

# Automated methods for REM Sleep Analysis

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## Overview:

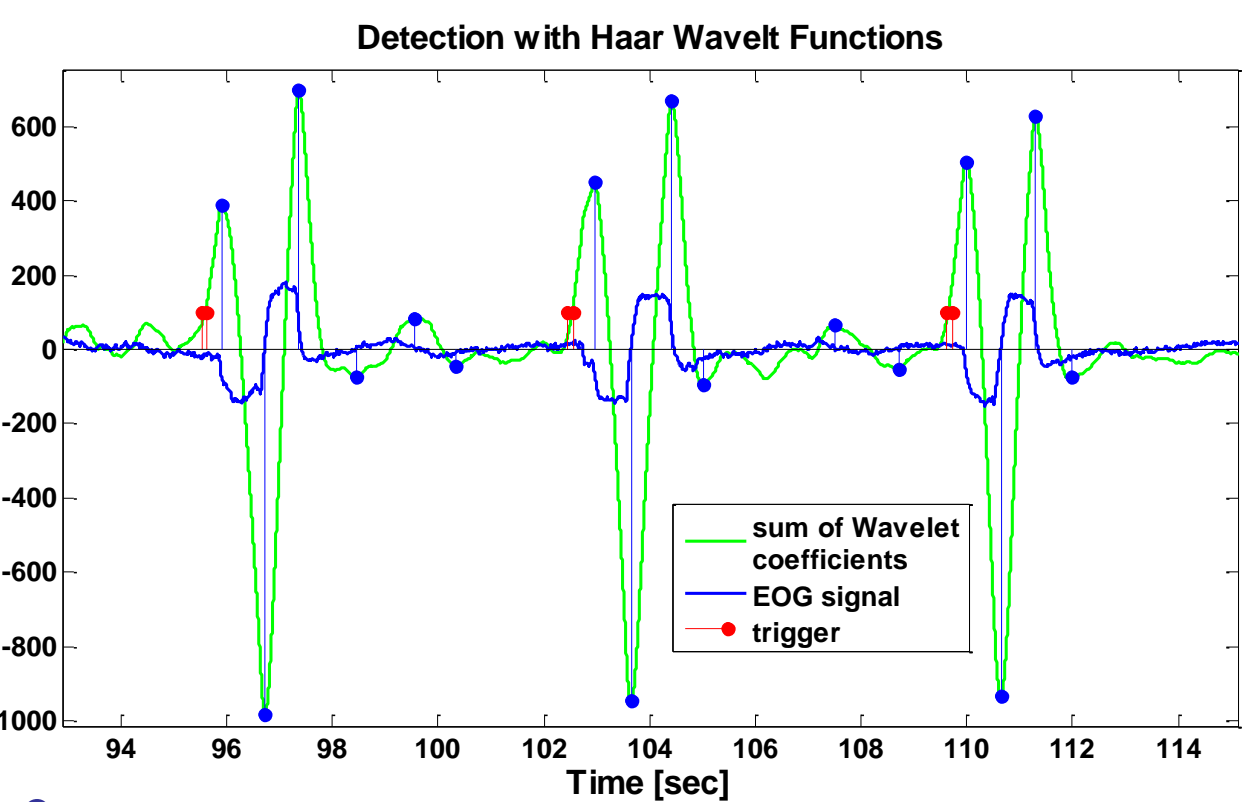
REM sleep, also referred as “paradoxical “ sleep, definitely differs from all the other sleep phases by the presence of low voltage fast EEG activity, suppression of muscle tone and Rapid Eye Movements (REMs). Insofar as these characteristics make it unique, they have seriously limited the studies on REM brain activity until now. The presence of wide eye movements produces, in fact, oscillating electrical potentials that become superimposed to the low amplitude cerebral ones, strongly corrupting

the EEG spectral power density in the frequency bands of interest (in particular the theta band around 4-8 Hz). Under these conditions the significance of normal REM EEG quantitative studies is strongly affected. At the same time REMs are not only a source of contamination but represent a prominent and informative feature of REM sleep. They occur episodically (14-27% of REM sleep), often grouped in burst (60-70%), and show a particular organization during the night. REMs time

