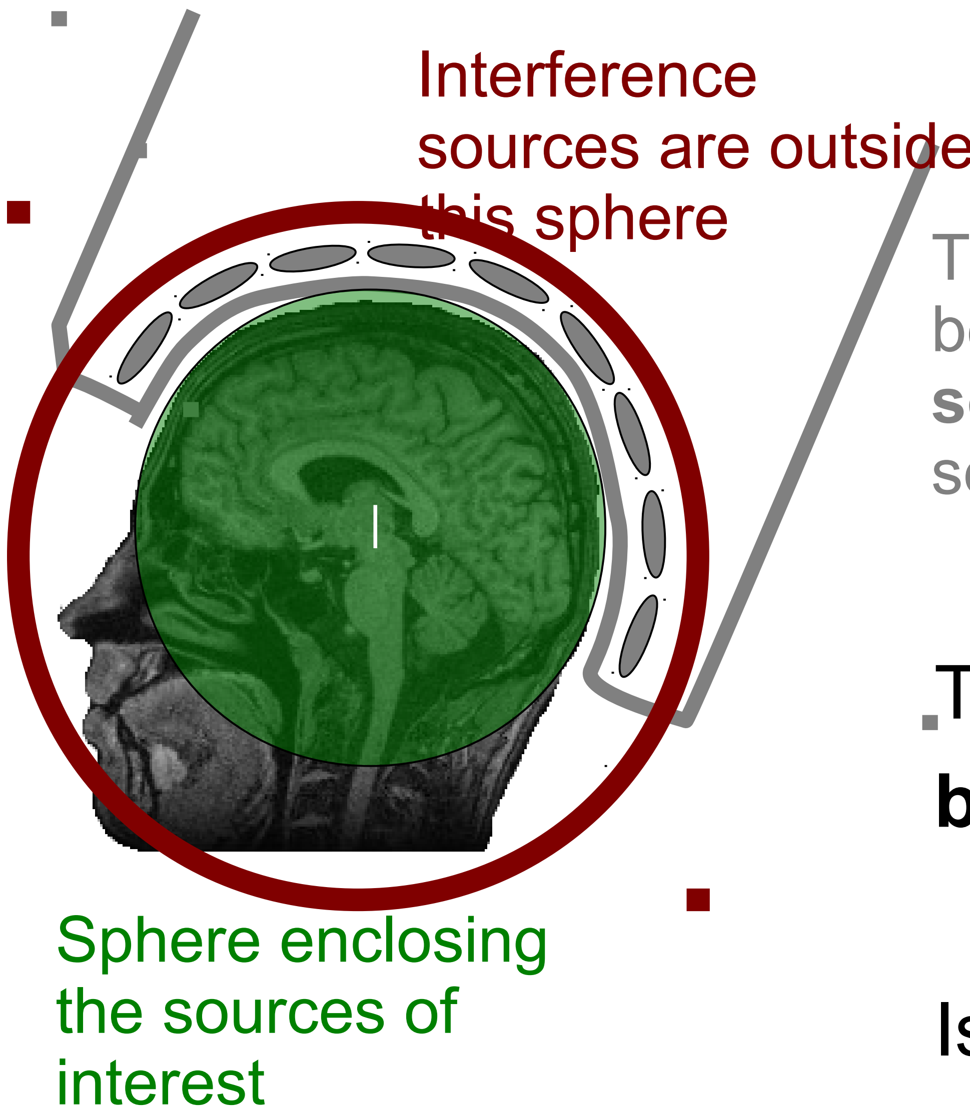
# SSP and a sample magnetometer channel



# SSP: Benefits and drawbacks

- High suppression factor for spatially stable interference sources (in excess of 60 dB)
- Adaptive: precise calibration of the sensor array not needed
- Not a generic method: the interference subspace must be given or learned by PCA
- Interference and brain-signal subspaces may not be orthogonal => SSP may change the spatial distribution of brain signals

# Signal space separation (SSS)



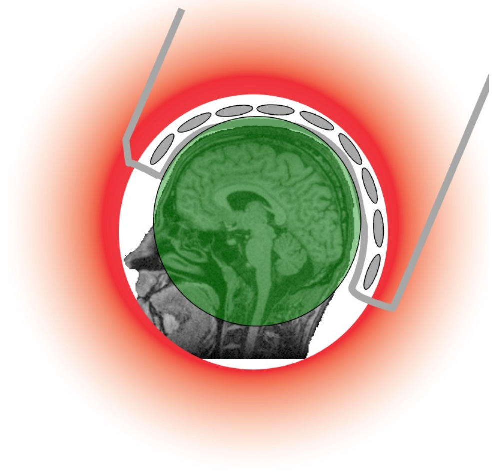

The region in-between has **no sources**, only the sensors!

