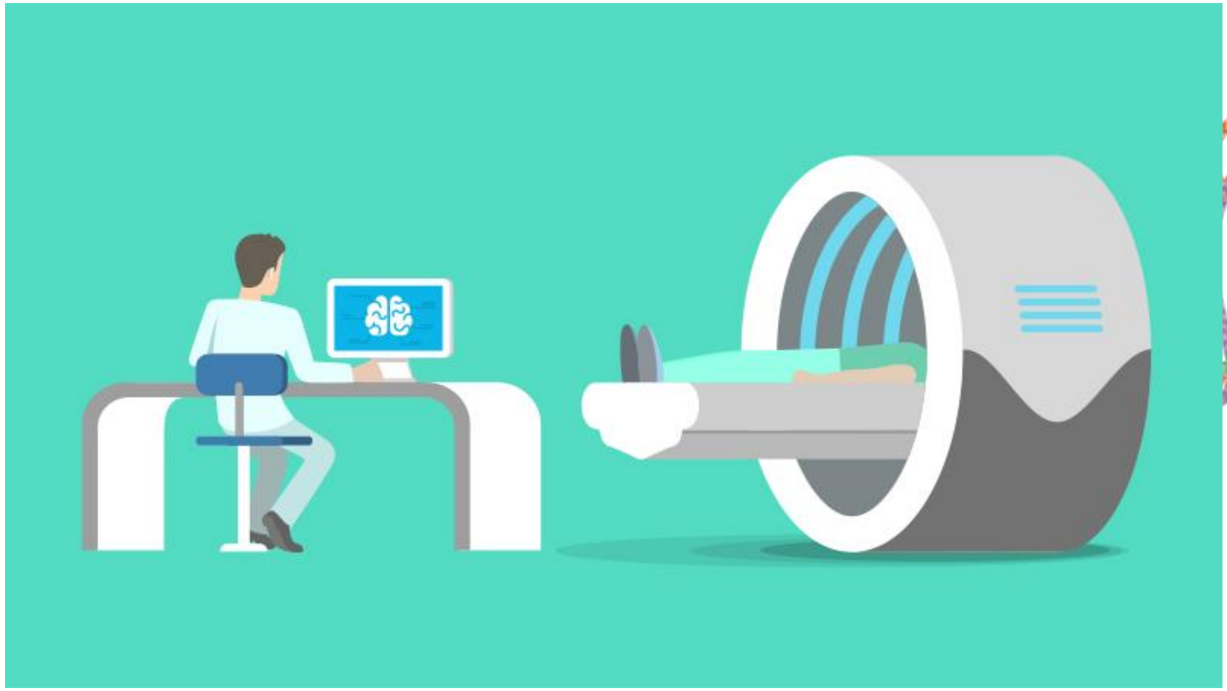
Removal of Ultra-Fast MR-Gradient and Ballistocardiogram Artifacts in High-Density EEG-Signals to Detect Sleep



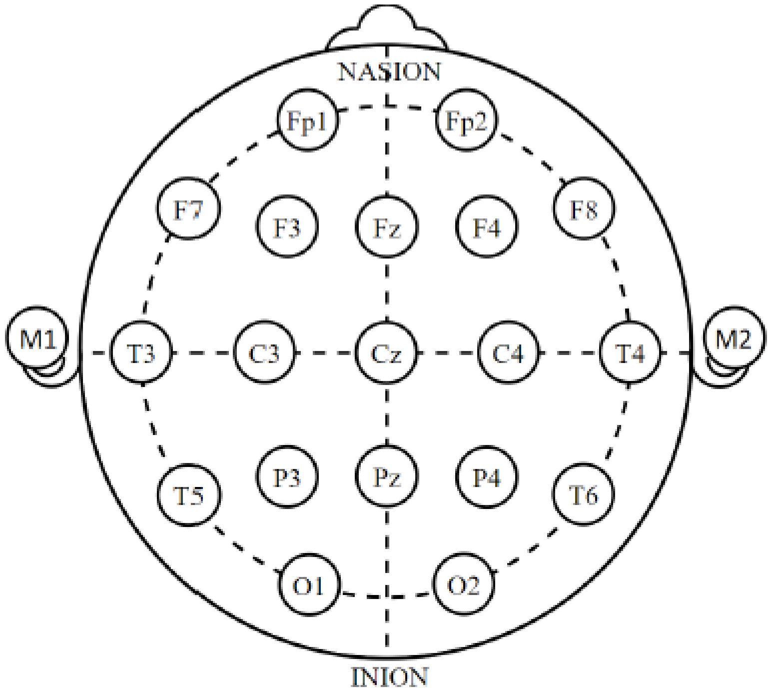
Anders Stevnhoved Olsen
BSc. Student – Medicine and Technology

Sleep

- Sleep is believed to be a process critical to the existence of human life, but we know very little about it
- A research team at NRU is set to explore new knowledge on sleep – more specifically the Glymphatic System – using simultaneous EEG and fMRI:
  - EEG is a well established modality for sleep observation but lacks spatial characteristics
  - fMRI makes images of the brain from which functionality can be interpreted

Electroencephalography (EEG)

- EEG measures electrical potentials on the surface of the brain caused by the slow postsynaptic potentials that follow action potentials
- A set of electrodes is placed on the scalp according to predefined locations
- The signals measured are mainly characterized by their frequency and amplitude
- Sleep can be described from these signals



Name	Symbol	Frequency range
delta	δ	$0.5 - 4Hz$
theta	θ	$4 - 8Hz$
alpha	α	$8 - 13Hz$
beta	β	$13 - 30Hz$
gamma	γ	$> 30Hz$