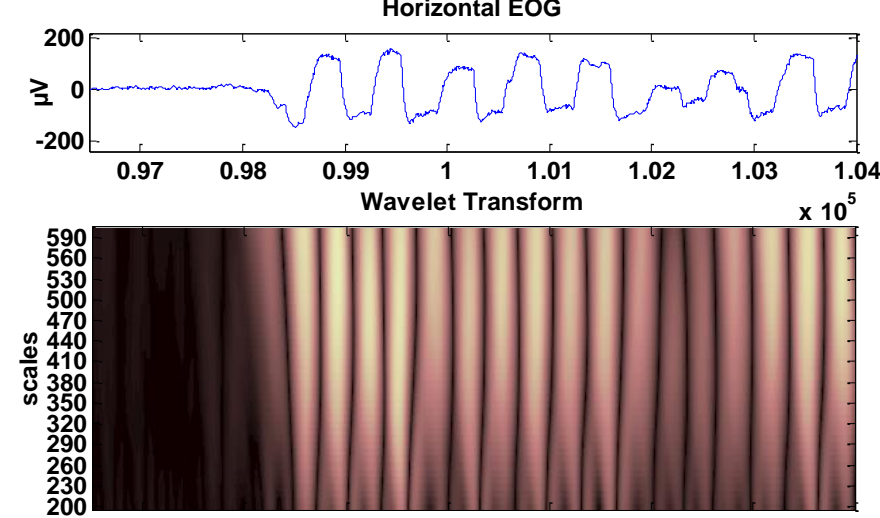
density and aggregation tendency are parameters of physiological and clinical interest. However, due to bidirectional contamination between EEG and EOG signals, the cerebral and ocular information is normally mixed together in experimental recordings. For these reasons, the development of an automated procedure, including a stage for both the ocular artifact removal and the REMs detection and characterization, would represent a valuable tool in both clinical and research activities.

