

# EEG Signal Processing

Saeid Sanei

Cardiff, January 2008

## Research Staff at the Centre of Digital Signal Processing, Cardiff University



Professor A  
Belcher  
  
Acoustics  
Instrumentation



Dr J Hicks  
  
Computer  
Vision



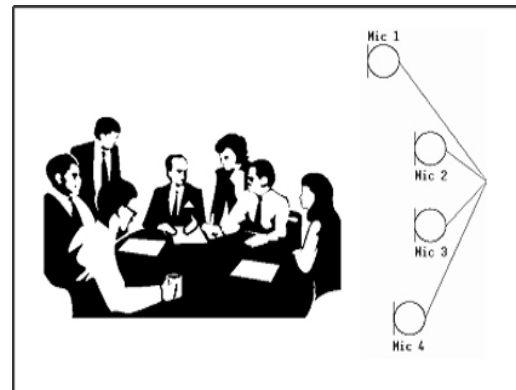
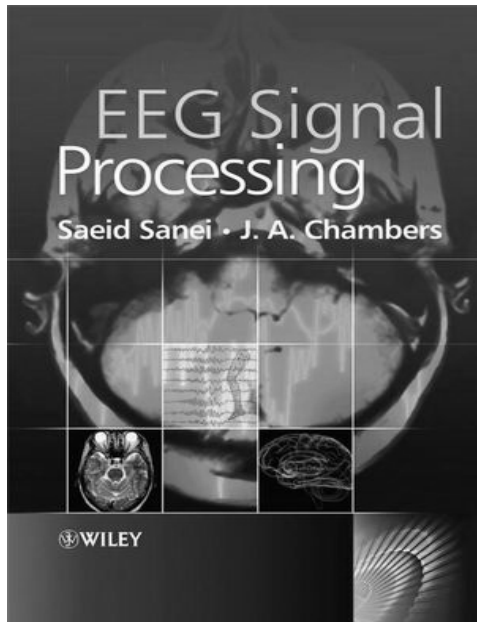
Professor J  
McWhirter  
  
Signal  
Processing



Dr S Sanei  
  
Biomedical  
Signal  
Processing

# Activities

## Recent Highlights:



**15th International Conference on Digital  
 Signal Processing**  
 July 1-4 2007  
 Cardiff, Wales, UK

**DSP2007**

# Projects within Biomedical Group

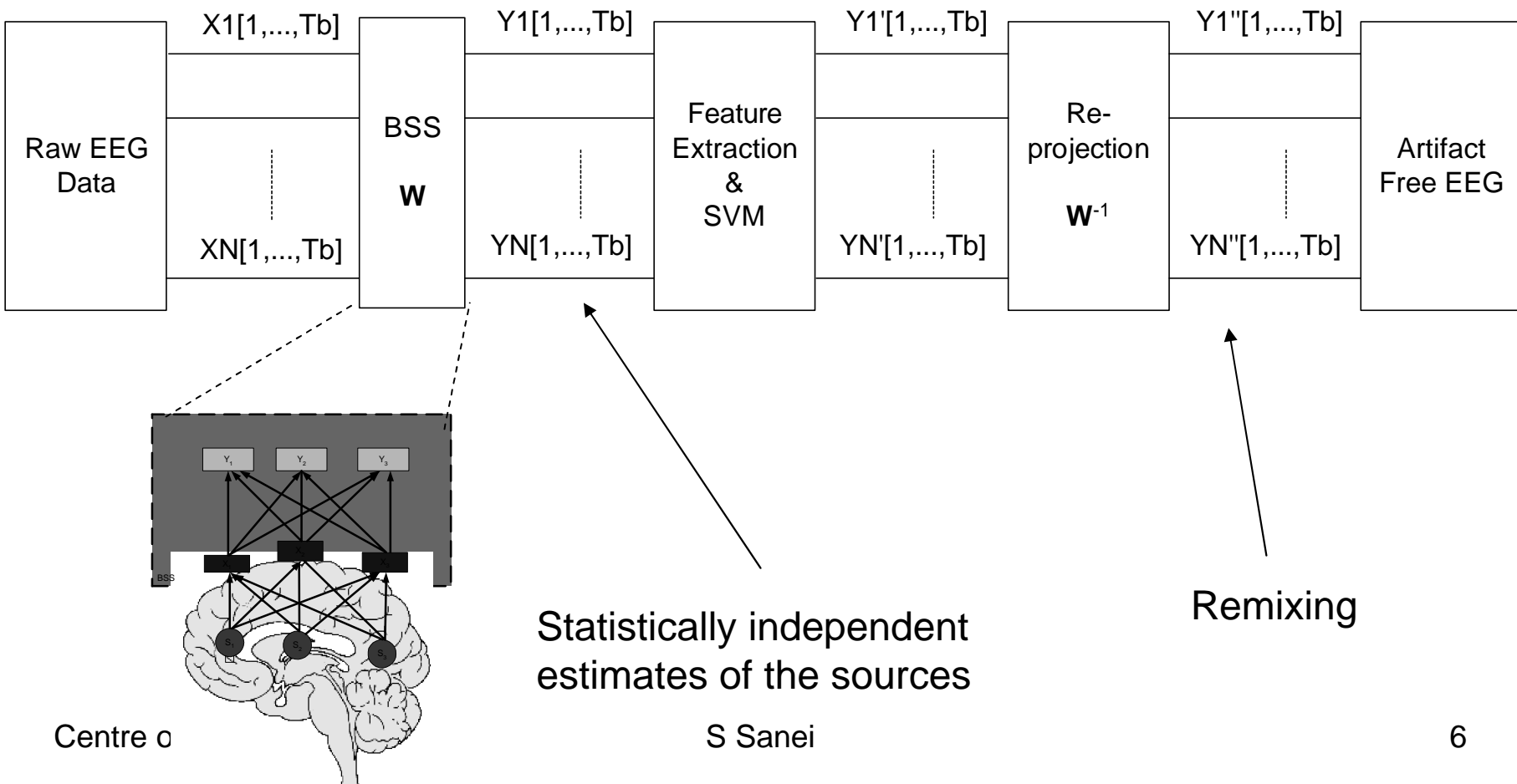
- Brain Computer Interfacing
- ERP Detection and Localization
- Blind Source Separation
- Beamforming
- Parallel Factor Analysis
- EEG-fMRI joint analysis
- Particle filtering
- Seizure Prediction
- Mental Fatigue
- Sleep
- Other biomedical signal and image processing applications

# Artefact Removal from EEGs

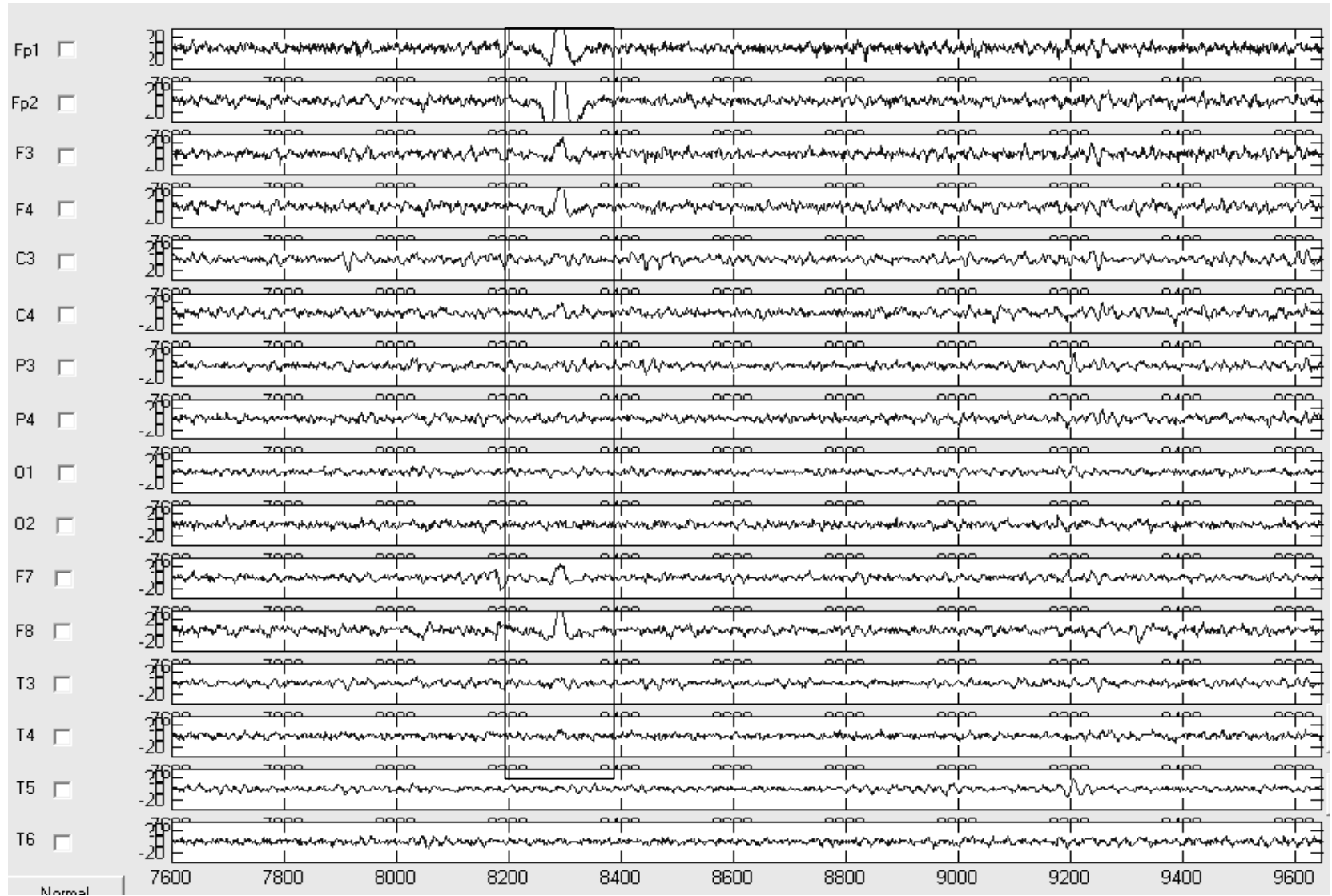
- Problem: The information within the EEG is masked by the eye blinks
- Two strategies to mitigate these artefacts:
  - Constrained Blind Source Separation (BSS)
  - Combine BSS with Support Vector Machines