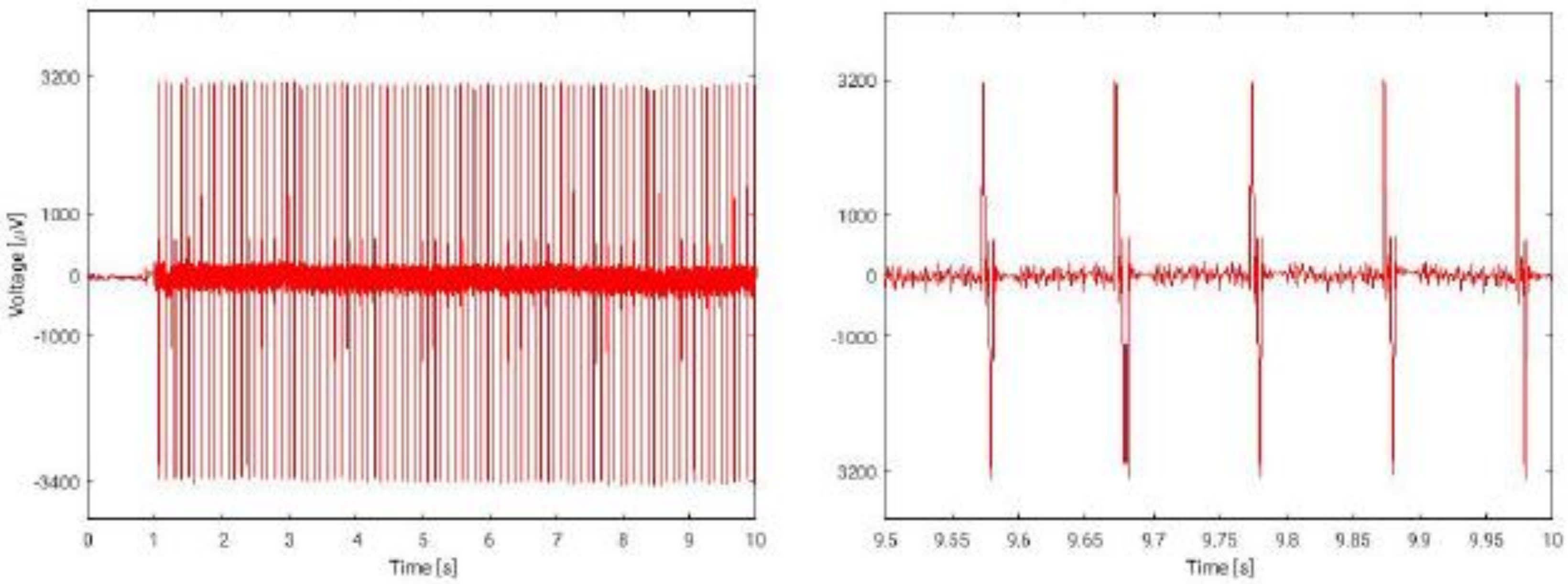
Magnetic Resonance Imaging

- Using a strong magnetic field (B_0) and some smaller magnetic gradients, MRI can create images of the brain.

- Some different causes for artifacts in EEG inside MR:
  - Switching of magnetic gradients
    - Gradient Artifact (GA)
  - The strong constant magnetic field B_0
    - Ballistocardiogram (BCG)
  - Head motion

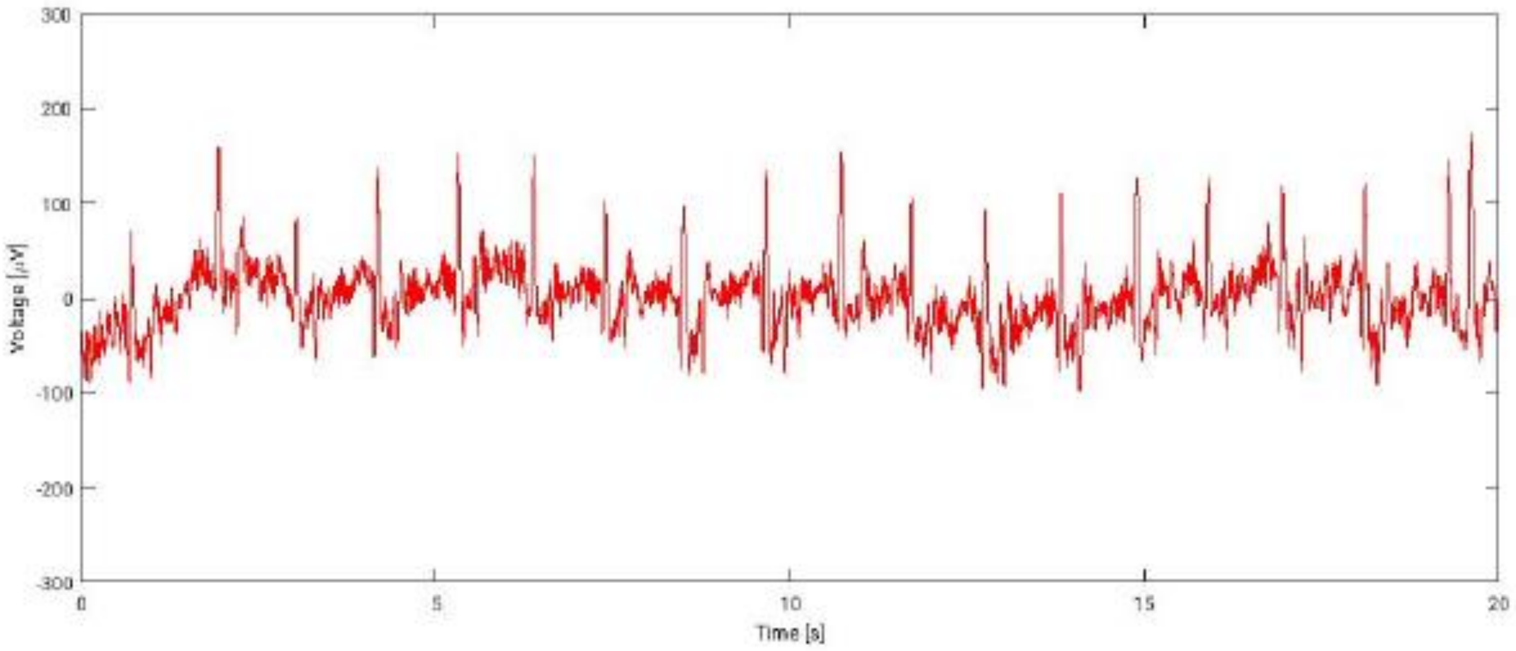
The Gradient Artifact (GA)

- Caused by the switching of magnetic gradients
- Morphology:
  - Steeply rising transients
  - Shows little fluctuation over time
  - Frequency of (in this thesis) 5-10 Hz



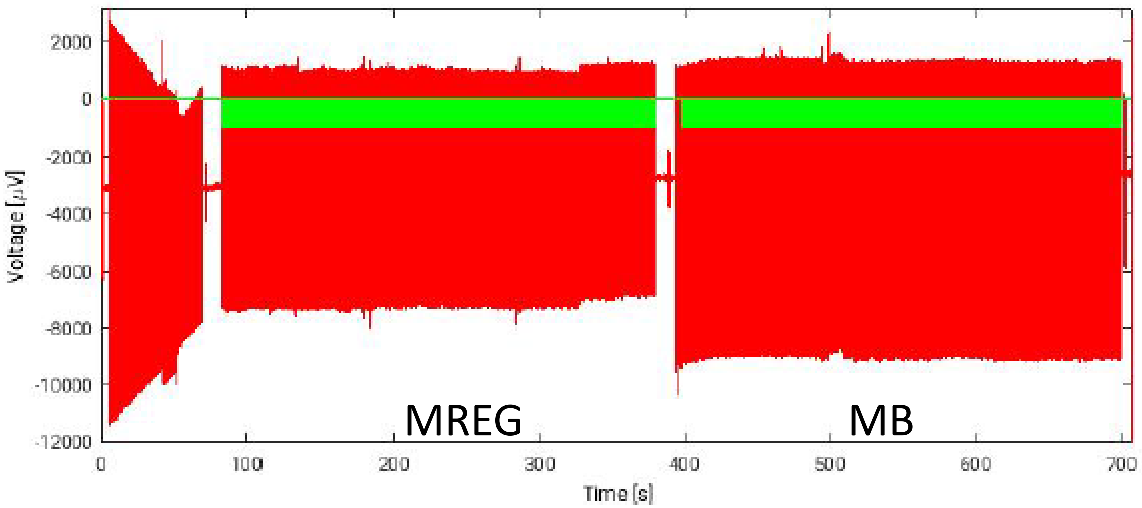
The Ballistocardiogram (BCG)