## Methods:

### REMs Detection (Wavelet Transform)

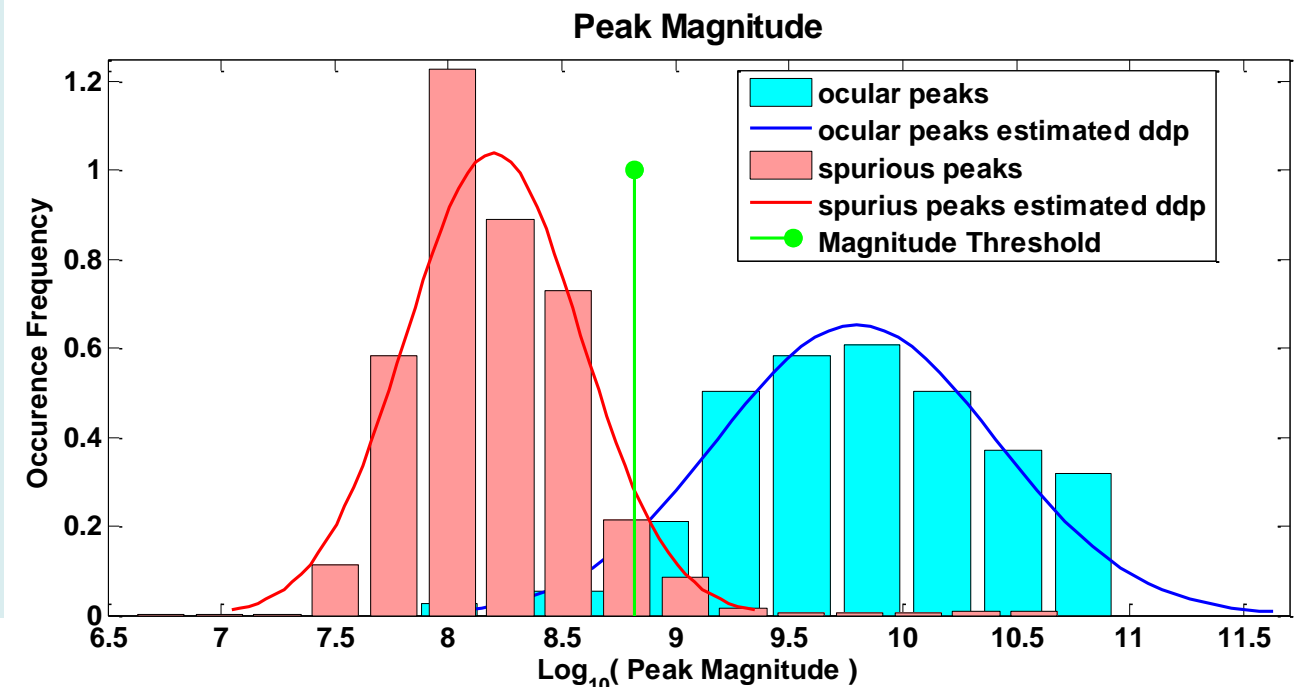


- Haar Wavelet function
- Sum of coefficients in the 200-600 range of scale (0.8-5Hz)



- ✓ Mark the elementary movement time-period
- ✓ No overlap between responses to consecutive movements