PhD Student: Leor Shoker

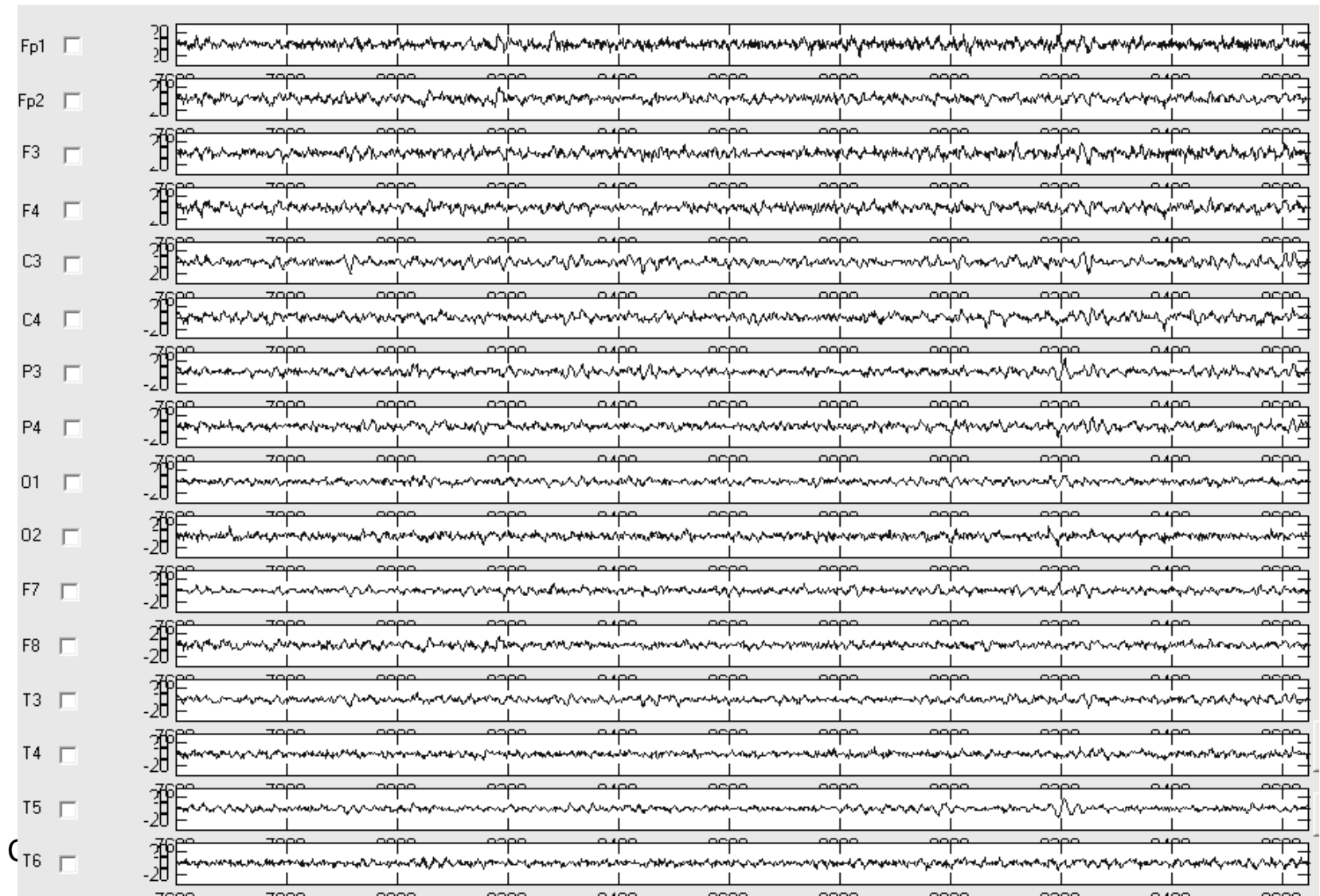
# Hybrid BSS-SVM for Artifact Removal



# Results: Contaminated EEG



# Results: Corrected EEG





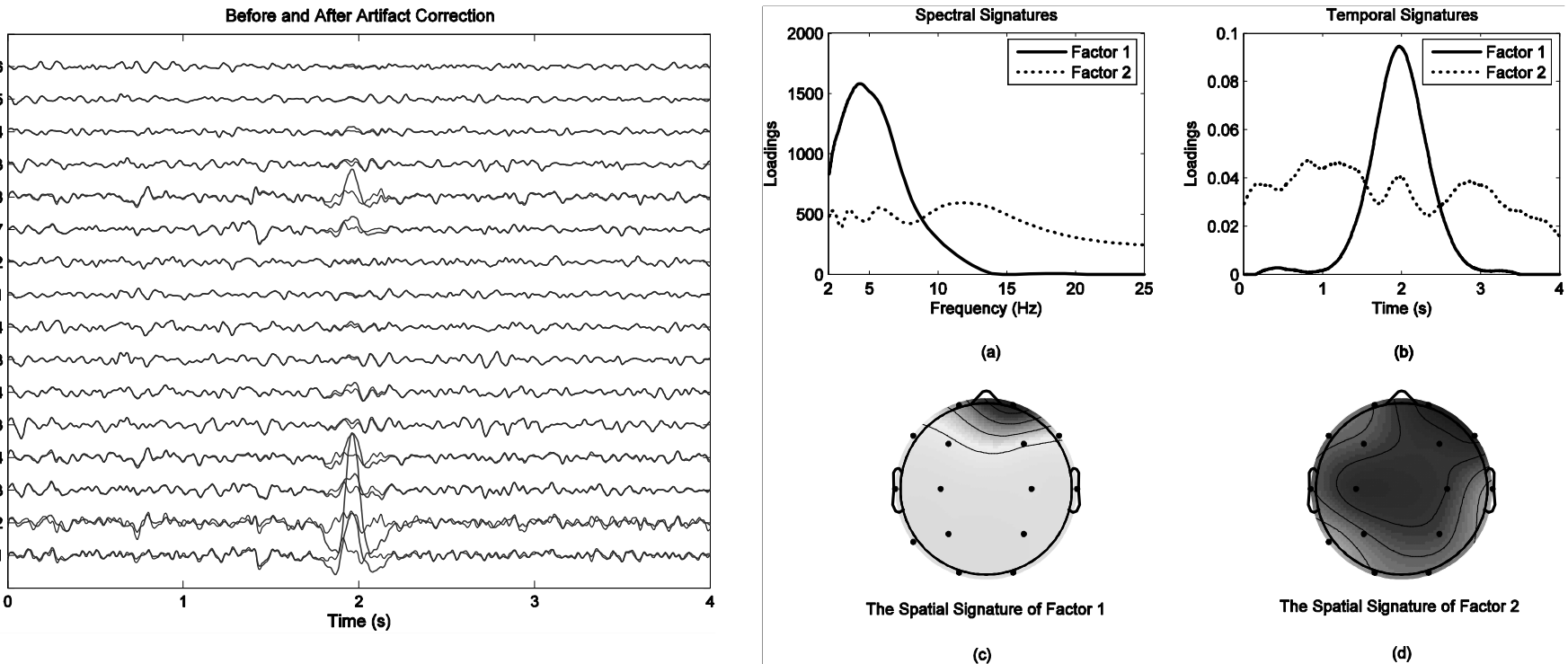
# Eye-Blink Artifact Removal from EEGs: A hybrid Beamforming- PARAFAC Approach

PhD Student: Kianoush Nazarpour

# Semi-Blind Signal Extraction (SBSE) Method

- Summary:
  - Space-Time-Frequency Modelling of EEG Potentials
  - Automatic Eye-Blink (EB) Component Selection
  - Using the Spatial Signature of the EB in the Source Extraction Algorithm
  - Deflation to Obtain the Artifact-Free EEGs

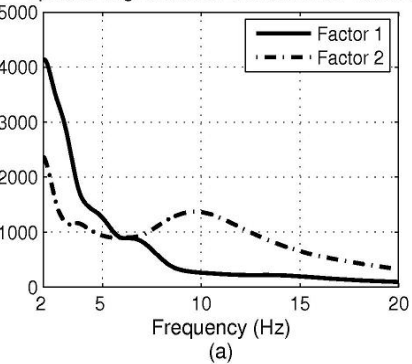
# Semi-Blind Signal Extraction Method



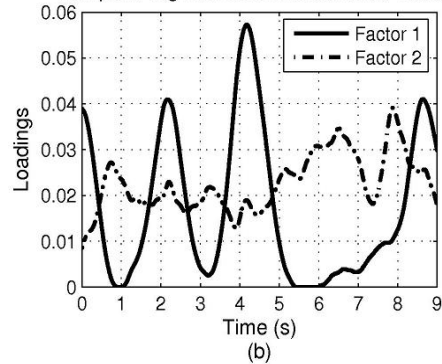
K. Nazarpour, H. R. Mohseni, C. W. Hesse, J. A. Chambers and S. Sanei,  
 “A novel semi-blind signal extraction approach incorporating PARAFAC for the removal of the  
 removal of eye-blink artifact from EEGs,” ***EURASIP J. Advances Sig. Process.***, 2007, *submitted*.

# STF-TS Modelling and Robust Beamforming

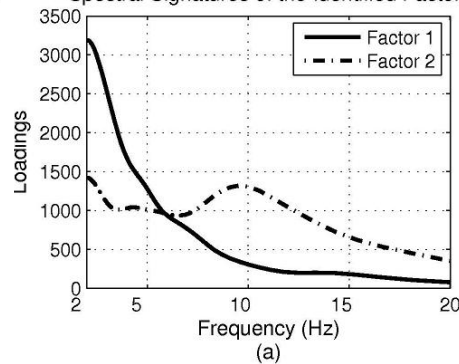
Spectral Signatures of the Identified Factors



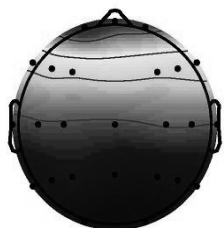
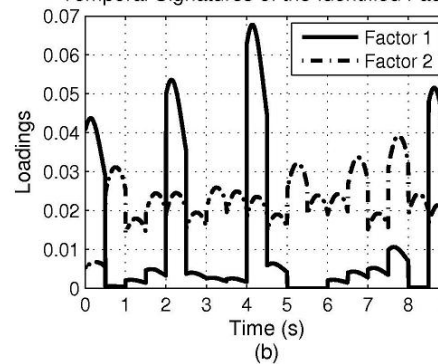
Temporal Signatures of the Identified Factors



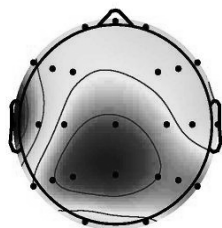
Spectral Signatures of the Identified Factors



Temporal Signatures of the Identified Factors



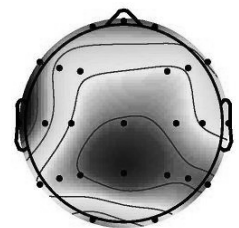
Spatial Signature of Factor 1  
(c)



Spatial Signature of Factor 2  
(d)



Spatial Signature of Factor 1  
(c)



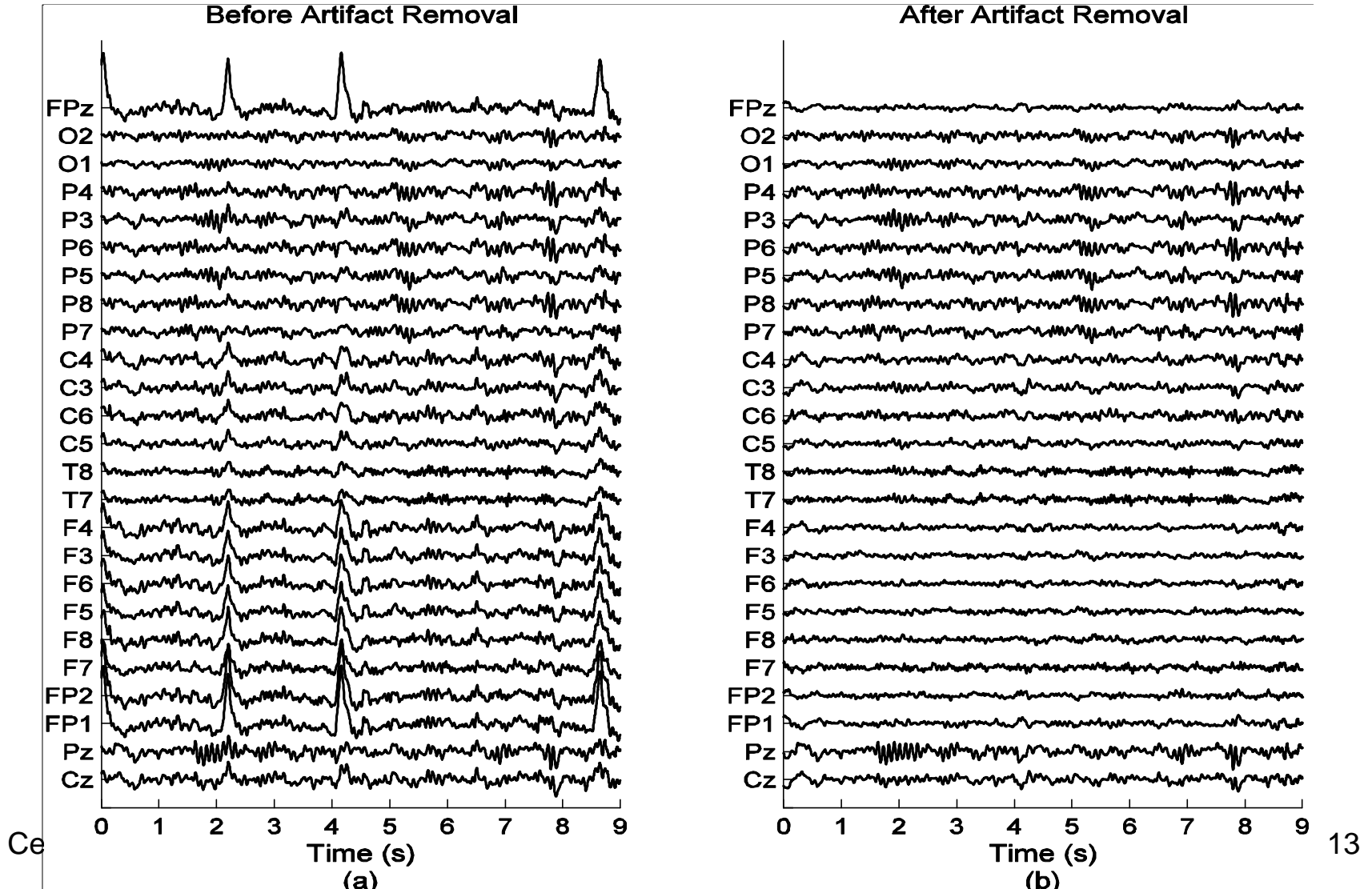
Spatial Signature of Factor 2  
(d)