- Originates from the heart
- Heavily amplified by the B_0-field
- Morphology:
  - Fluctuates more than the GA
  - Frequency is not constant

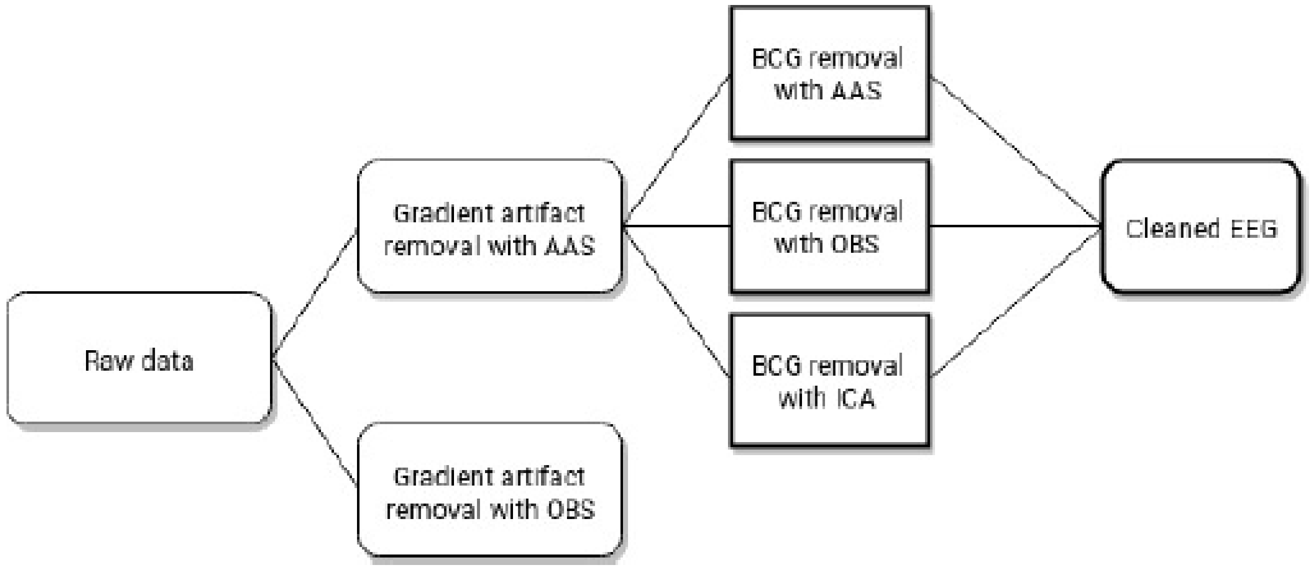


Thesis setup

- Data from 2 healthy volunteers
- 256 EEG-channels and 1 ECG-channel
- Trigger signal from MR-scanner
- 12 data sets of ≈5 minutes
- Sampling rate of 1000Hz

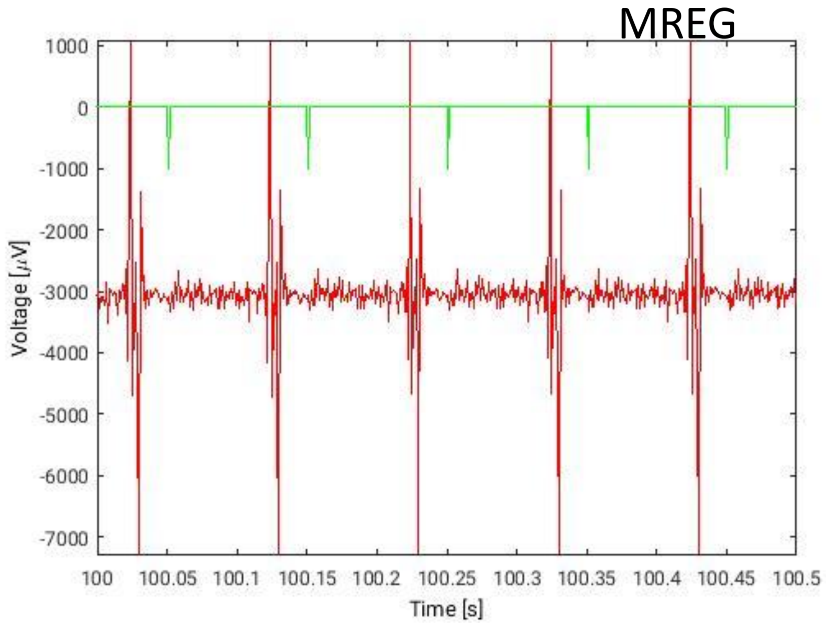


- GA removal with AAS and OBS
- OBS removal with AAS, OBS and ICA
- QRS-detection