- ✓ Provide further information about the versus of the movement
- ✗ Spurious peaks caused by propagation of typical theta EEG oscillations

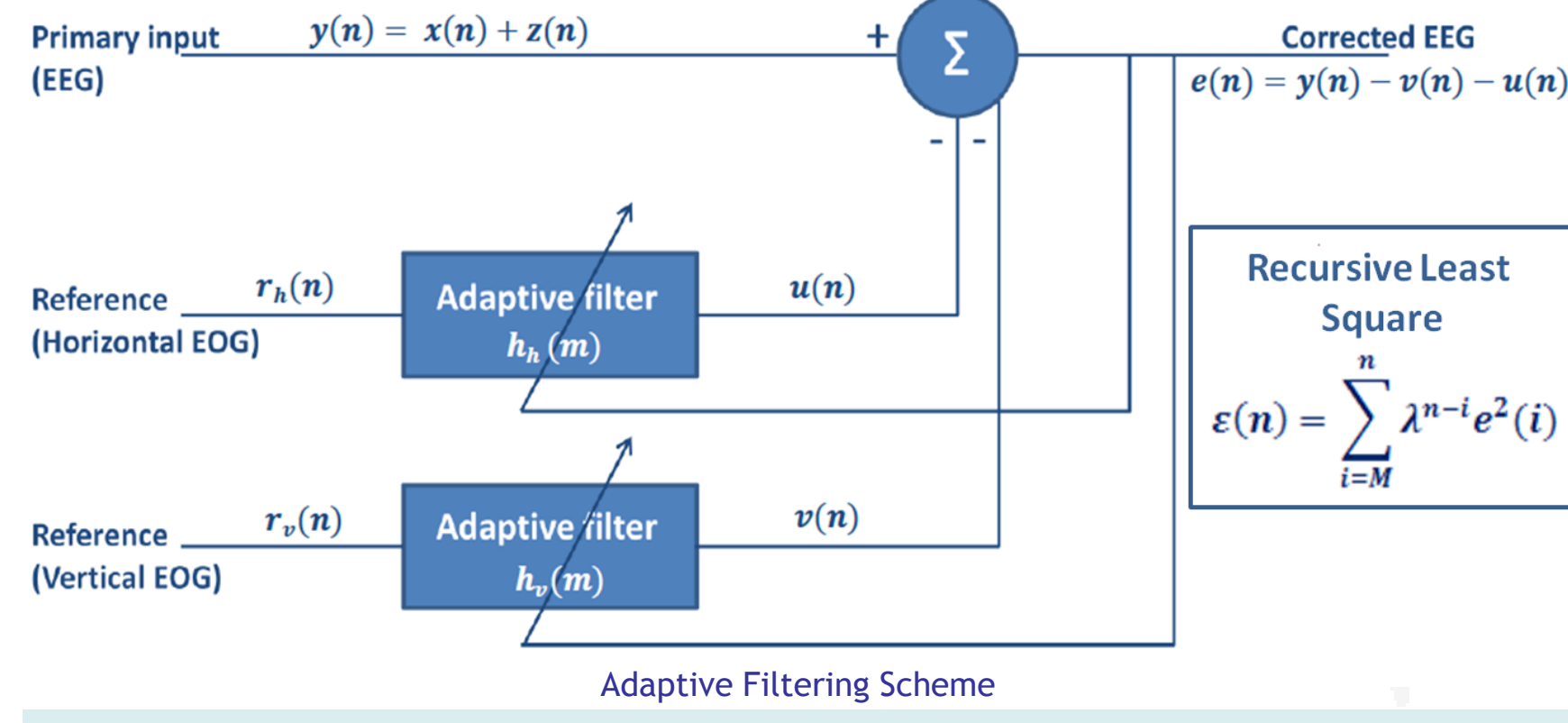
#### Thresholds Selection from experimental data