Classic STF Model

Proposed STF-TS Model

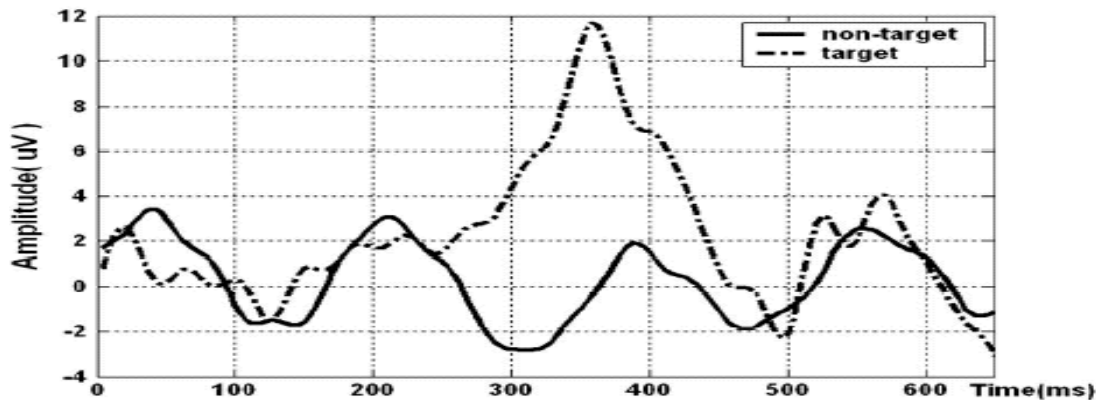
K. Nazarpour, Y. Wongsawat, S. Sanei, J. A. Chambers and S. Orintara,  
 "Removal of the eye-blink artifacts from EEGs via STF-TS modeling and robust minimum  
 variance beamforming," *IEEE Trans. Biomed. Eng.*, 2007, in Press.

# STF-TS Modelling and Robust Beamforming



# P300 and its subcomponents

- *P300 is a positive ERP occurs at about 300ms after rare or task relevant stimuli*
- Can be by visual or audio stimulations



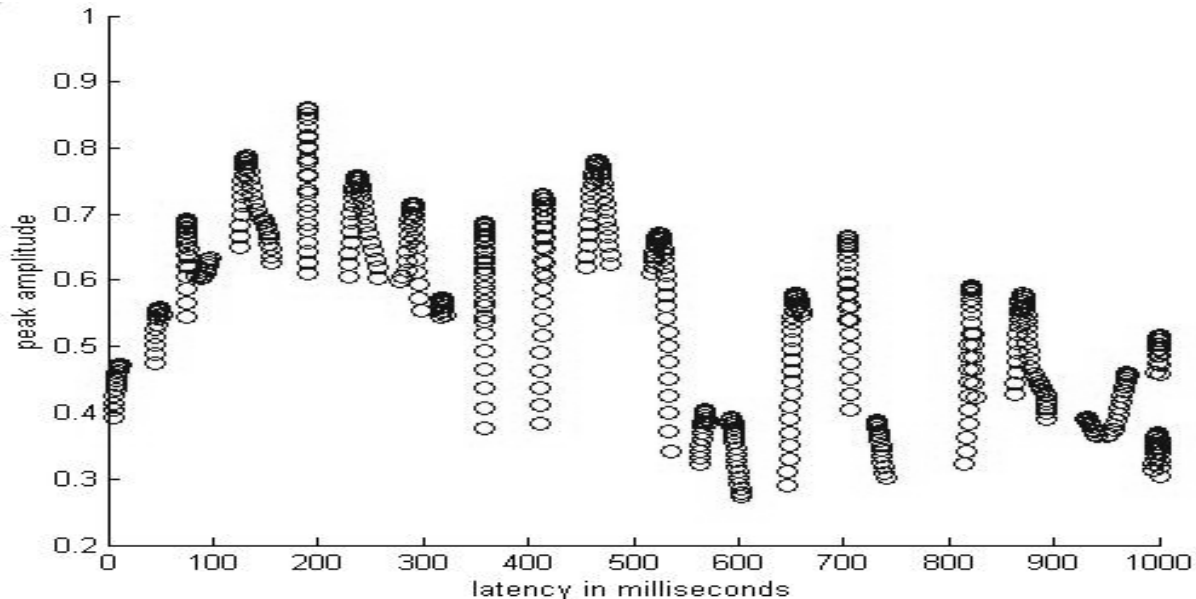
PhD Student Loukianos Spyrou

# Subcomponents of P300; P3a and P3b

- *P3a : Early peak, due to attention, larger amplitude, with more frontal distribution*
- *P3b: later peak, due to reaction or intention to respond, with more centoparietal distribution*

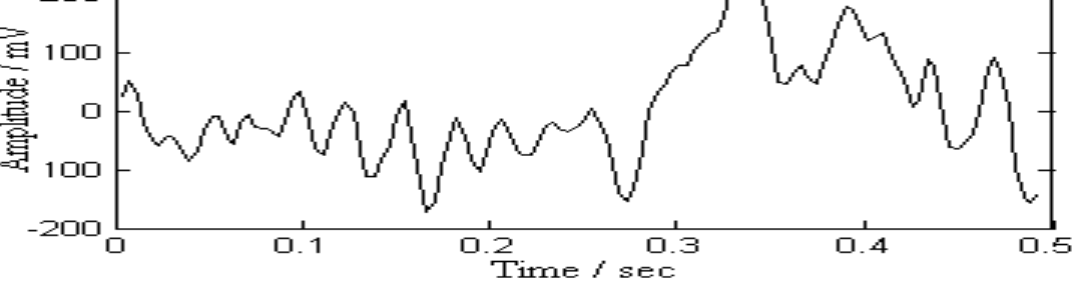
$$\mathbf{w}_{lOpt}^T = \arg \min_{\mathbf{w}_l} \left\| \mathbf{s}_l - \mathbf{w}_l^T \mathbf{X} \right\|_2^2, \quad \mathbf{y}_l = \mathbf{w}_l^T \mathbf{X}$$

$$s_i(t) = e^{-(t-t_i)^2} / \mathbf{s}_i^2$$



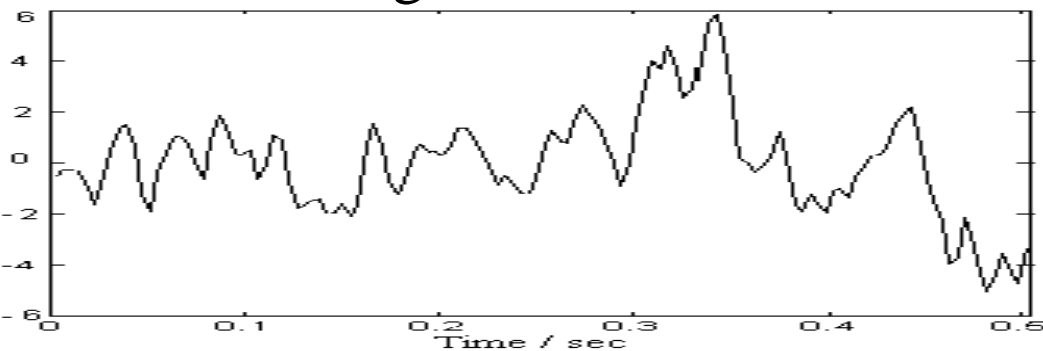
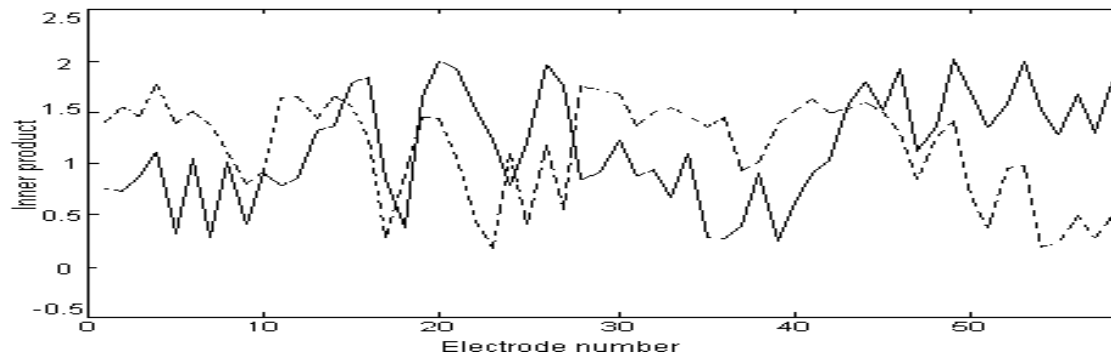
L. Spyrou, Min Jing, S. Sanei, and A. Sumich, “Separation and localisation of P300 sources and the subcomponents using constrained blind source separation,” EURASIP Journal on Advances in Signal Processing, vol. 2007, paper ID: 82912, pp. 1-10, 2007.





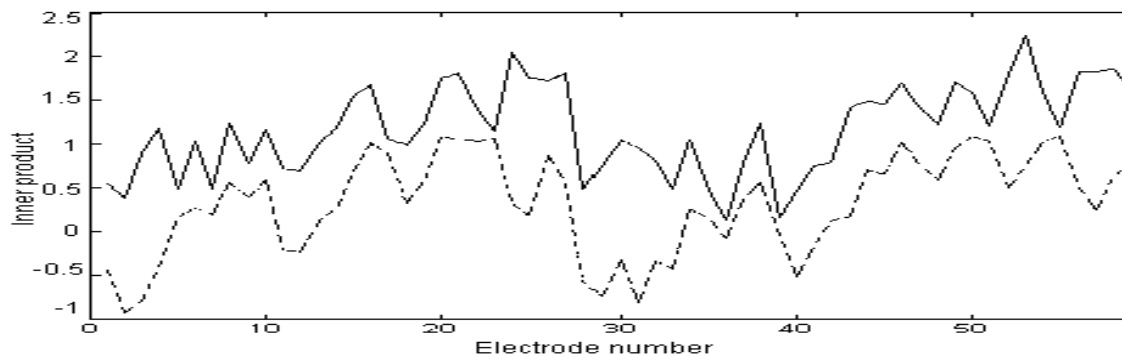
Estimate visual P3a

The correlation measures between the detected visual P3a and the electrode signals.