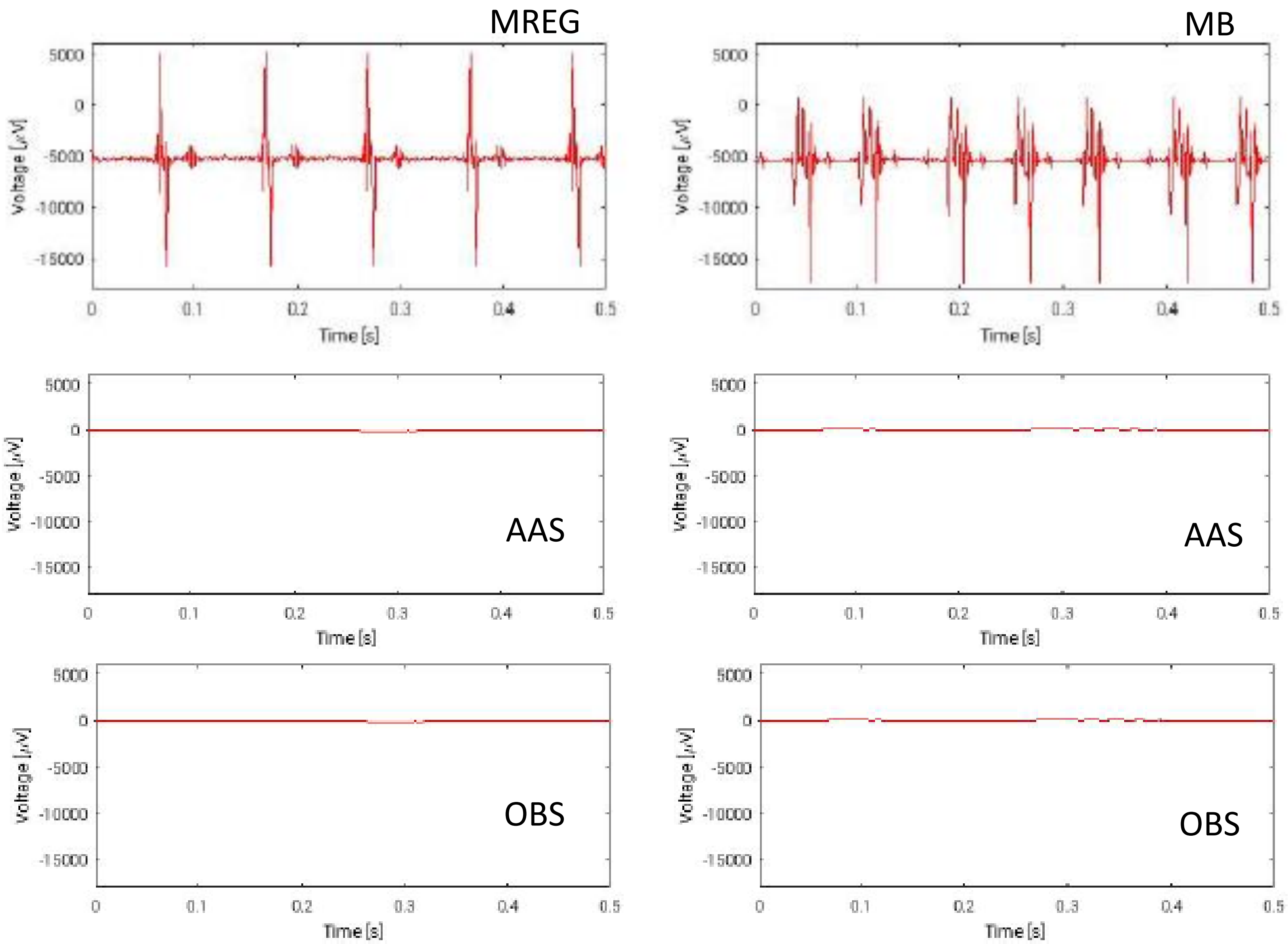
Average Artifact Subtraction (AAS)
Optimal Basis Sets (OBS)

- Assumes high similarity between adjacent artifacts
- Creates template artifacts using a moving average window
- Templates are made at points of:
  - MR-trigger signal for GA



- OBS is an extension to AAS to capture and remove residual artifacts
- It combines the moving average window with a Principal Component Analysis (PCA)
- Both algorithms operate channel-wise

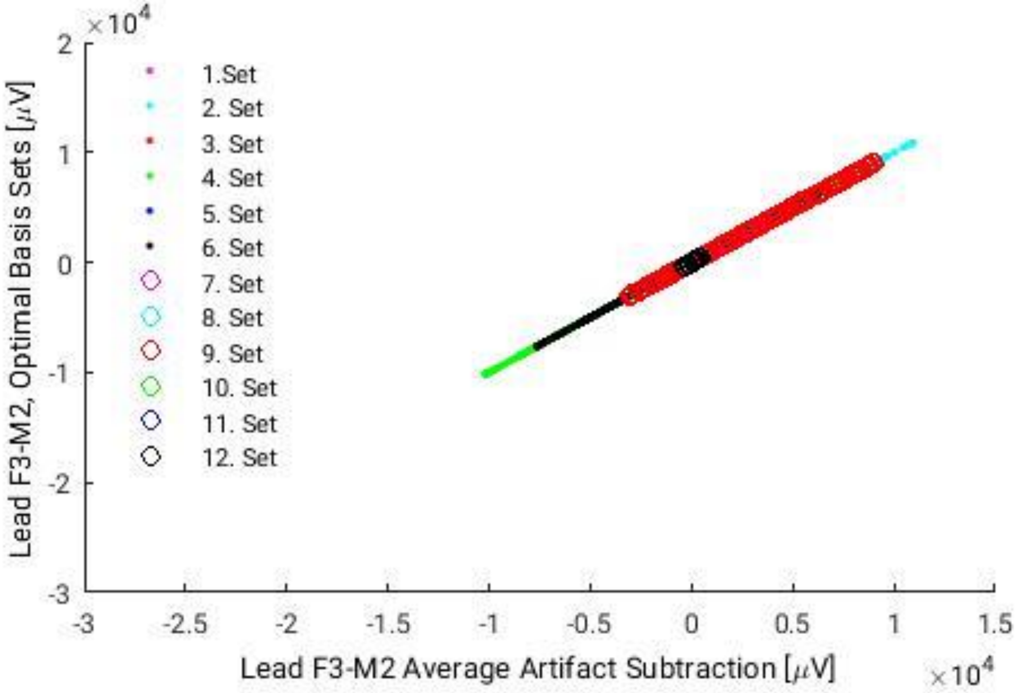
Comparison of GA-correction methods



Comparison of GA-correction methods

- A subset of leads is chosen
- The first comparison is the correlation between methods

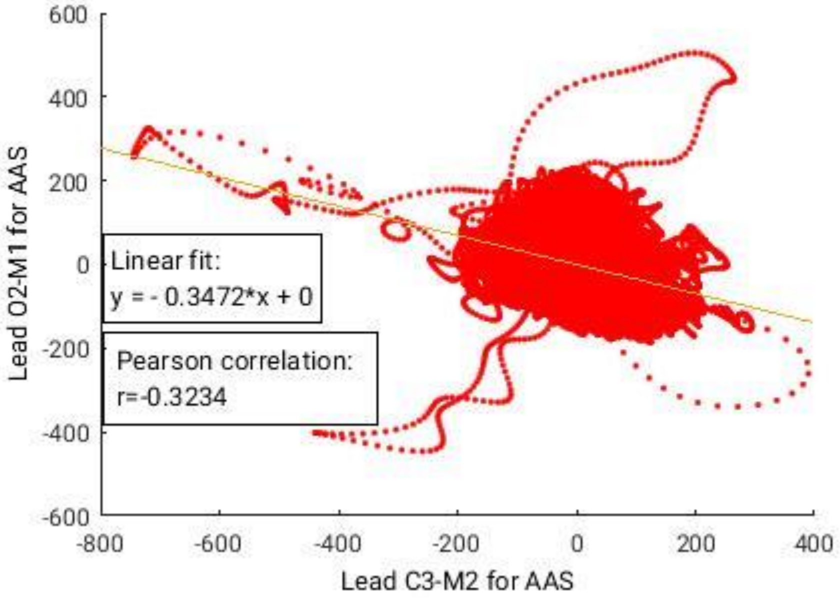
Frontal	Central	Occipital
F3-M2	C3-M2	O1-M2
F4-M1	C4-M1	O2-M1