The measured signal

$\mathbf{b} = \mathbf{b}_{in} + \mathbf{b}_{out} + \mathbf{n}$

Is it possible to separate $\mathbf{b}_{in}$ from $\mathbf{b}$?

# Signal Space Separation in a Nutshell



$$\mathbf{B} = -\nabla V,\ \nabla^2 V = 0$$

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

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

# SSS basis, matrix notation

- Matrix representation:

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

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

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

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

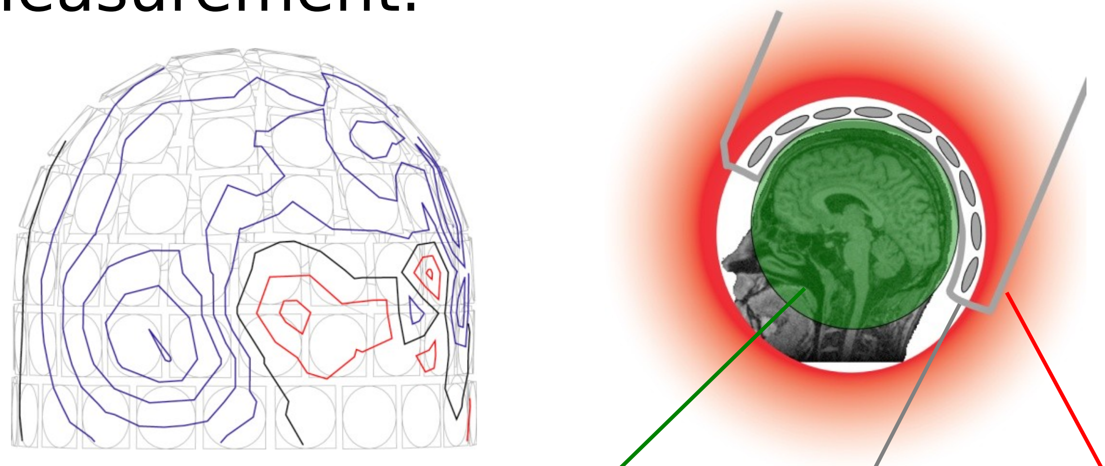
$$\mathbf{x}_{\text{out}} = [\beta_{1,-1} \ldots \beta_{L_{\text{out}}L_{\text{out}}}]^{\text{T}}.$$

- 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 biomagnetic and external interference components:

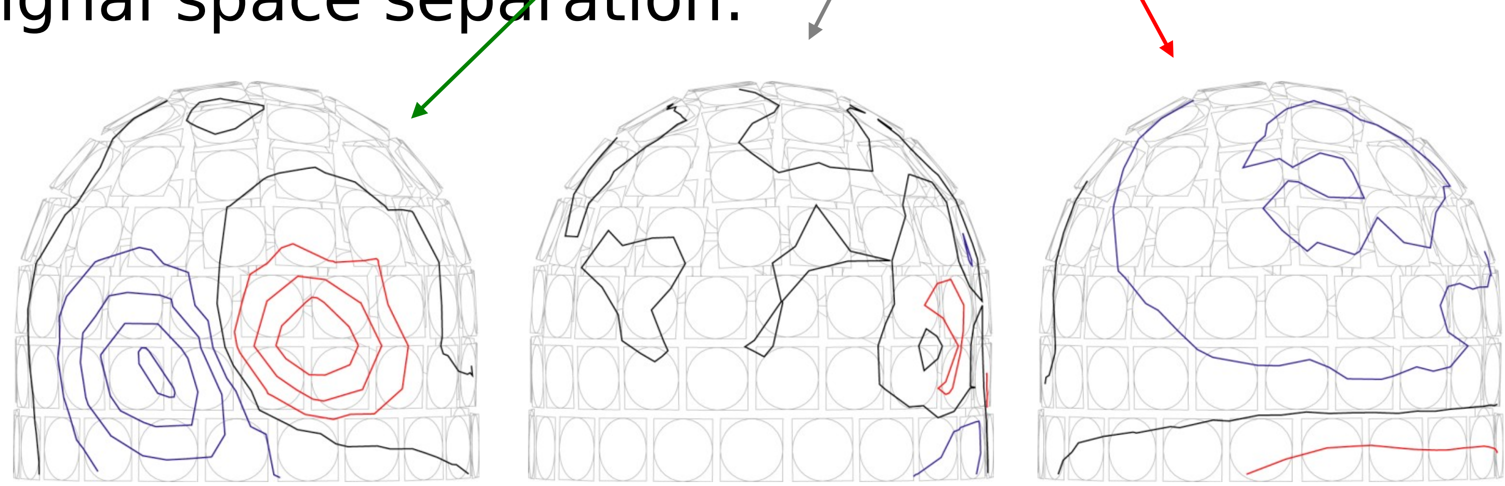
$$\hat{\mathbf{x}} = \begin{bmatrix} \hat{\mathbf{x}}_{\text{in}} \\ \hat{\mathbf{x}}_{\text{out}} \end