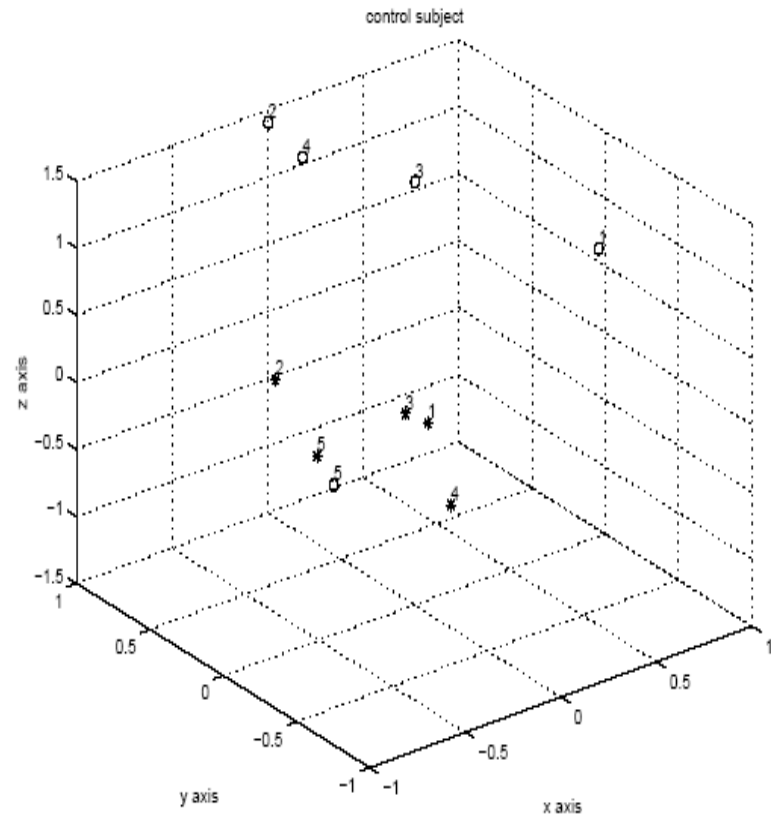
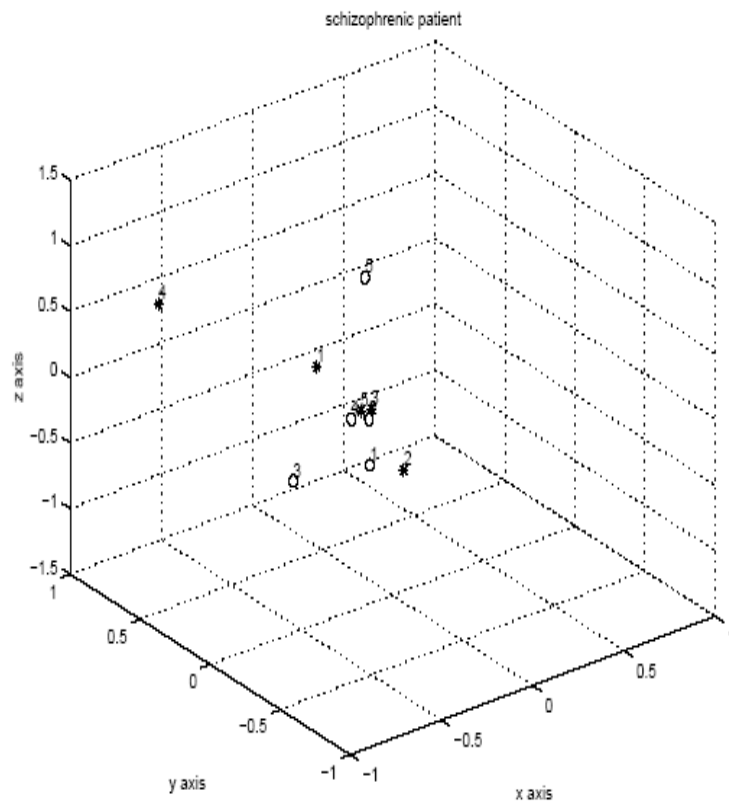


Estimated audio P3a

The correlation measures between the detected Audio P3a and the electrode signals.



# Source Localisation Results



Location of p3a and p3b sources for (a) the patients suffering from schizophrenia, (b) healthy individuals

# A New Beamforming Approach for ERP Localization

## Spatial Notch Filtering

- L. Spyrou and S. Sanei “Source localisation of event related potentials incorporating spatial notch filters,” To appear in IEEE Trans. Biomedical Engineering, 2007.

# Spatial Notch Filter (Null Beamformer)

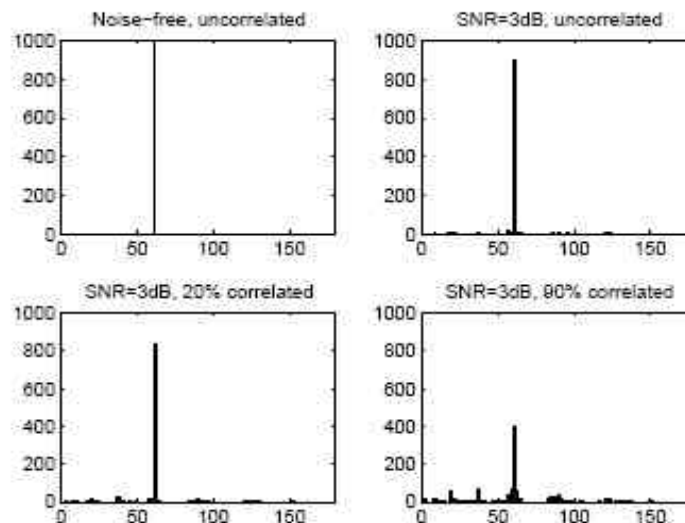
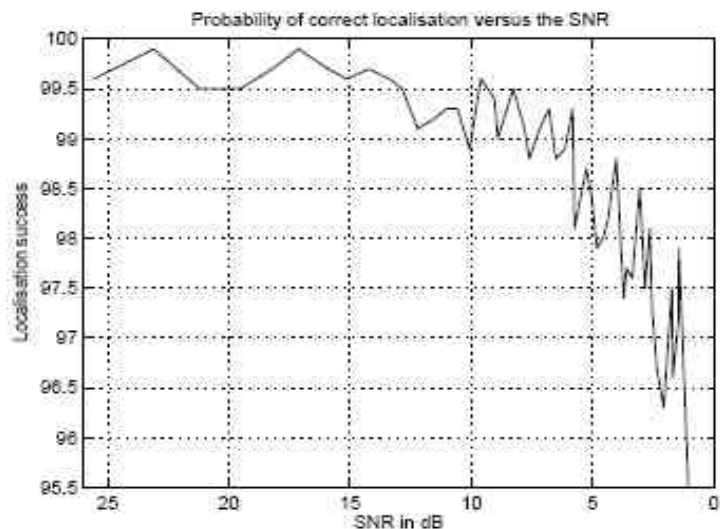
- Localises sources with approximately known waveforms
- Requires knowledge of the mixing system, in this case head model
- Number of sources not required.
- Uses constrained optimisation to solve the problem
- Two parts of the cost function deal with a) the waveform, b) the location

$$\text{a) } f_d(\mathbf{w}) = \|\mathbf{r}_i - \mathbf{w}^T \mathbf{X}\|_2^2$$

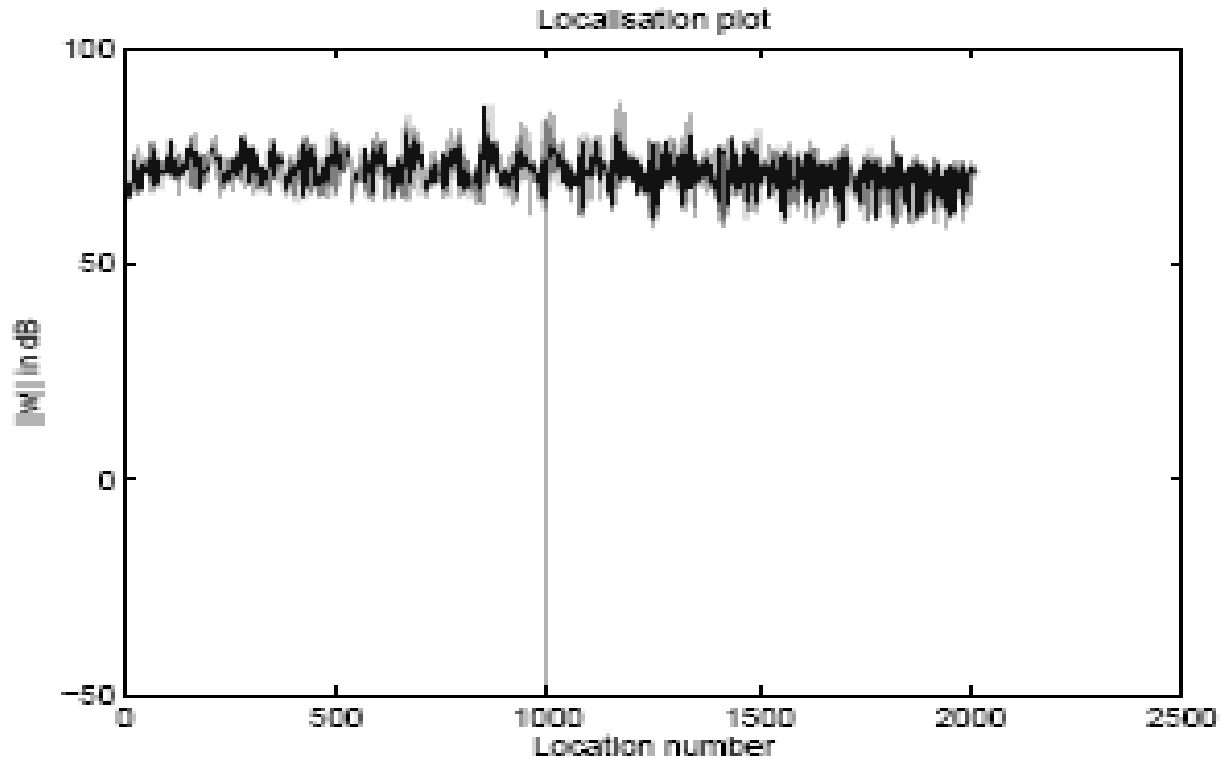
$$\text{b) } f_c(\mathbf{w}) = \mathbf{w}^T \mathbf{H}(p) = 0$$

# Spatial Notch Filter

- Good localisation rate even in the presence of noise and correlation between sources.



# Spatial Notch Filter (Localization)



# Sequential Monte Carlo Methods (Particle Filtering) for ERP Detection and Localization

PhD Student: Hamid R Mohseni

H. R. Mohseni, E. Wilding, and S. Sanei, "A wavelet based particle filtering approach for estimation of single trial event-related potentials, Submitted to IEEE Trans. on Biomedical Engineering, 2007

# Problem Statement in the State Space

- State Space

$$\mathbf{x}_k = f_{k-1}(\mathbf{x}_{k-1}, \mathbf{w}_{k-1})$$
$$\mathbf{y}_k = h_k(\mathbf{x}_k, \mathbf{v}_k)$$

- We search for the filtered estimates of  $\mathbf{x}_k$  based on a set of all available outputs  $\mathbf{y}_{1:k} = \{\mathbf{y}_i, i = 1, \dots, k\}$ .
- Recursive calculation of the posteriori density function  $p(\mathbf{x}_k | \mathbf{y}_{1:k})$  of state  $\mathbf{x}_k$  at time  $k$ .
- Bayes Rule for recursive estimation

$$p(x_k | y_{1:k}) = \frac{p(y_k | x_k) p(x_k | y_{1:k-1})}{p(y_k | y_{1:k-1})}$$