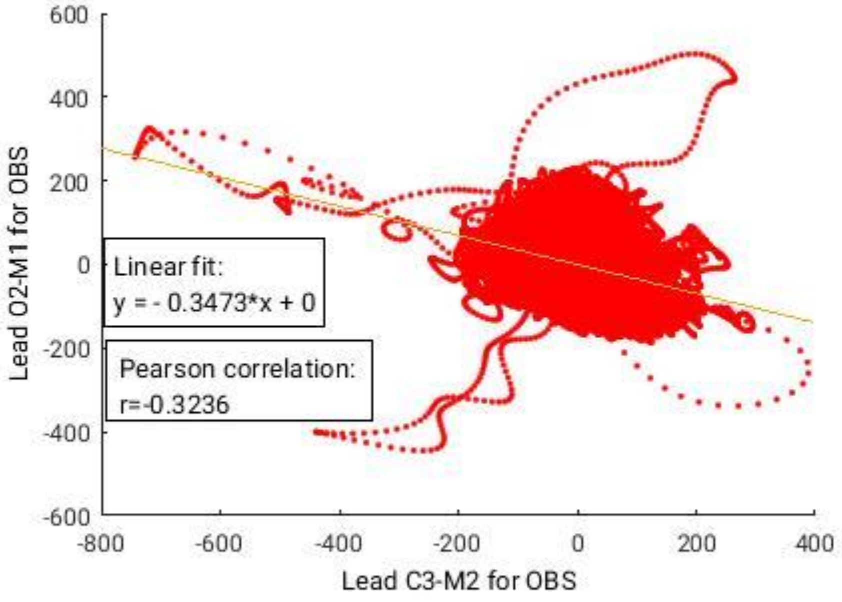


- Pearson correlation coefficients for all leads and all data sets were all $r > 0.9999$
- Indicating high similarity

Comparison of GA-correction methods

- To strengthen any conclusions made, other statistics are made:
  - Fisher's r-to-z transformation on differences of correlation coefficients
  - Paired t-test on the differences in slopes of linear fit





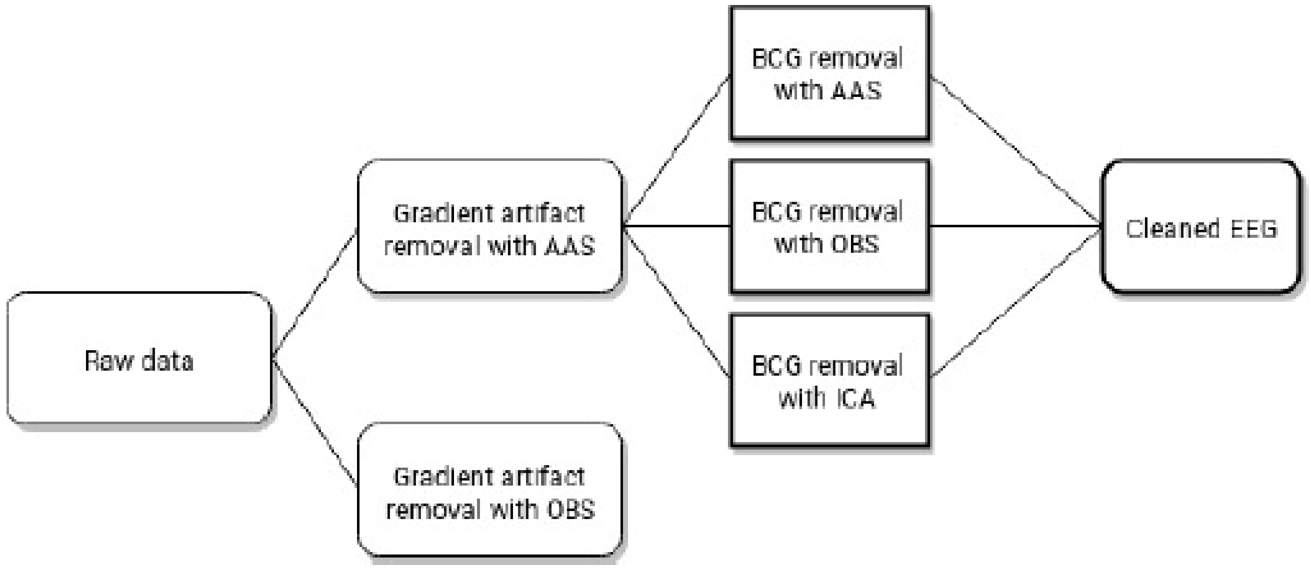
Comparison of GA-correction methods

- Fisher’s r-to-z transformation showed no significant differences in 180 comparisons.

- It is concluded that the two methods are *not* different for GA-correction

Ballistocardiogram removal

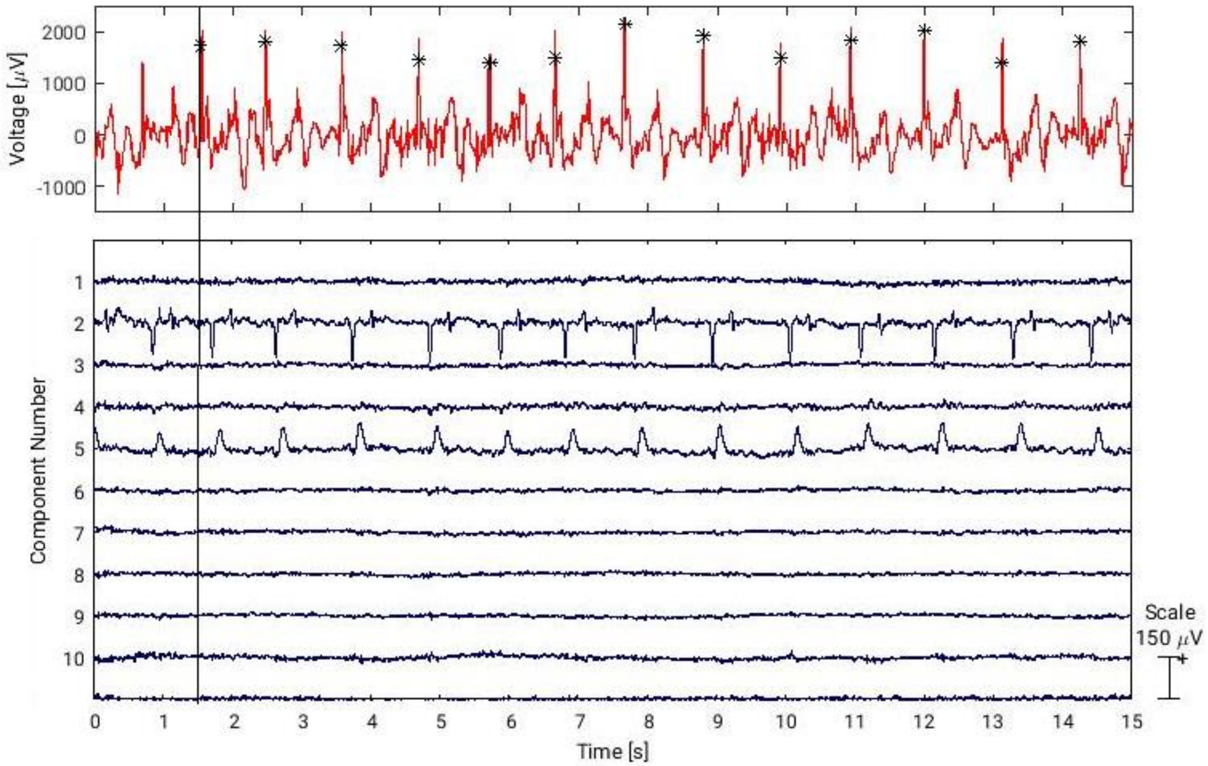
- Three different methods for BCG removal