#### Detection Algorithm

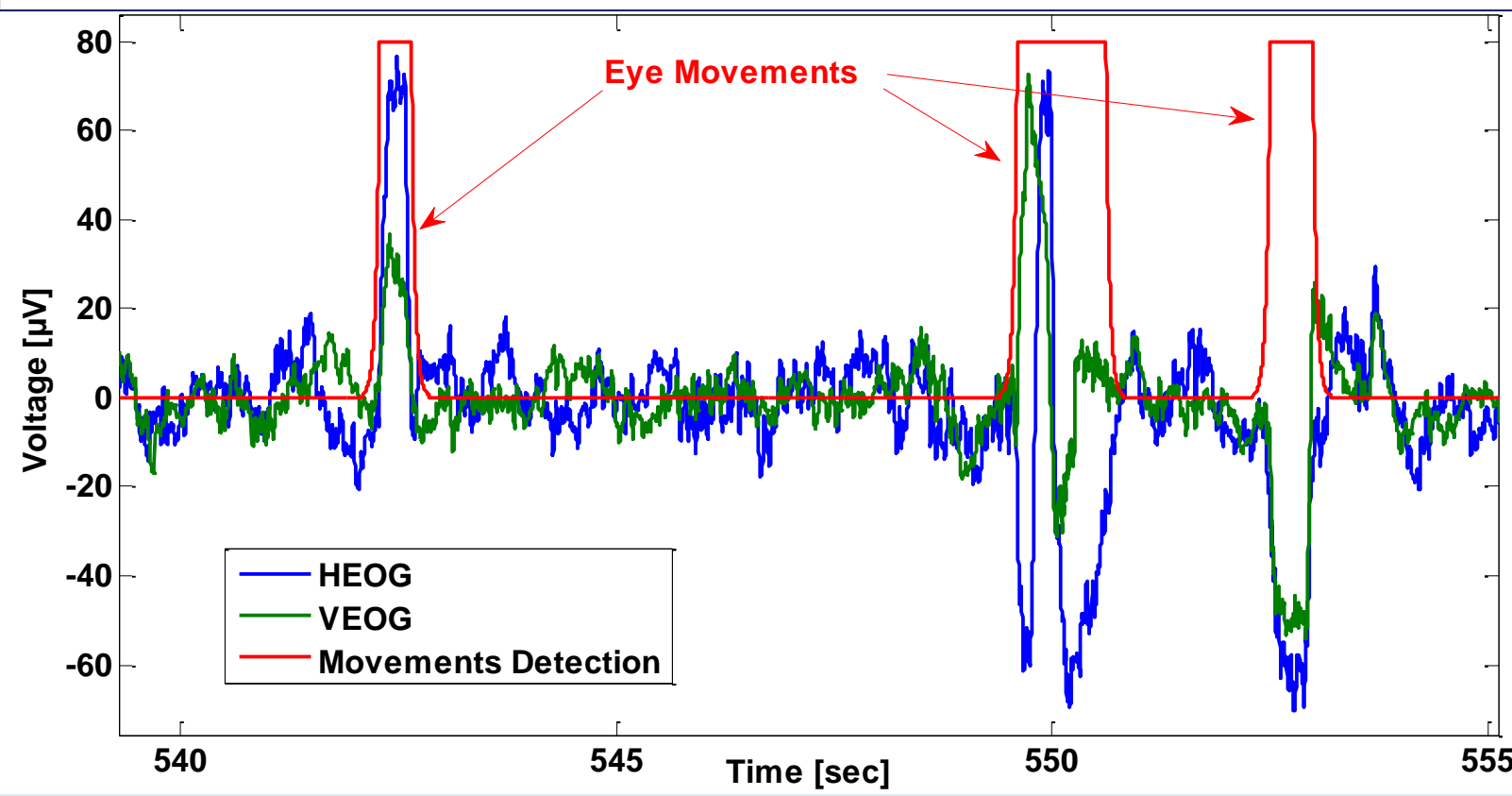
- Wavelet Transform
- Peaks detection
- Features evaluation for each peak pair
- Selection of the pairs fulfilling the constrains
- Merge of concurrent vertical and horizontal detections