# Single Trial Estimation Results

- Simulation Results

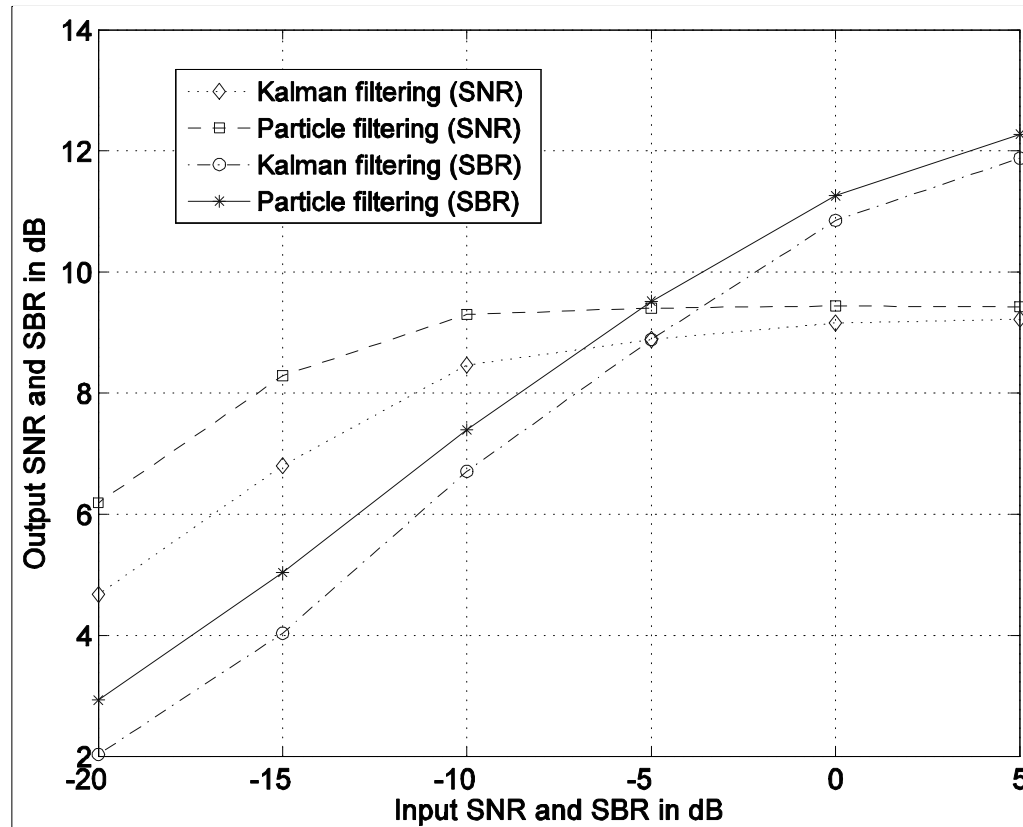
- two Gaussian functions were used resembling P300 and N400 components.
  - The dynamic of amplitude and latencies of the first peak were assumed to change sinusoidally
  - the amplitude and latency of the second peak were assumed to change according to a uniform random distribution.
  - The variances of both peaks were constant during
- GWN and real background EEG activity were considered as two different kinds of noise

$$SNR = 10 \log \left[ \frac{P(signal)}{P(GWN)} \right]$$

$$SBR = 10 \log \left[ \frac{P(signal)}{P(background)} \right]$$

# Single Trial Estimation Results (continue)

- Input SNR and SBR vs output SNR and SBR

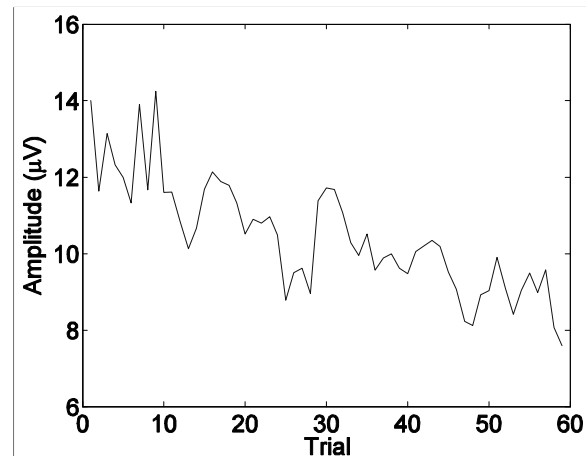
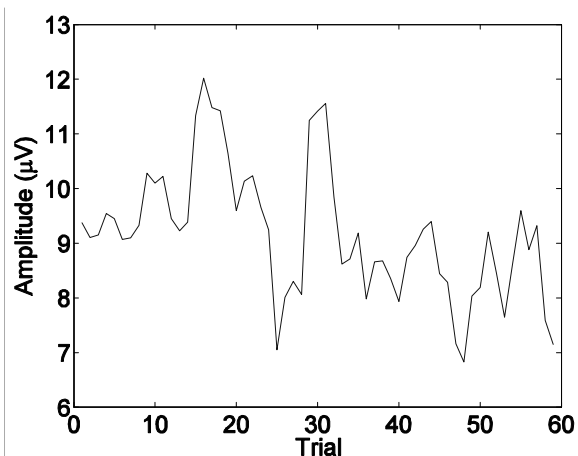
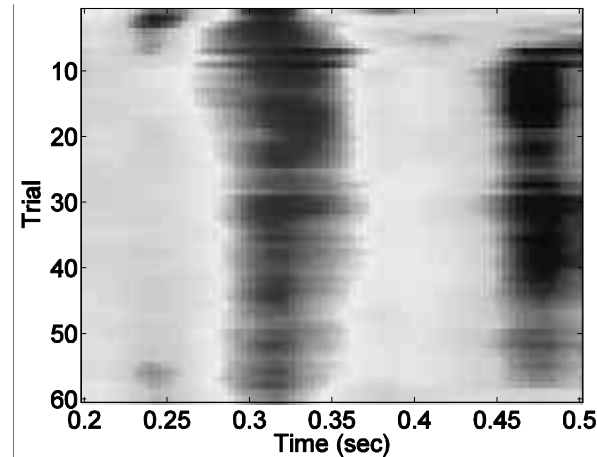
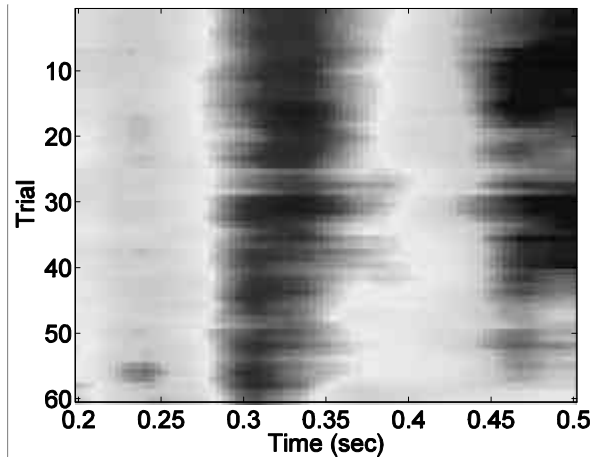


# Single Trial Estimation Results (continue)

## Experimental Results

- odd-ball paradigm in the Cognitive Electrophysiology Laboratory, School of Psychology, Cardiff University.
- 300 tones (240 frequent (80%) and 60 infrequent (20%)).
- Frequency bandwidth was 0.03-40 Hz and the sampling rate was 250 Hz.
- An Fz reference was employed during acquisition, and the data were re-referenced off-line to the average of the left and right mastoids.
- Epochs from 200ms to 500ms time-locked to stimulus onset were extracted.
- A 150ms pre-stimulus interval was used for baseline correction.

# Single Trial Estimation Results (continue)



# Dipole Source Localisation

- Localisation Formulation in state Space
  - Assumptions:
    - Realistic head Model
    - Grid based method
    - Linear Forward Model
  - So the state equations can be rewritten as:

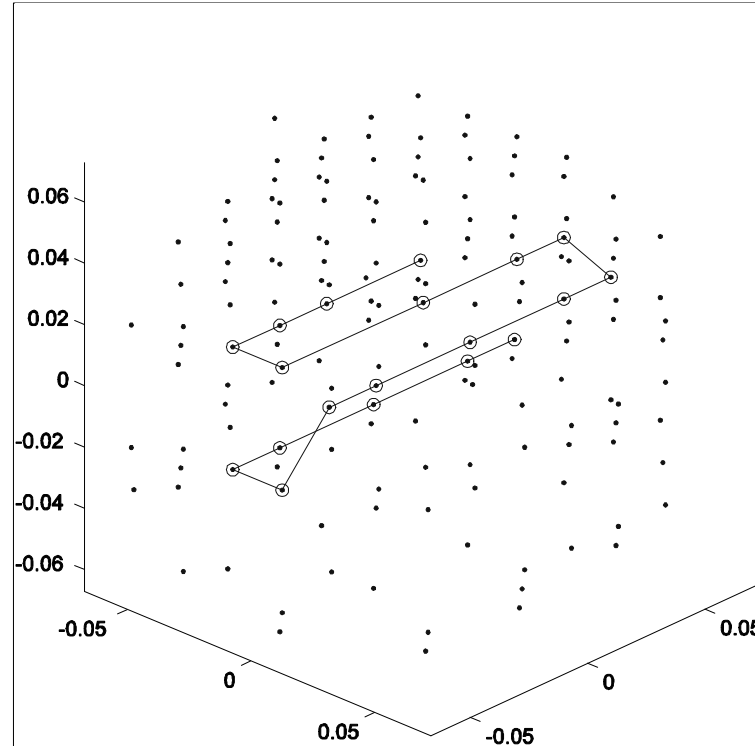
$$\mathbf{s}_k = \mathbf{s}_{k-1} + \mathbf{v}_{k-1}$$

$$\mathbf{y}_k = \mathbf{F}\mathbf{s}_k + \mathbf{w}_k \quad \mathbf{s}_k = [n_k \quad x_k \quad y_k \quad z_k]$$

- where  $n$  is the grid index of source (The head is modelled with some grids)
- $x, y, z$  are moments of source in the  $x, y, z$  direction respectively
- $\mathbf{F}$  is the matrix of forward model
- $\mathbf{W}$  and  $\mathbf{V}$  are Gaussian white noise.

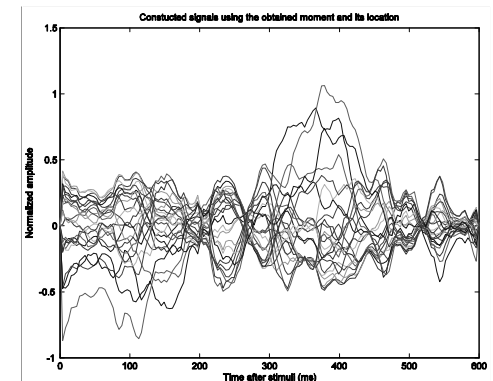
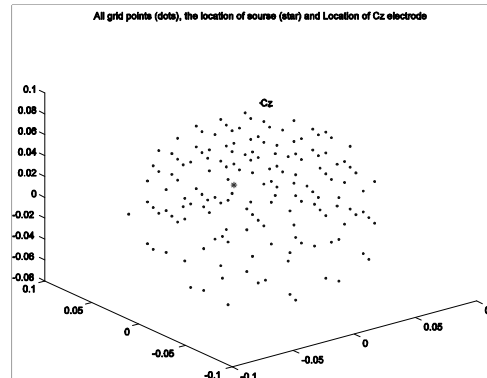
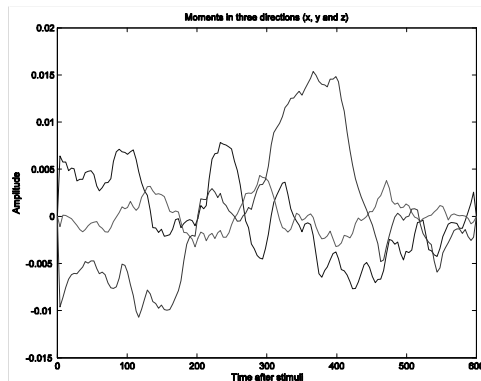
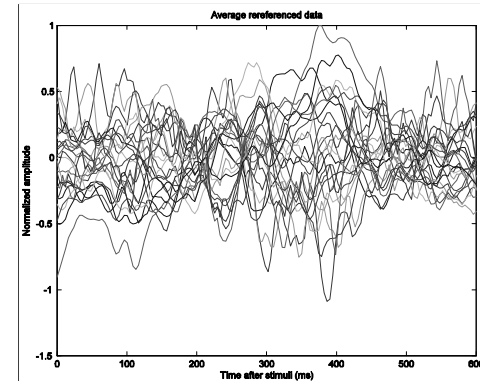
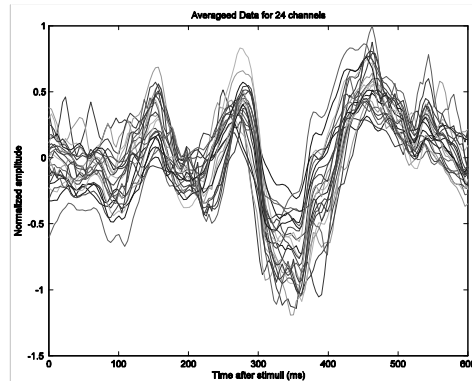
# Localisation Results (continue)

- Tracking (Moments are constant/ some additive noise)



# Localisation Results (continue)

- Real Data Results



# Incorporating BSS to Epileptic Seizure Predictability Measure from Scalp EEGs

## ➤ Blind Source Separation

Separate seizure components as independent sources from scalp EEGs.

## ➤ Nonlinear dynamic method

Short-Term Lyapunov exponents (STLmax) was used to quantify the spatio-temporal dynamic changes of epileptic seizures.