Independent Component Analysis (ICA)

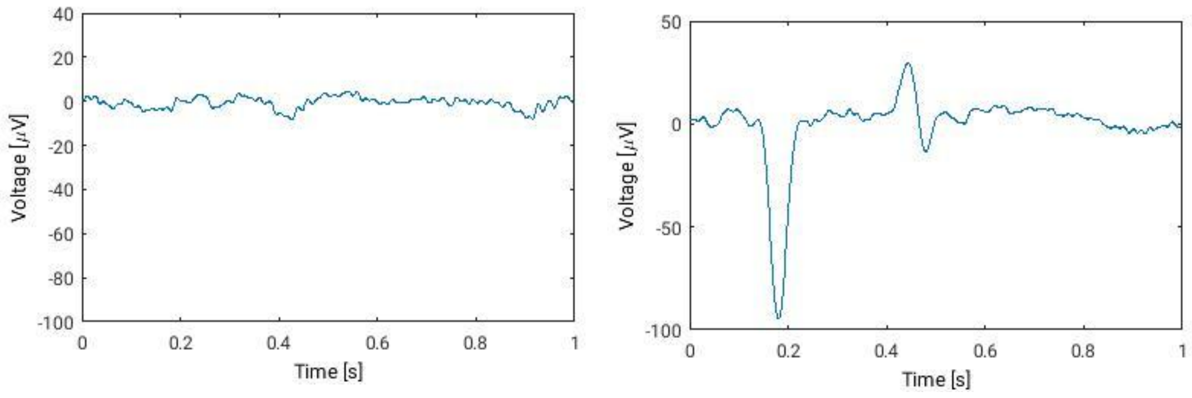
- Computes statistically independent components
- Does not operate channel-wise
- 256 channels gives 256 independent components

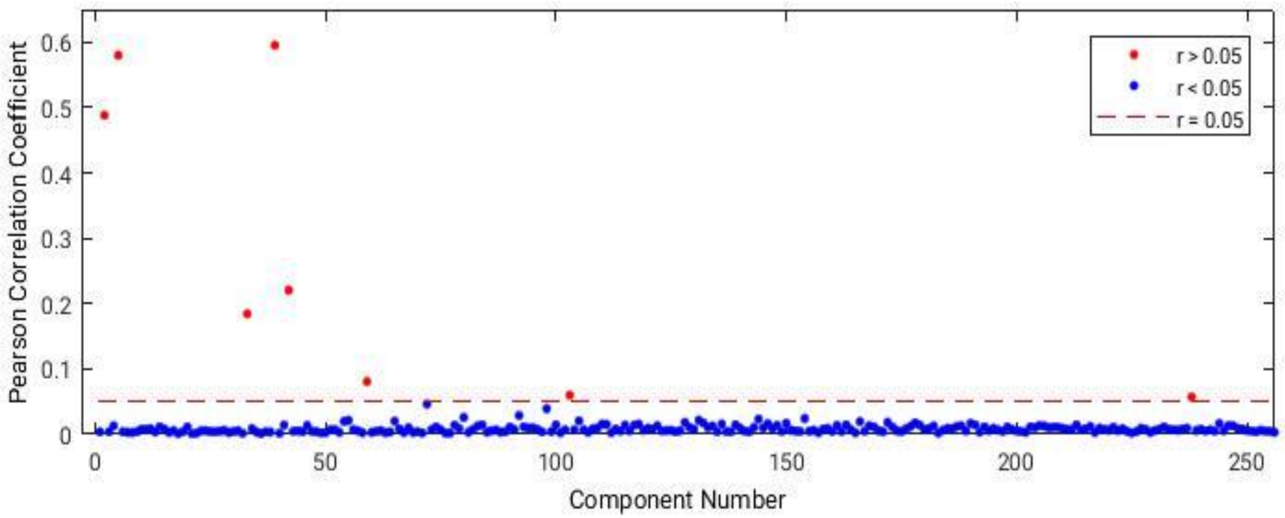
- Disadvantages:
  - Scrolling through all components is time consuming
  - Potential high variability in which components are chosen between data sets