### Ocular Artifacts Removal (Adaptive Filtering)



- ✓ More accurate than regression
- ✓ Deal with Non-Stationarity
- ✗ Undesired Removal of Cortical Activity

Integration with the Detection Stage:  
The adaptive filter-based correction was performed only in correspondence of detected eye movements



✓ Minimization of the Brain Activity Removal

### REMs Classification (K-Nearest Neighbors)

Classifier features (Adaptive Sequential Floating Search Methods”, Pudel )

#### Classes of movements

- (1) Vertical
- (2) Horizontal
- (3) Oblique
- (4) Circular

- ✓ Power on the horizontal and vertical EOG derivation, evaluated in different frequency bands
- ✓ Normalized Area in the horizontal-vertical EOG plane
- ✓ Direction of maximum variance (PCA)

#### Inter-Subject Cross-Validation

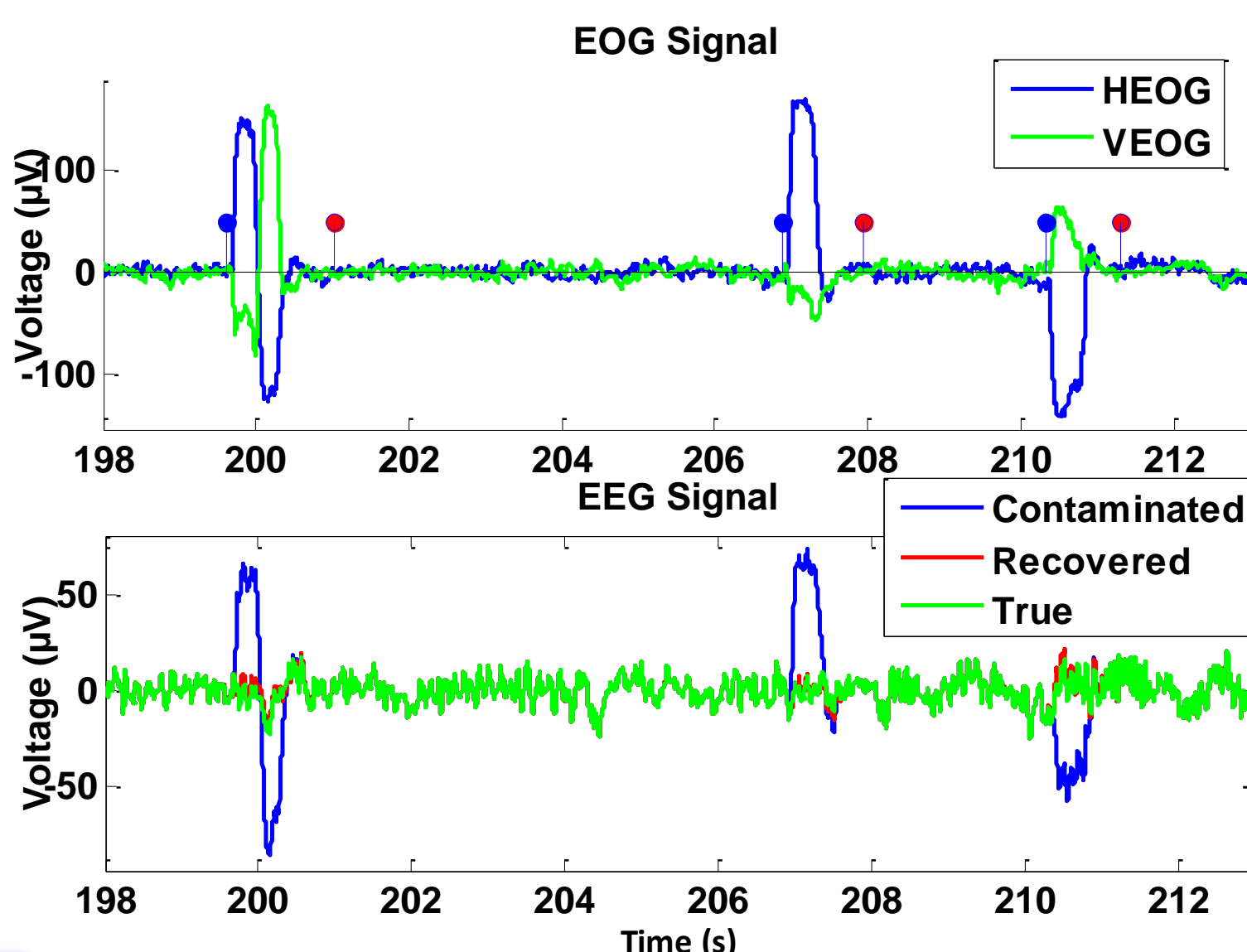
		Nearest Neighbor				
		1	2	3	4	
Output Class	1	175 30.1%	2 0.3%	1 0.2%	15 2.6%	90.7% 9.3%
	2	5 0.9%	139 23.9%	48 8.2%	8 1.4%	69.5% 30.5%
	3	3 0.5%	51 8.8%	83 14.3%	10 1.7%	56.5% 43.5%
	4	9 1.5%	3 0.5%	2 0.3%	28 4.8%	66.7% 33.3%
		91.1% 8.9%	71.3% 28.7%	61.9% 38.1%	45.9% 54.1%	73.0% 27.0%
		Target Class				
		1	2	3	4	

## Validation on simulated REM signals:

#### Effectiveness of Detection Algorithm

$P_c$	$P_m$	$P_w$
94.78%	5.22%	1.8%

- Percentage of Correct Detections ( $P_c$ ) -> Detected Movements/Total Movements
- Percentage of Missed Detections ( $P_m$ ) -> Not-Detected Movements/Total Movements
- Percentage of Wrong Detections ( $P_w$ ) -> Wrong Detection/Total Detections



#### Accuracy in recovering true EEG signals

Comparison between total removal system (first row) and adaptive filters only (second row)

#### Time Domain

$MSE_t$	$MSE_b$	$MSE_a$
0.0122	0.0002	0.0631
0.1159	0.1018	0.2114

“Mean Square Error” evaluated over the whole signal ( $MSE_t$ ), and separately in the intervals where the artifact was present ( $MSE_b$ ) and absent ( $MSE_a$ ).