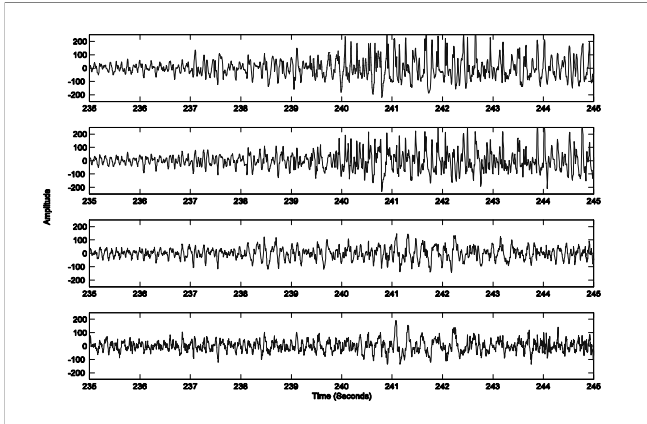
$$\lambda = \lim_{N \rightarrow \infty} \frac{1}{N} \sum_{n=1}^N \ln \left( \frac{dx_{n+1}}{dx_n} \right)$$

PhD Student: Min Jing

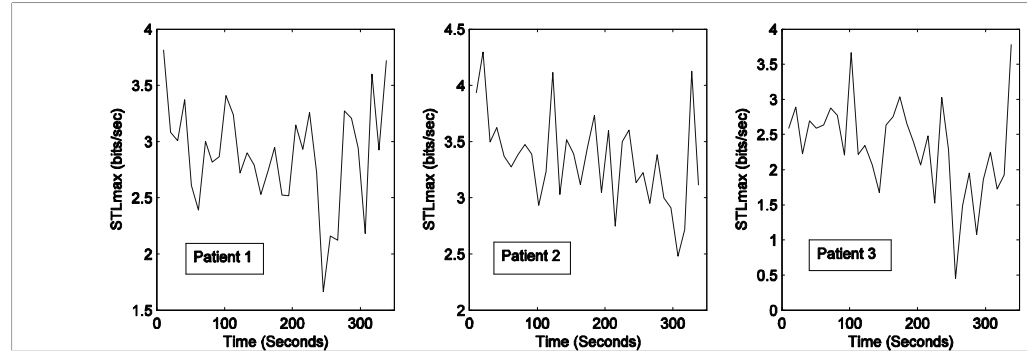


# Results

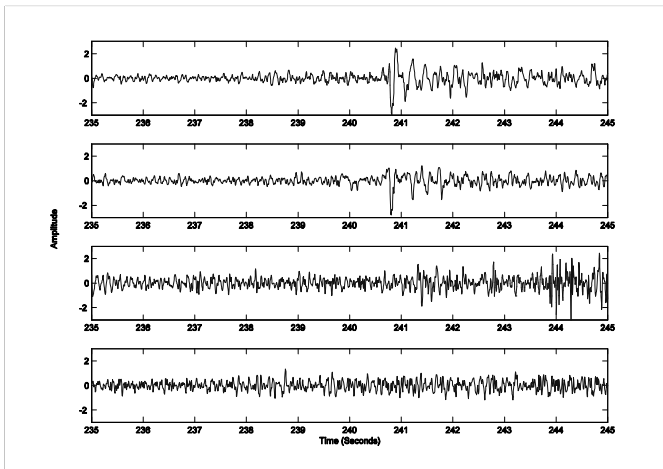
## Intracranial EEGs



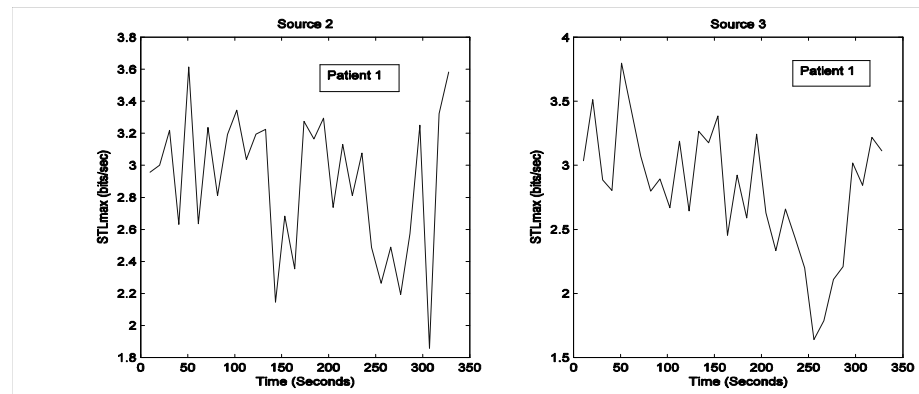
## STLmax from intracranial EEGs



## Source from scalp EEGs



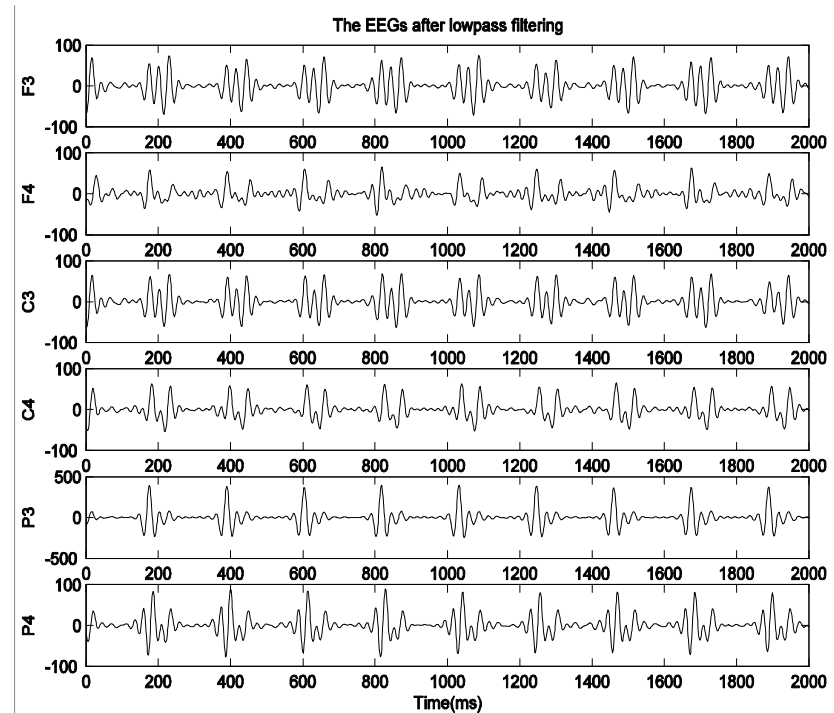
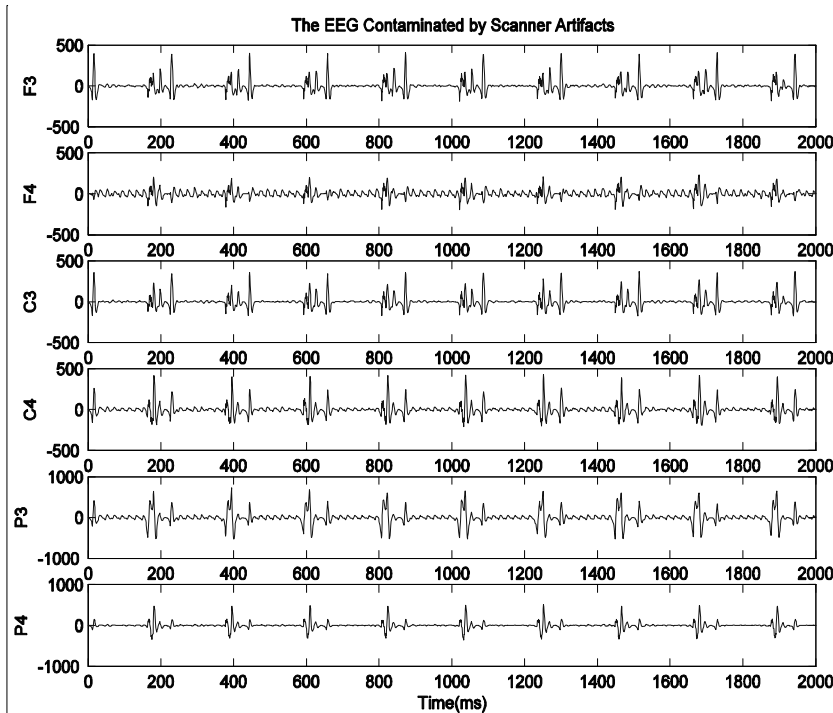
## STLmax from separated sources



# **Simultaneous EEG-fMRI study: A Blind Approach for Mitigation of Scanner Artifact in EEGs**

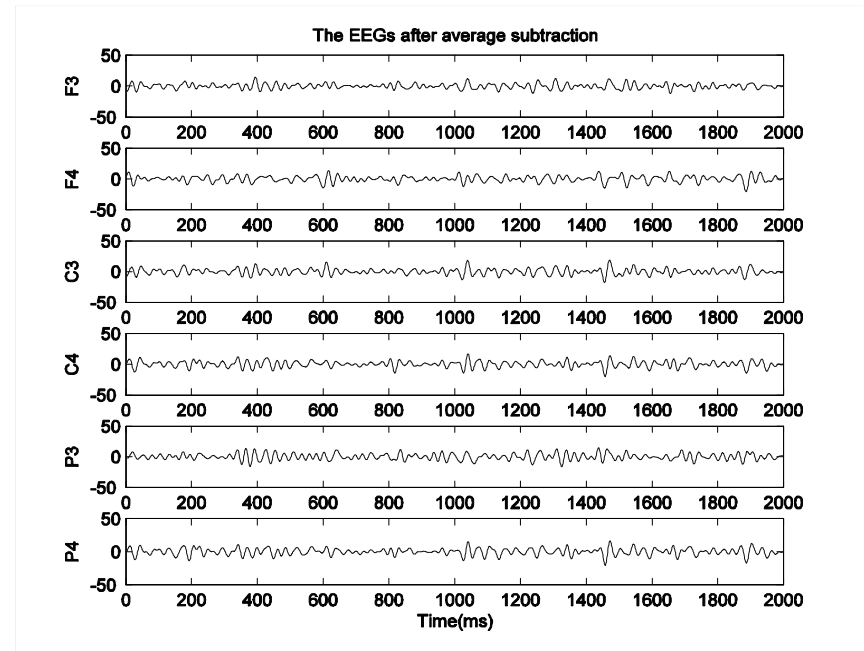
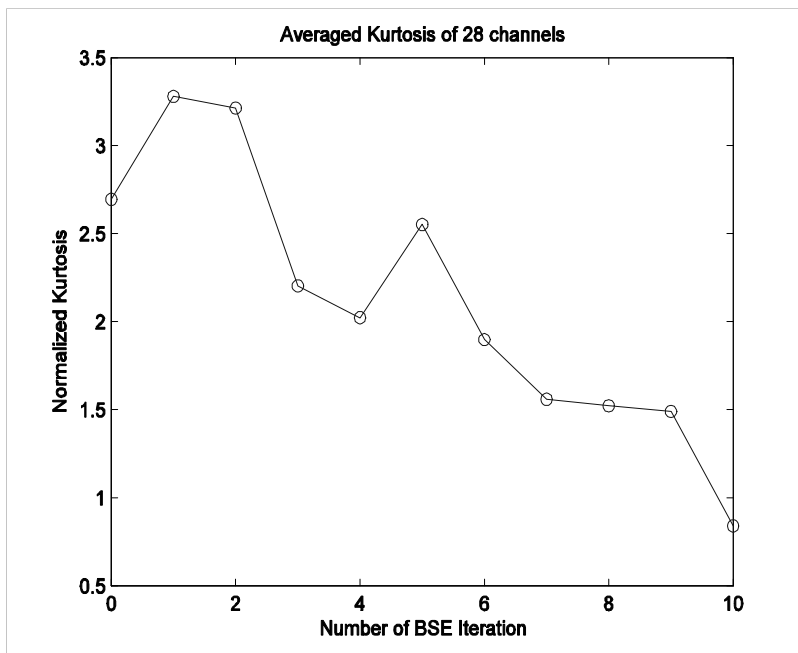
# Experimental Results

- EEGs contaminated by scanner artifacts



# Experimental Results

- Averaged Kurtosis obtained from 28 channels; it can be seen that the kurtosis decreases with the iteration number of BSE