An extension to ICA

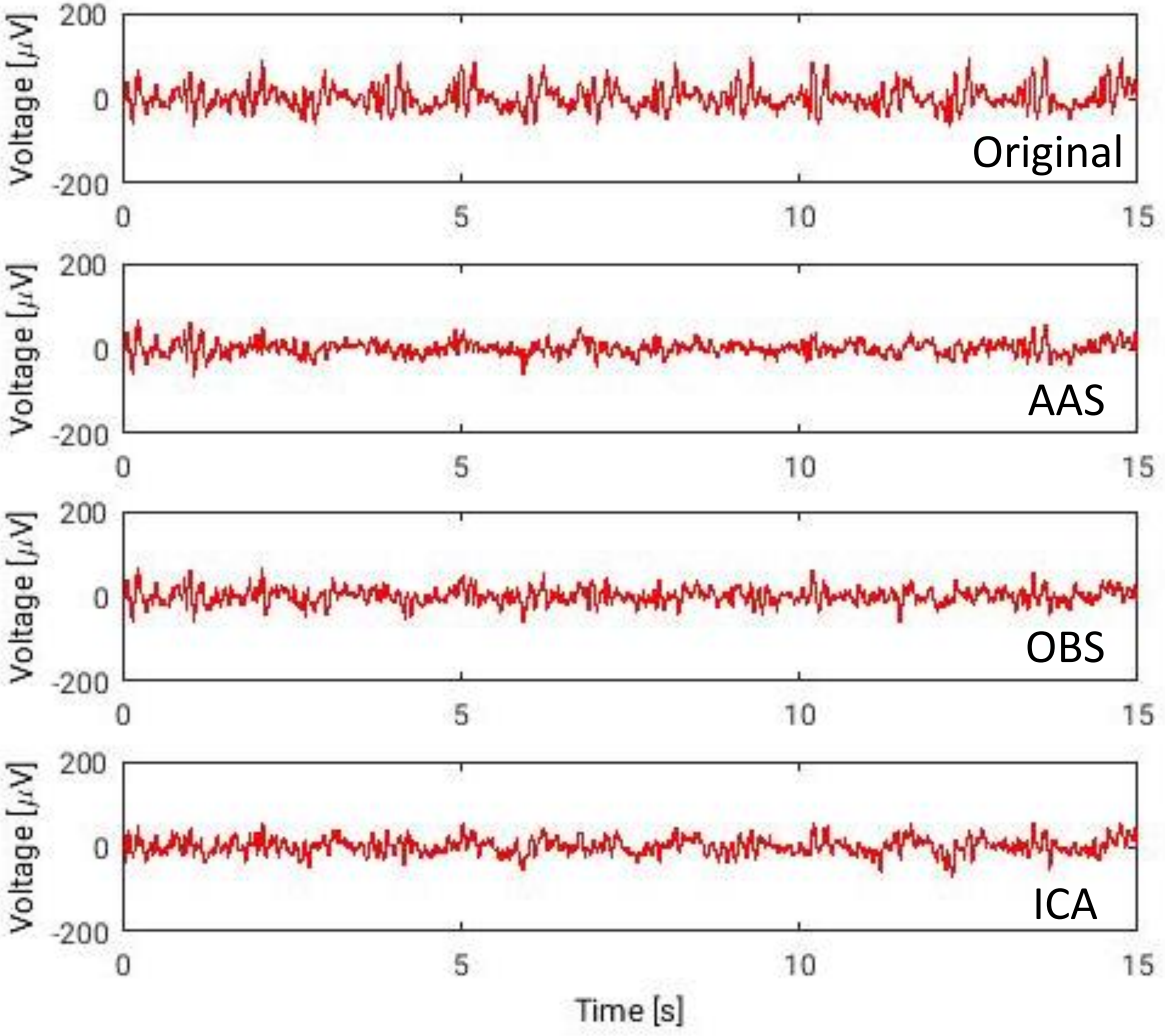
- An extension to ICA is proposed to tackle the disadvantages.
- Each component is divided into artifact long segments
- The segments are averaged
- The averaged segments are repeated at time points of R-peaks
- The Pearson correlation coefficient is found