#### Frequency Domain

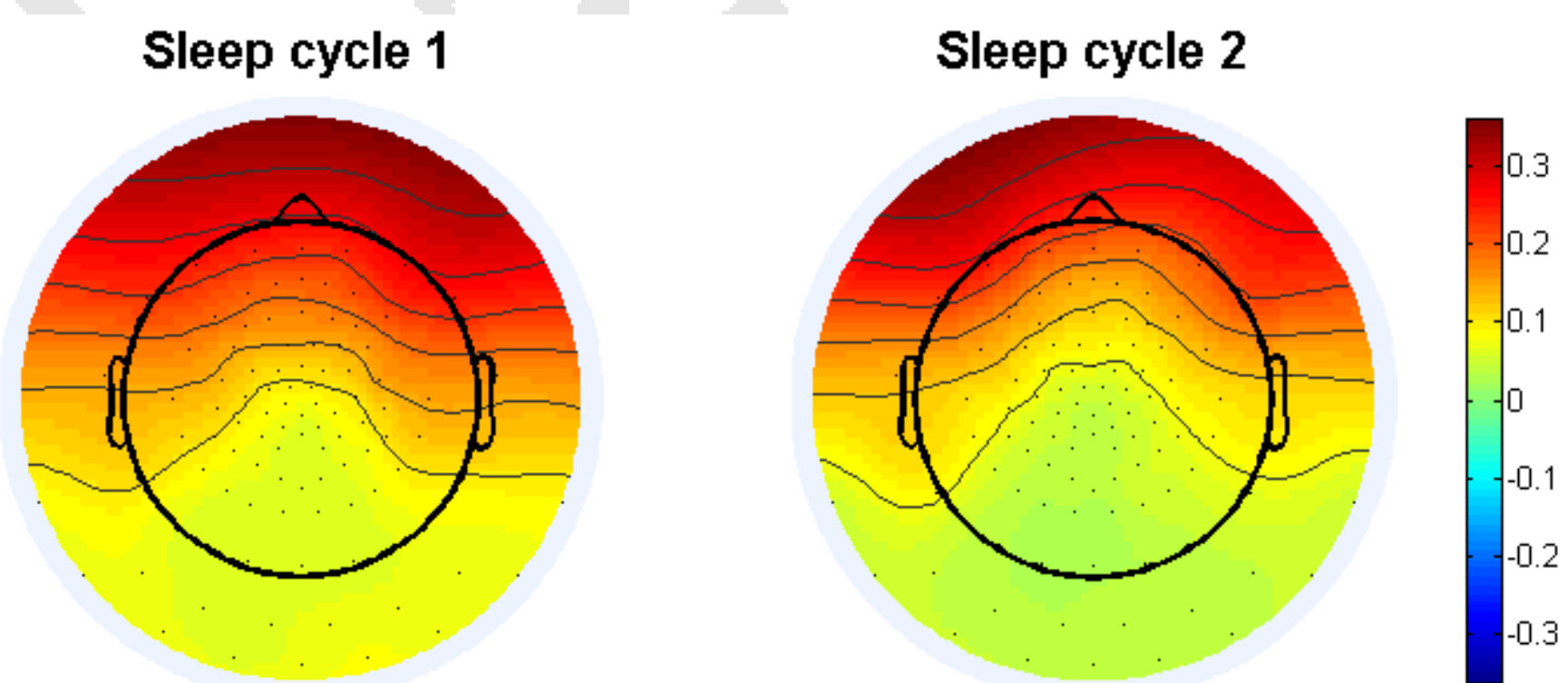
$MAE_\delta$	$MAE_\theta$	$MAE_\alpha$	$MAE_\sigma$	$MAE_\beta$
0.0096	0.0098	0.0114	0.0122	0.0123
0.1506	0.2241	0.2514	0.2926	0.2941

“Mean Absolute Error” evaluated for five frequency bands (0.5-4, 4-8, 8-12, 12-16, 16-25 Hz)