{bmatrix} = \mathbf{S}^{\dagger}\phi$$

# SSS example: Contaminated VEF response

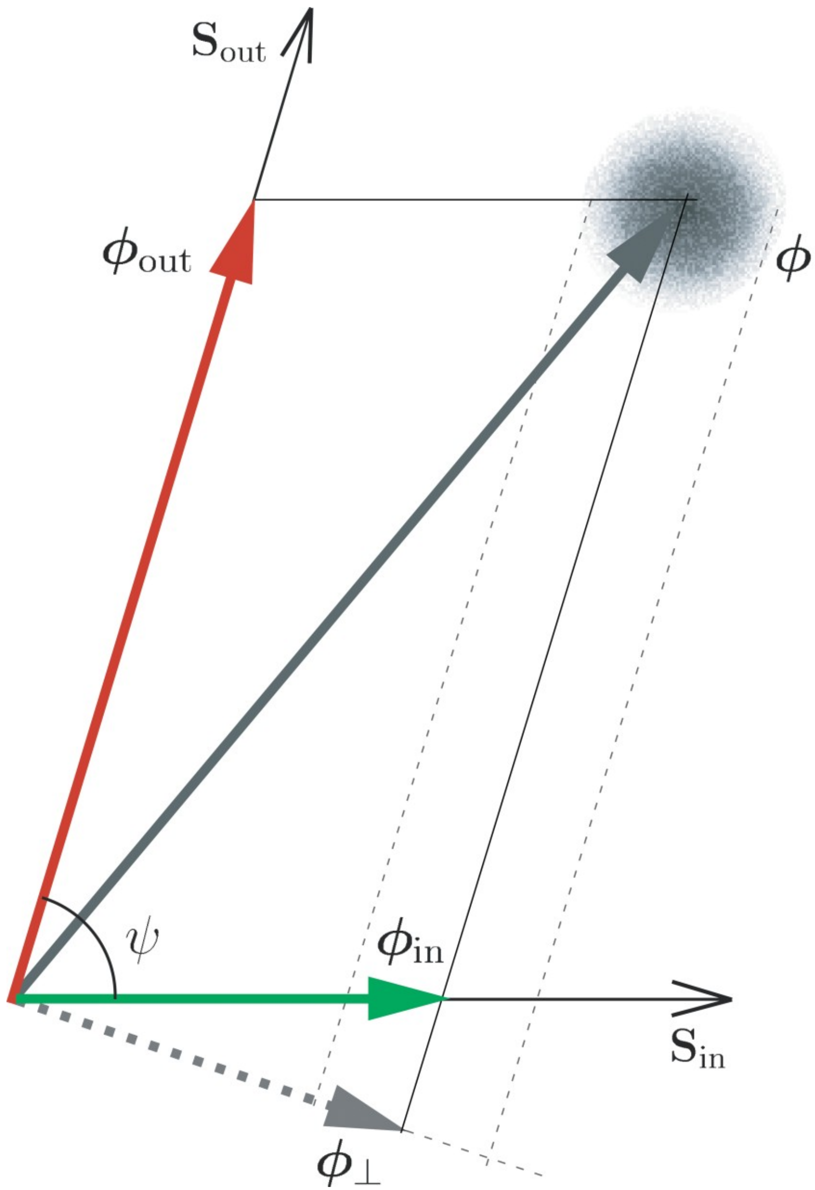
Measurement:



Signal space separation:



# Comparing SSP and SSS




**Brain signals**

Green:

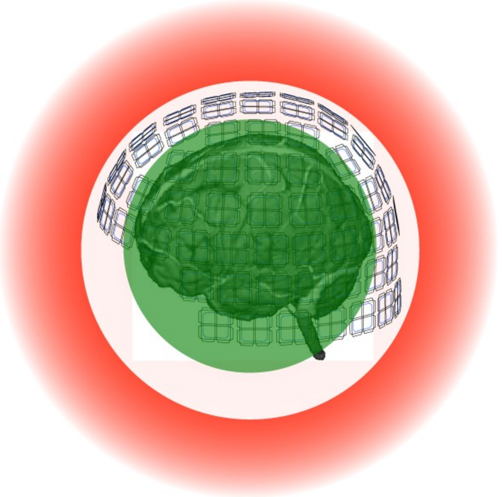
- after SSS suppression
- no distortions

Gray:

- SSP projects also a part of brain signals
- needs correction in source modelling

Comparison of waveforms after SSP and SSS can be done only after correcting the SSP'd signals!

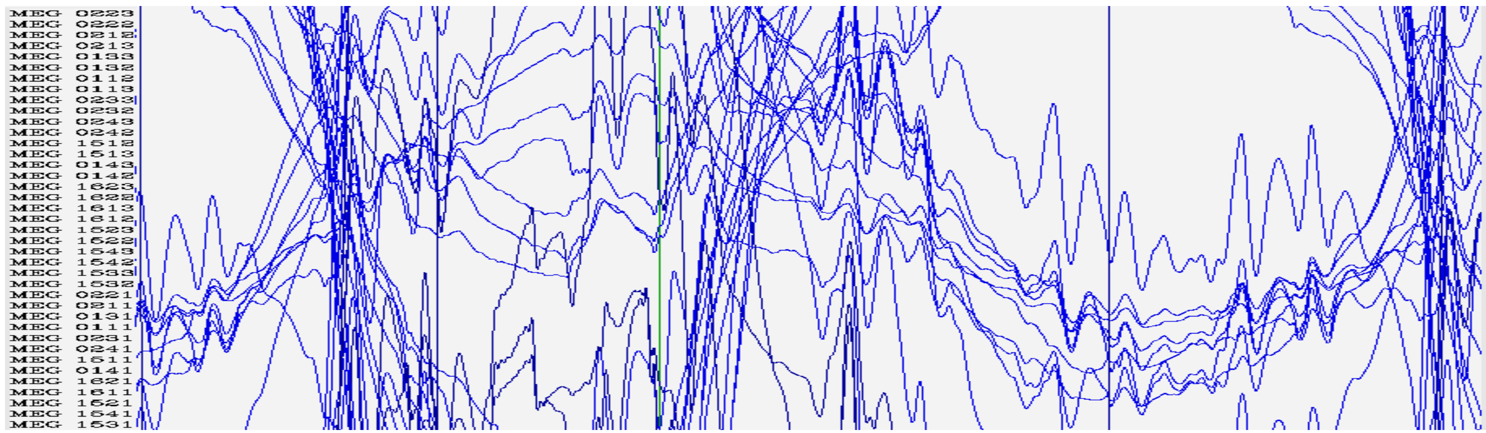
# Temporal extension of SSS



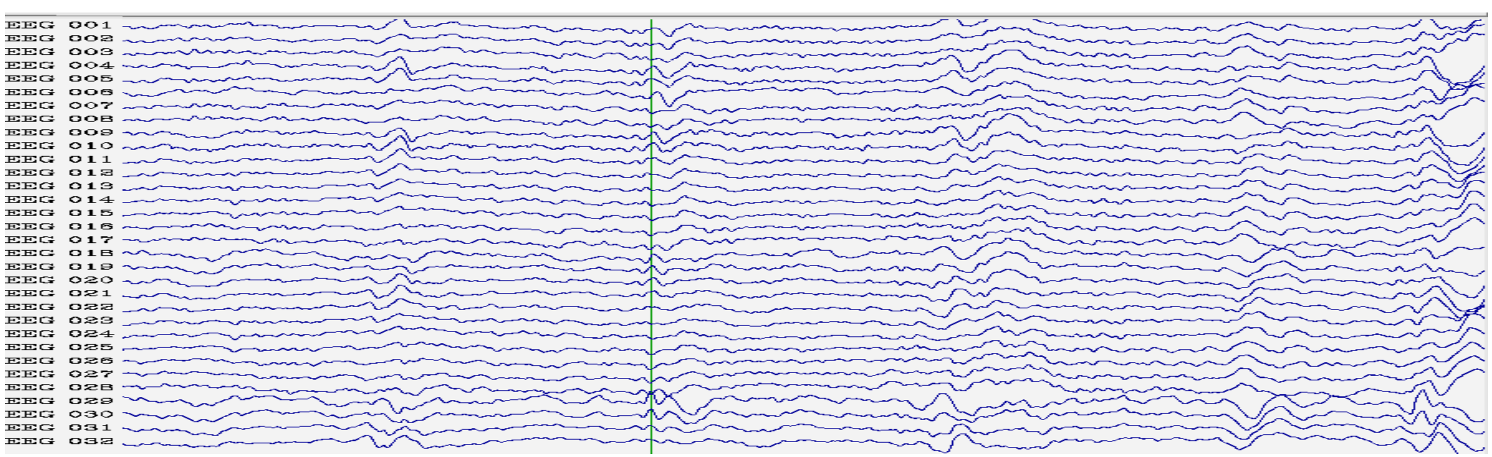
- Separation of signal space to the brain and the exterior subspaces by normal SSS
- Removal of signals showing similar temporal behavior in both subspaces (Taulu and Simola, 2006): “Signal Space Projection in Time Domain” => temporal SSS (tSSS)
- tSSS removes strong signals emanating from artifacts but leaves the small brain signals intact