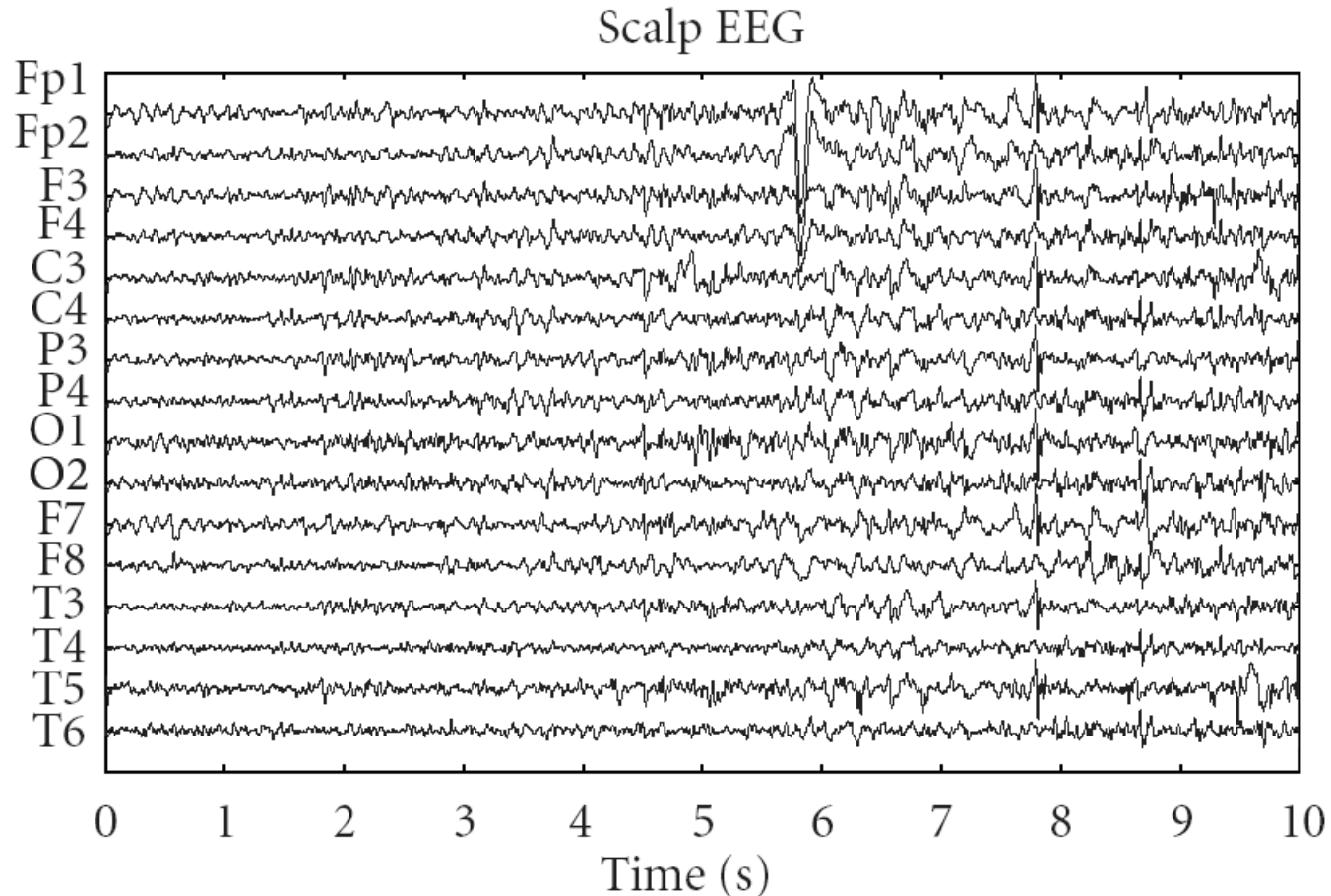


# Seizure Signal Separation using Constrained Topographic Blind Source Separation

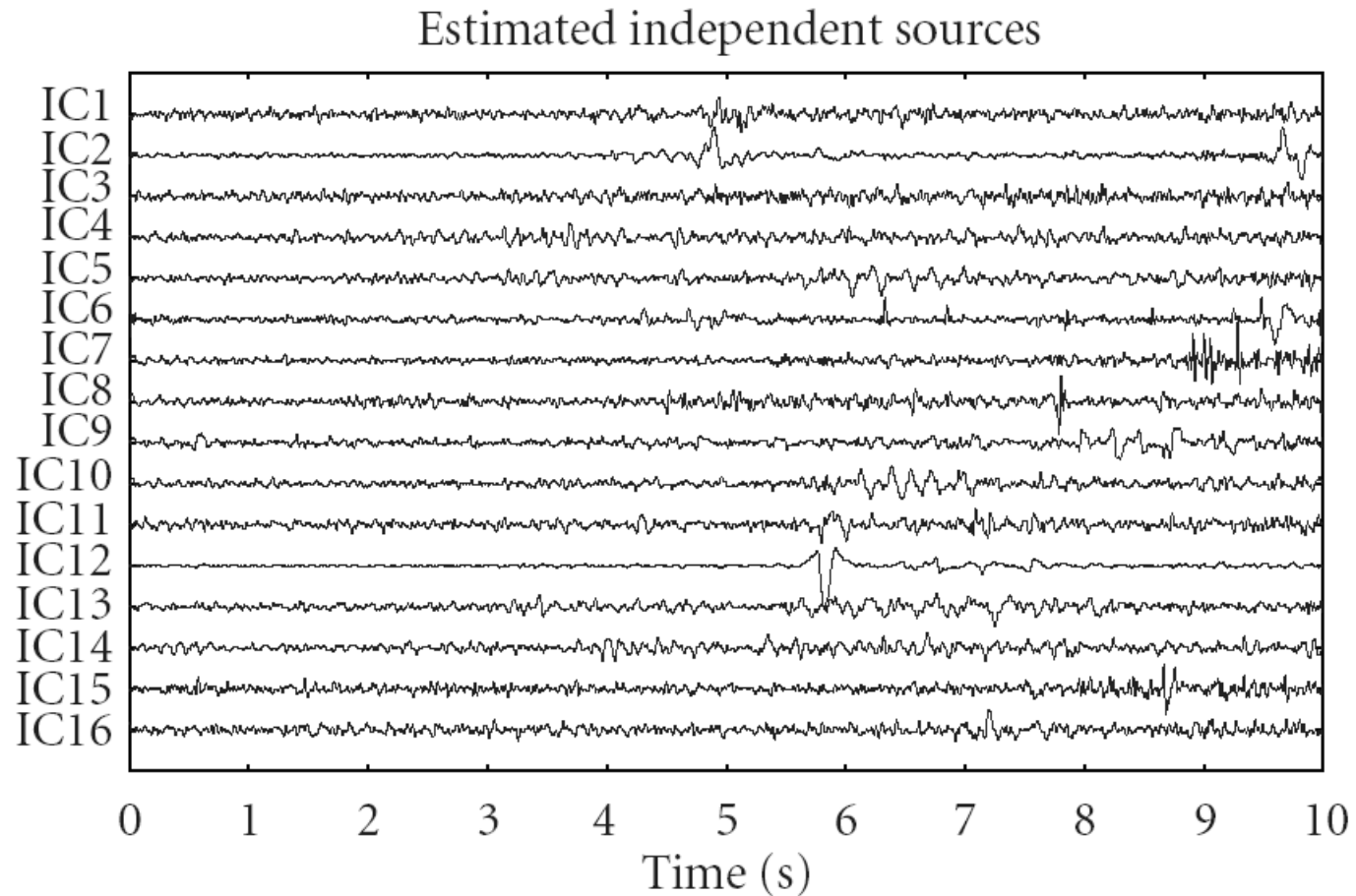
PhD Student: Min Jing

# Experimental Results

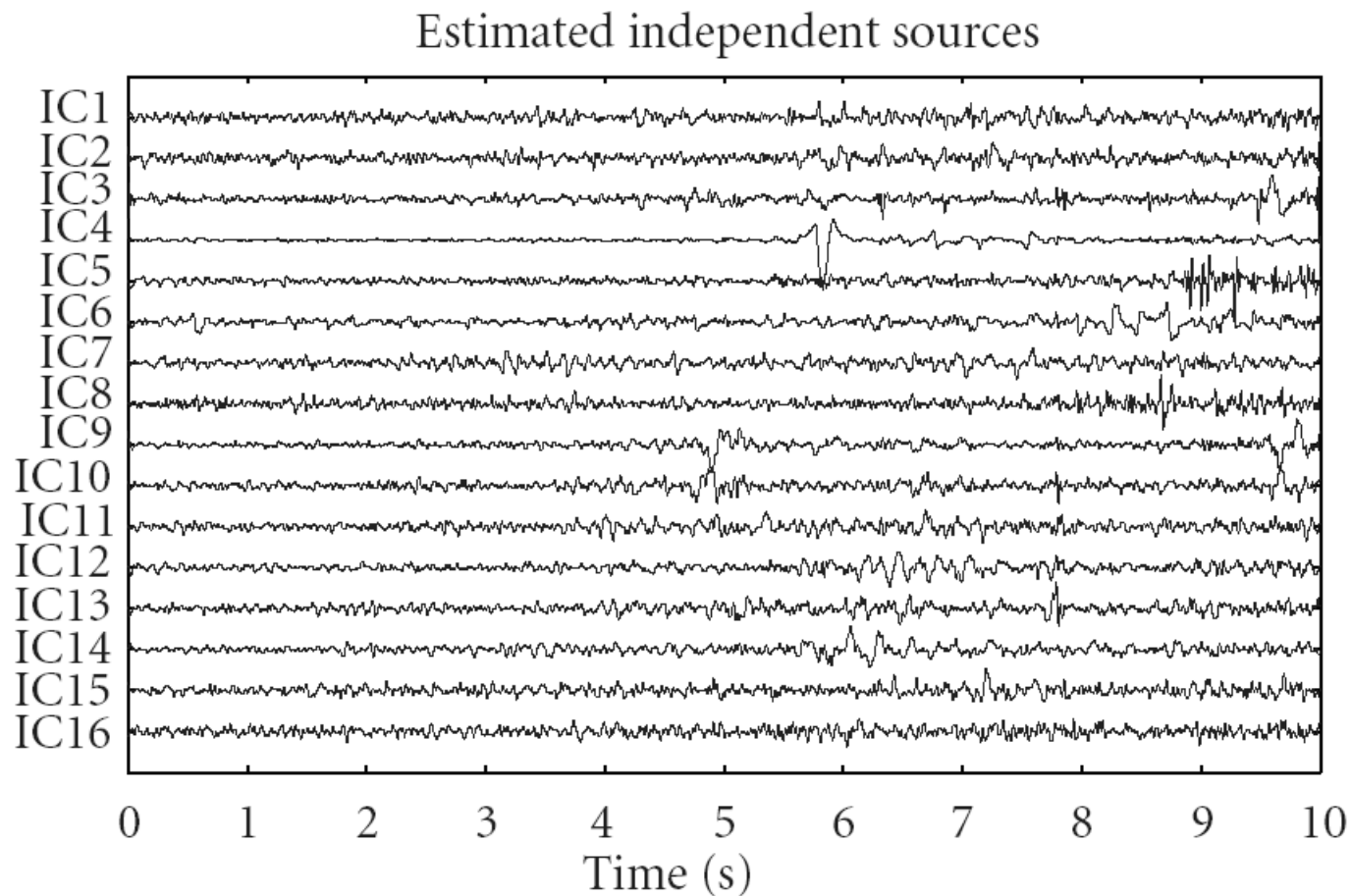
The reference signal is constructed by averaging the signals from F3, F4 , F7, F8, C3, and C4 electrodes, filtered using a bandpass order 8 Butterworth filter.