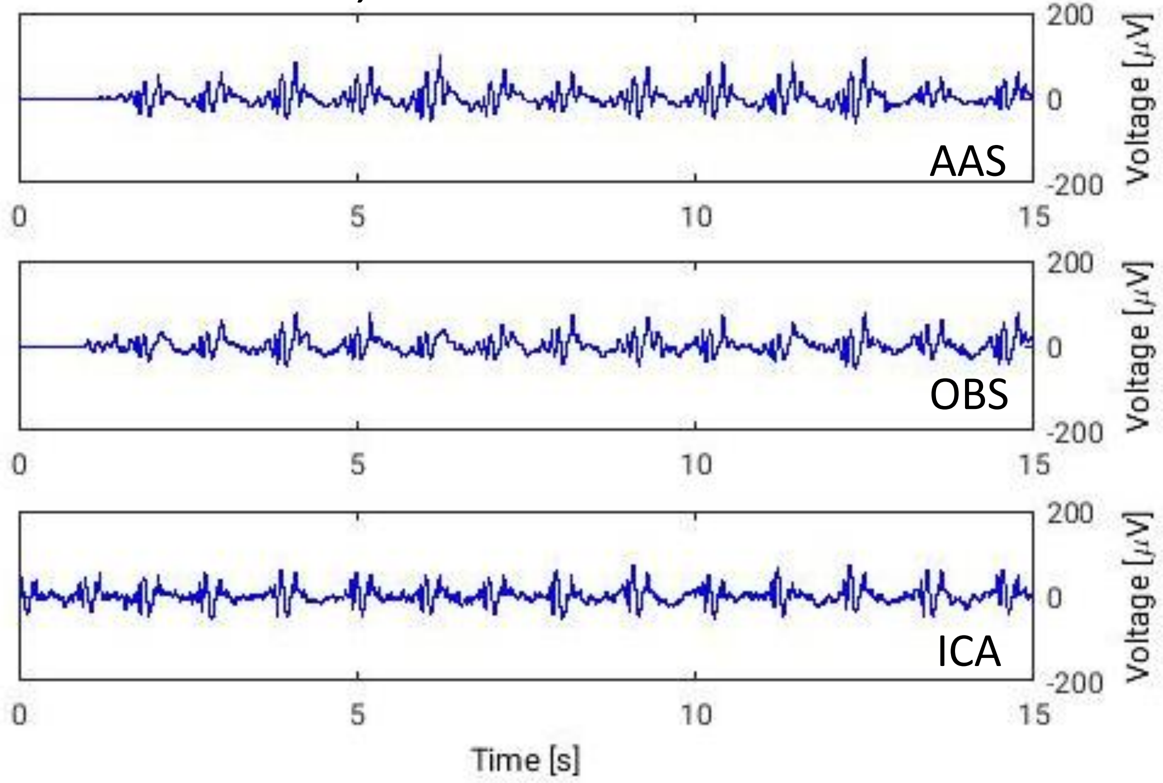


Comparison of BCG-correction methods

A lead after BCG-correction



Residuals, i.e. what is subtracted



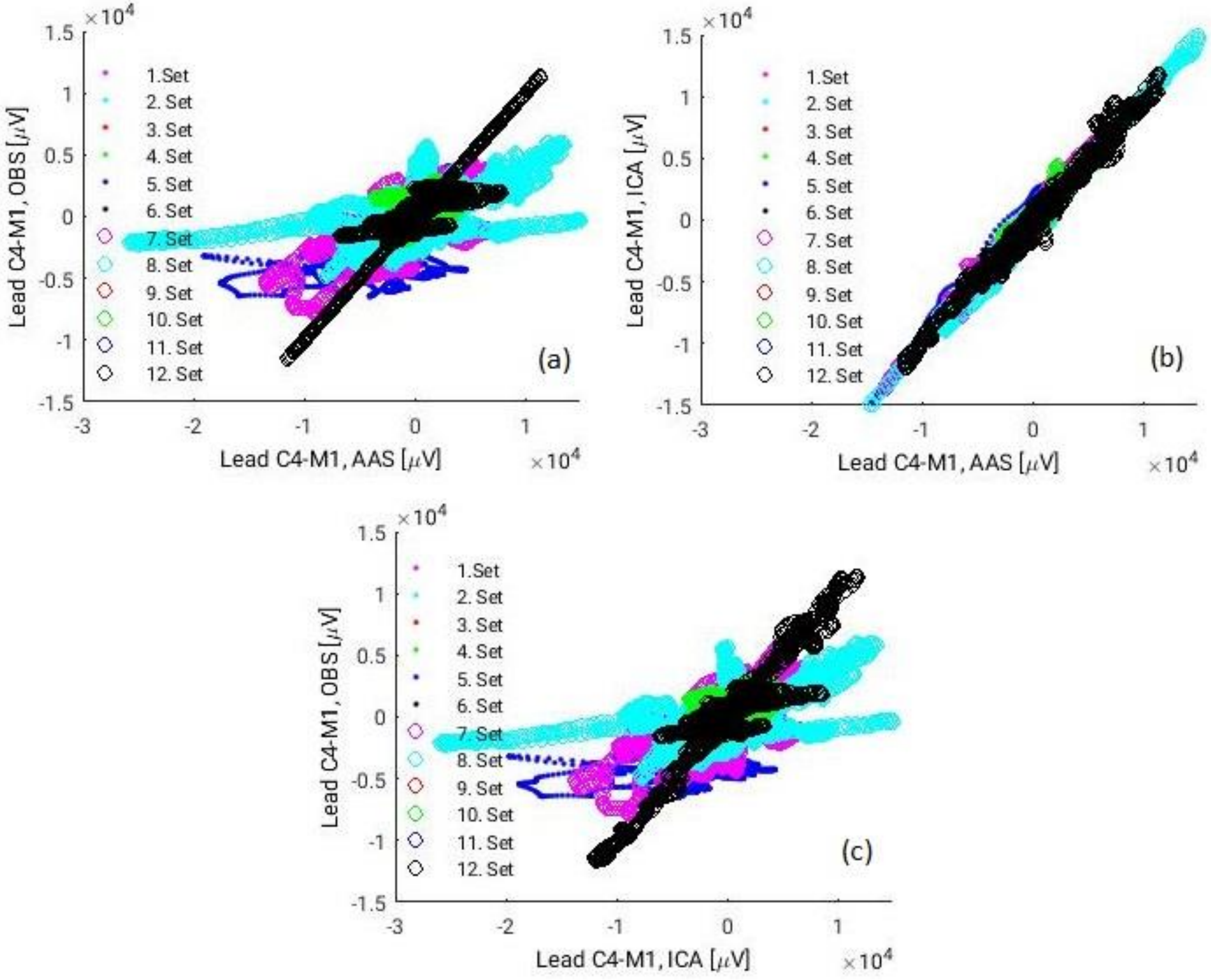
Comparison of BCG-correction methods

- 3 comparisons to make

AAS vs OBS	Mean	Standard deviation
F3-M2	0.80	0.11
F4-M1	0.78	0.13
C3-M2	0.77	0.12
C4-M1	0.79	0.13
O1-M2	0.77	0.091
O2-M1	0.79	0.14

AAS vs ICA	Mean	Standard deviation
F3-M2	0.91	0.058
F4-M1	0.91	0.069
C3-M2	0.90	0.073
C4-M1	0.93	0.036
O1-M2	0.89	0.076
O2-M1	0.91	0.066

OBS vs ICA	Mean	Standard deviation
F3-M2	0.75	0.093
F4-M1	0.74	0.11
C3-M2	0.71	0.093
C4-M1	0.76	0.11
O1-M2	0.72	0.069
O2-M1	0.75	0.12



Comparison of BCG-correction methods

- Fisher's r-to-z transformation showed significant difference in most comparisons
- Most in those involving OBS

Lead 1	Lead 2	AAS vs OBS	AAS vs ICA	OBS vs ICA
F3-M2	F4-M1	all	10 of 12	all
F3-M2	C3-M2	all	all	all
F3-M2	C4-M1	11 of 12	11 of 12	all
F3-M2	O1-M2	all	9 of 12	all
F3-M2	O2-M2	10 of 12	10 of 12	all
F4-M1	C3-M2	all	all	all
F4-M1	C4-M1	all	7 of 12	all
F4-M1	O1-M2	all	all	11 of 12
F4-M1	O2-M2	10 of 12	all	all
C3-M2	C4-M1	all	all	all
C3-M2	O1-M2	all	11 of 12	all
C3-M2	O2-M2	all	9 of 12	all
C4-M1	O1-M2	all	11 of 12	all
C4-M1	O2-M2	all	10 of 12	all
O1-M2	O2-M2	all	11 of 12	all

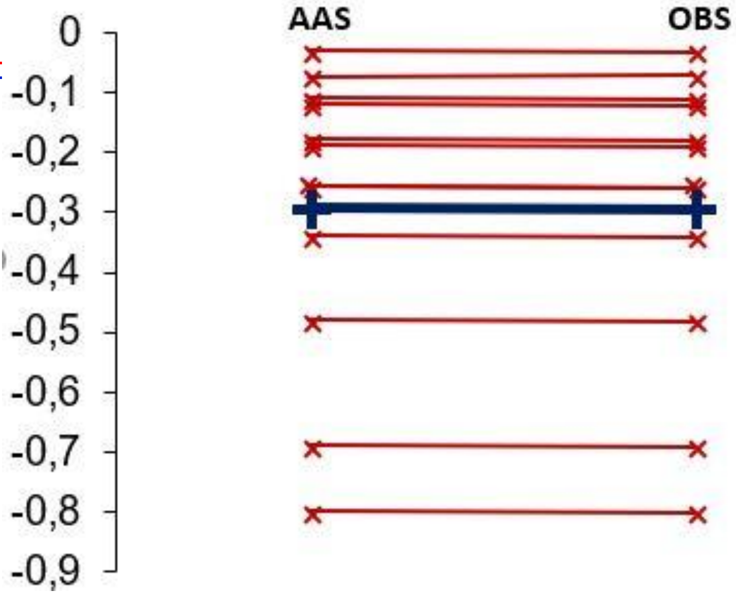
Conclusion

- AAS and OBS are not different for GA-correction

- AAS, OBS and ICA are all significantly different
- OBS seems to be more different

- Further analyses could include:
  - Component topography
  - Spectral analysis
  - Sleep-scoring on data by an expert

Slopes



For GA: The paired t-test showed significant differences in 6 of 15 comparisons. The example shown has $p = 0.0084$

For BCG: Only 2 out of 45 comparisons