# Suppressing artefacts due to an implanted vagal nerve stimulator (VNS)

## MEG, before tSSS



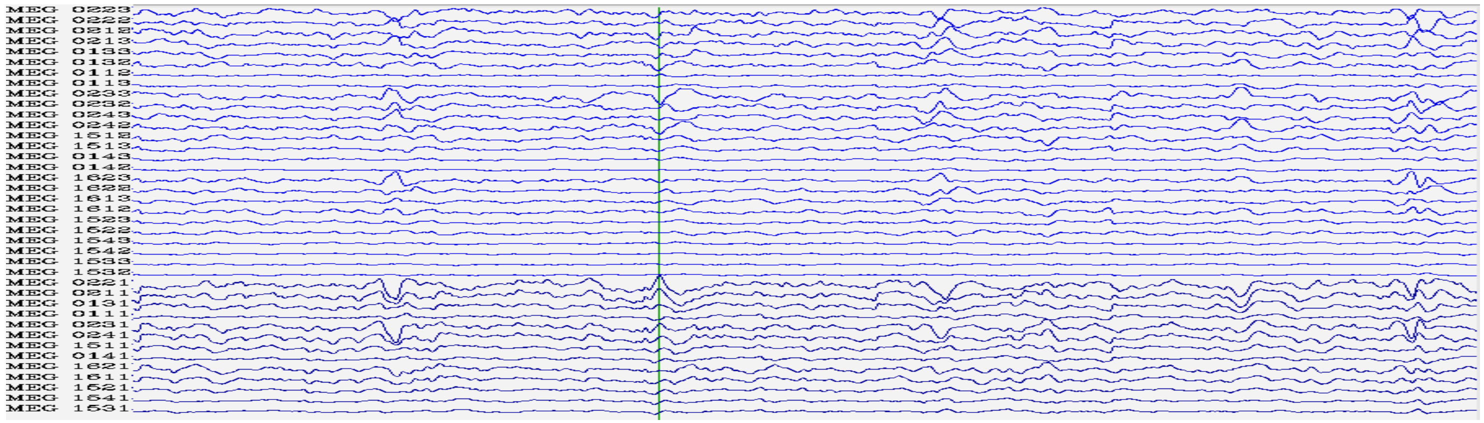

## EEG



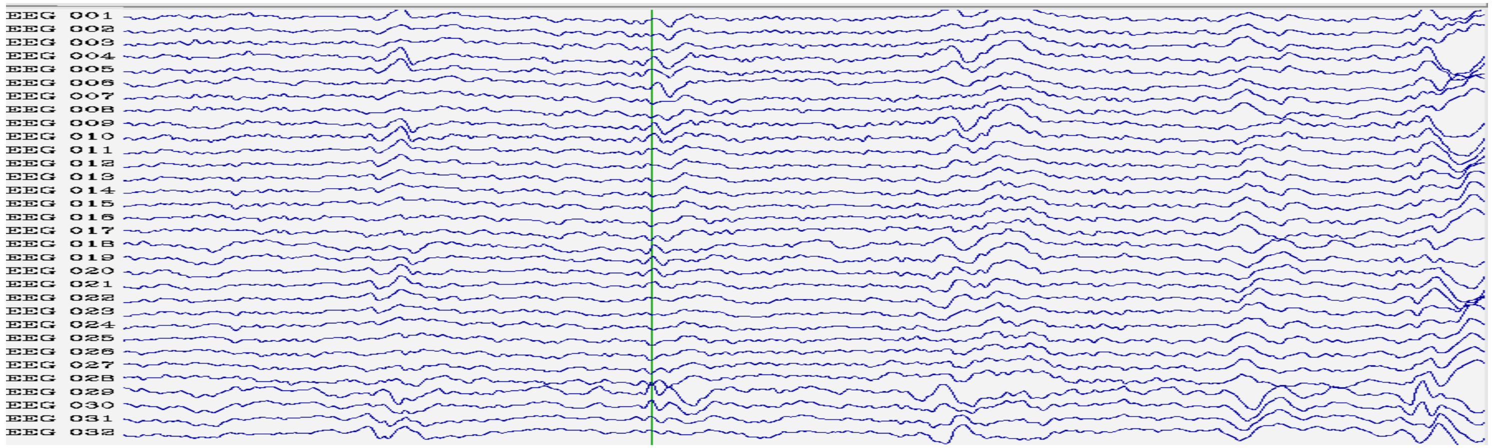

[Natsuko Mori et al., Massachusetts General Hospital]

# Suppressing artefacts due to an implanted vagal nerve stimulator (VNS)

## MEG, filtered with tSSS




## EEG




[Natsuko Mori et al., Massachusetts General Hospital]

# Pre-processing: Head motion correction

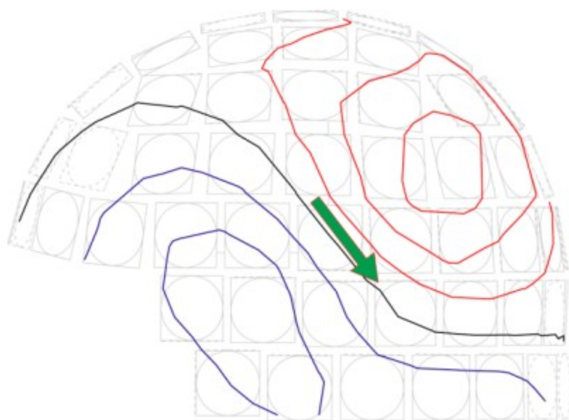
- Traditionally, a stable head position assumed and no correction applied:
  - Experienced subjects can indeed keep their head position very stable
  - Motion correction is non-trivial and proper methods have emerged only recently
- Motion correction: two approaches
  - Average data without correction but blur the source model to be fitted to the average according to the head movements. [*Uutela et al., 2001*]
  - Re-map the measured magnetic field at each time point to a virtual fixed head position. [*Uutela et al., 2001; Taulu et al., 2005*]