# Using TICA

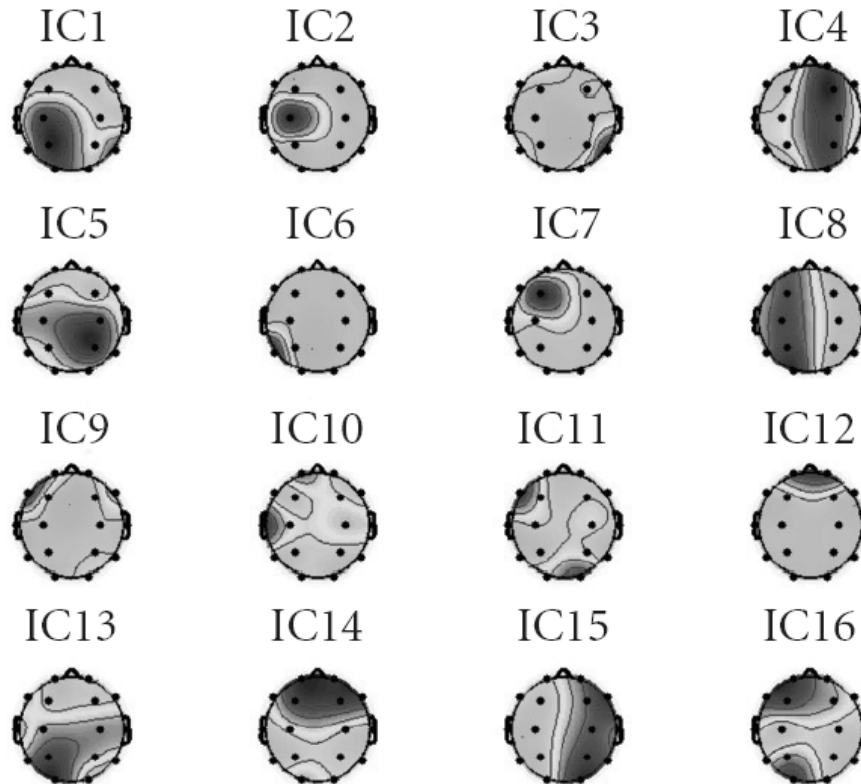


# Using CTICA



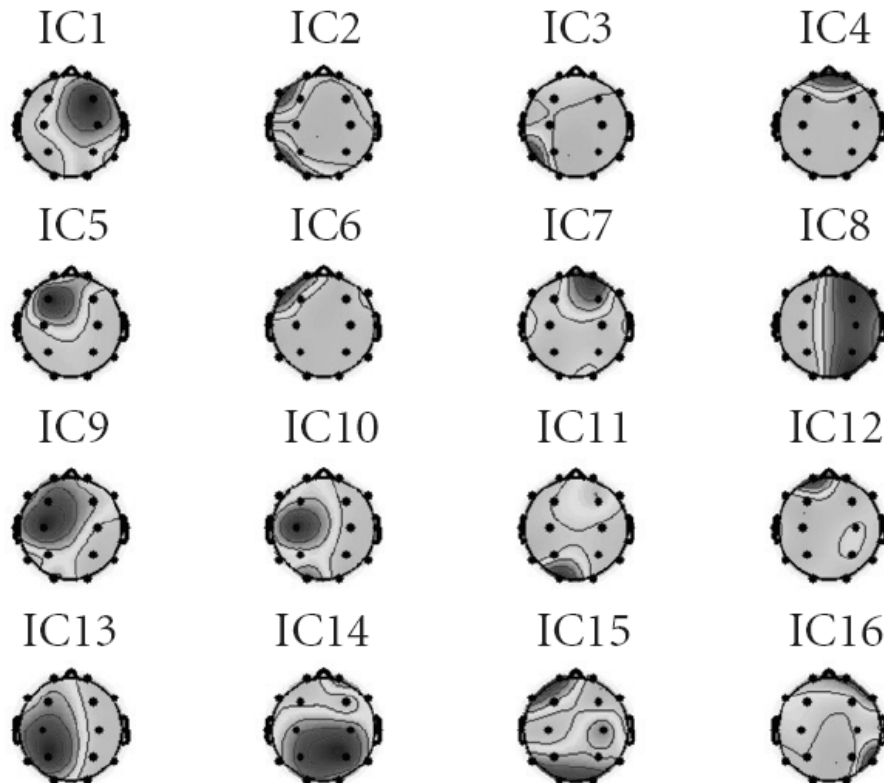


# Topography by backprojecting each IC from TICA



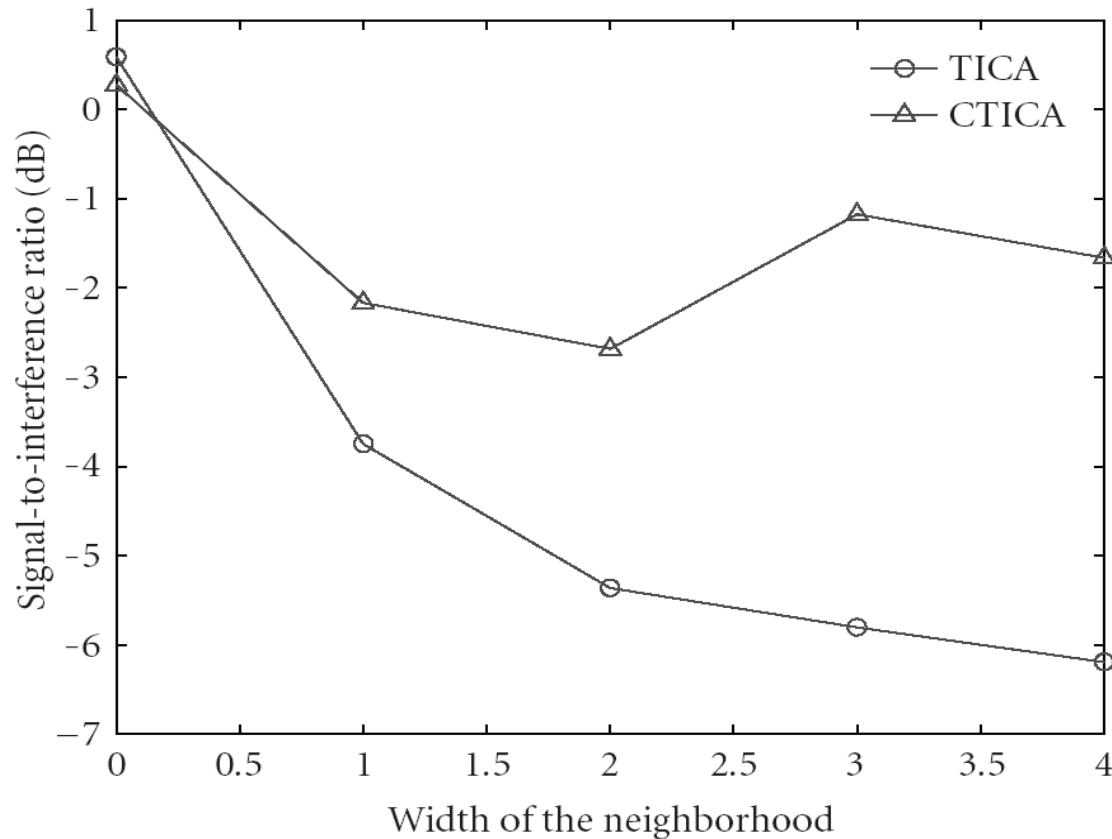
Topography of the estimated EEG sources from TICA

# Topography by backprojecting each IC from CTICA

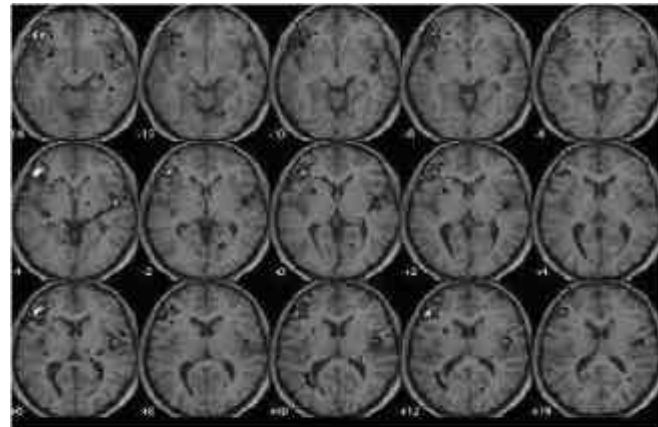


Topography of the estimated EEG sources from CTICA

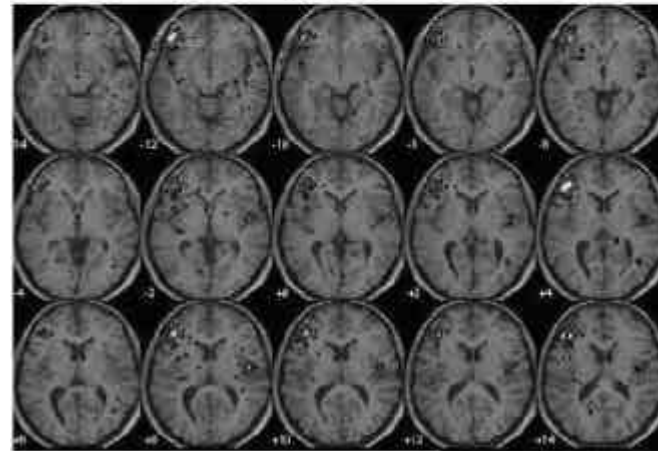
# The comparison of SIR in terms of the width of neighbourhood



# Constrained Spatial ICA for fMRI



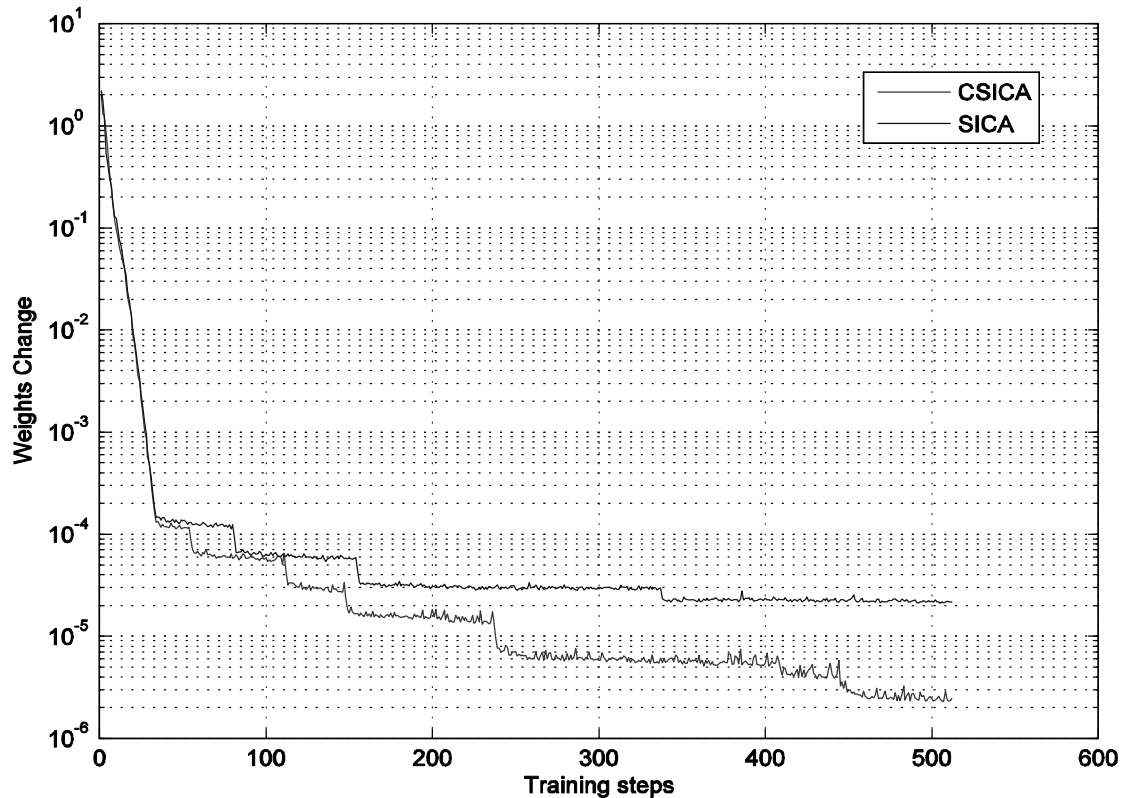
(a) SIICA



(b) CSICA



# Constrained Spatial ICA



M. Jing, S. Sanei, "A Novel constrained Topographic ICA for separation of epileptic seizure signals," To appear in the Journal of computational Intelligence and Neuroscience, 2007, ISSN:1687-5265.

# Future Research

- More on BCI
- Mental Fatigue Analysis
- Seizure analysis for the patients suffering Rett Syndrome
- Sleep Analysis
- Multi-modal techniques:
  - EEG-fMRI
  - EEG-MEG
  - Etc.