# Continuous head movement tracking

- Head Position Indicator (HPI) coils (typ. 3–5) are attached to subject's head
- Each coil is energized continuously with sinusoidal signals of different frequencies (typ. ~300 Hz)
- Essential for:
  - Infant studies
  - Epilepsy studies
  - Alzheimer, Parkinson, and Schizophrenia patients
  - Inexperienced healthy subjects

# Compensating head movements with SSS

Stationary

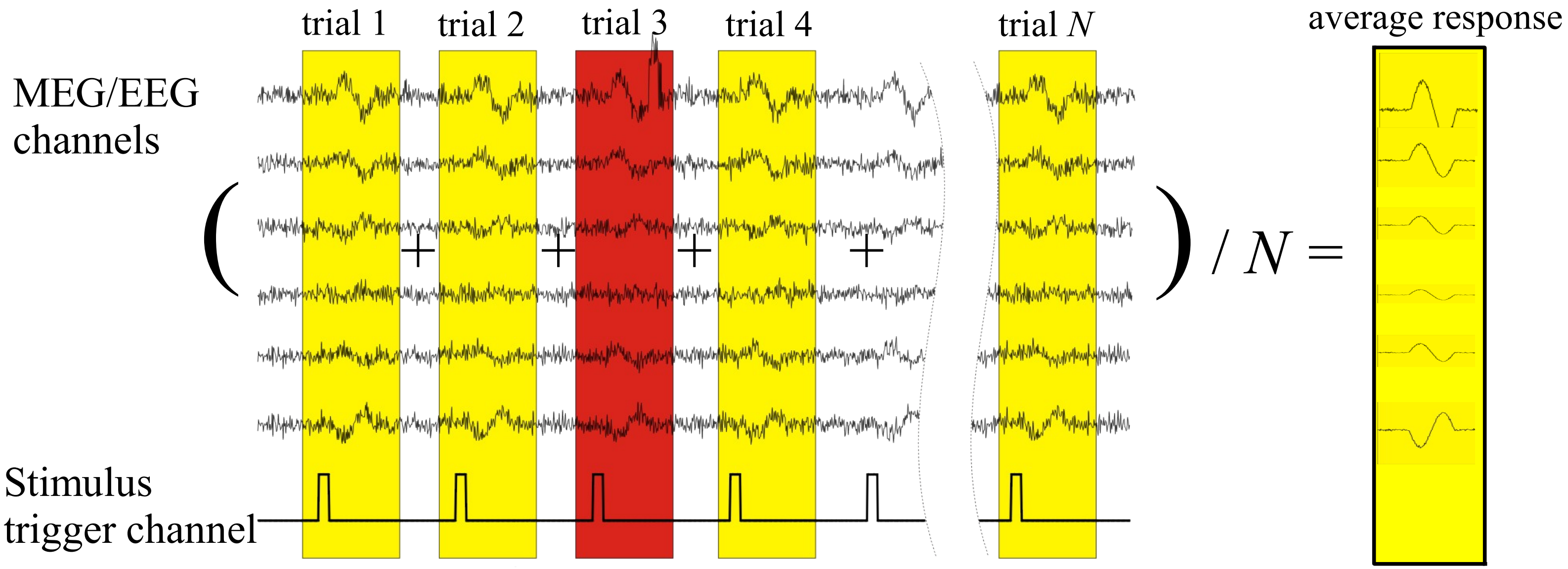


Moving

Compensated

Auditory evoked fields
N100m response

# Pre-processing: Averaging




- Signal model: stimulus-locked activity + uncorrelated noise
- Signal recovery by stimulus-locked averaging
- Linear operation: Order interchangeable with other linear operations such as filtering

# Pre-processing: Filtering

- Optimize the pass-band to gain in signal-to-noise ratio
- For typical evoked responses: 0.1 – 40 Hz pass-band (except for somatosensory evoked fields 0.1 – 100 Hz)
- Filters can mislead when used incorrectly
  - Abolished or distorted responses: too narrow pass-band, too “sharp” filters
  - Fake responses due to zero-phase-shift high-pass filters with too high cut-off frequencies