✓ Improved accuracy in ocular artifacts removal

## Application to real data:

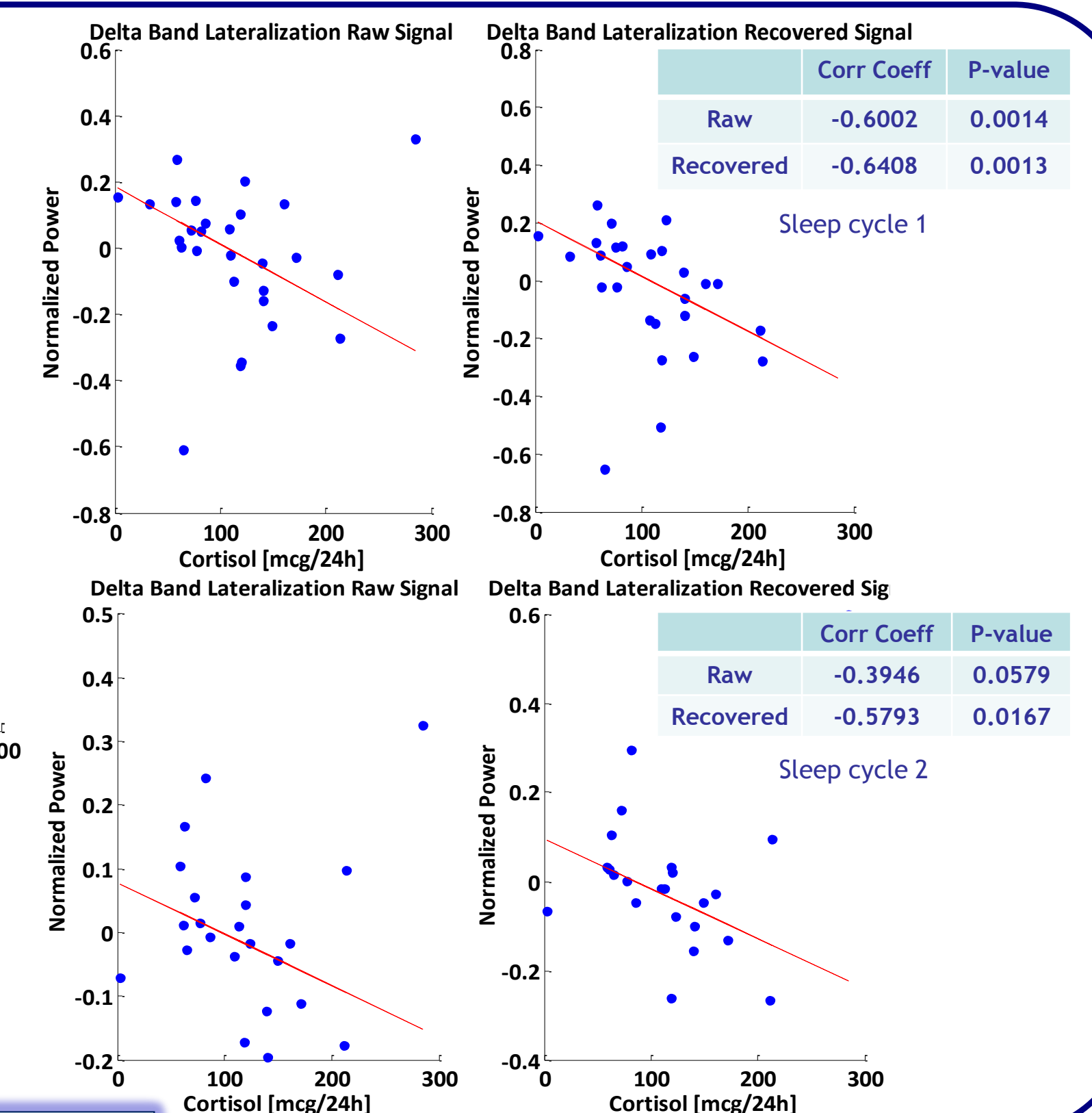
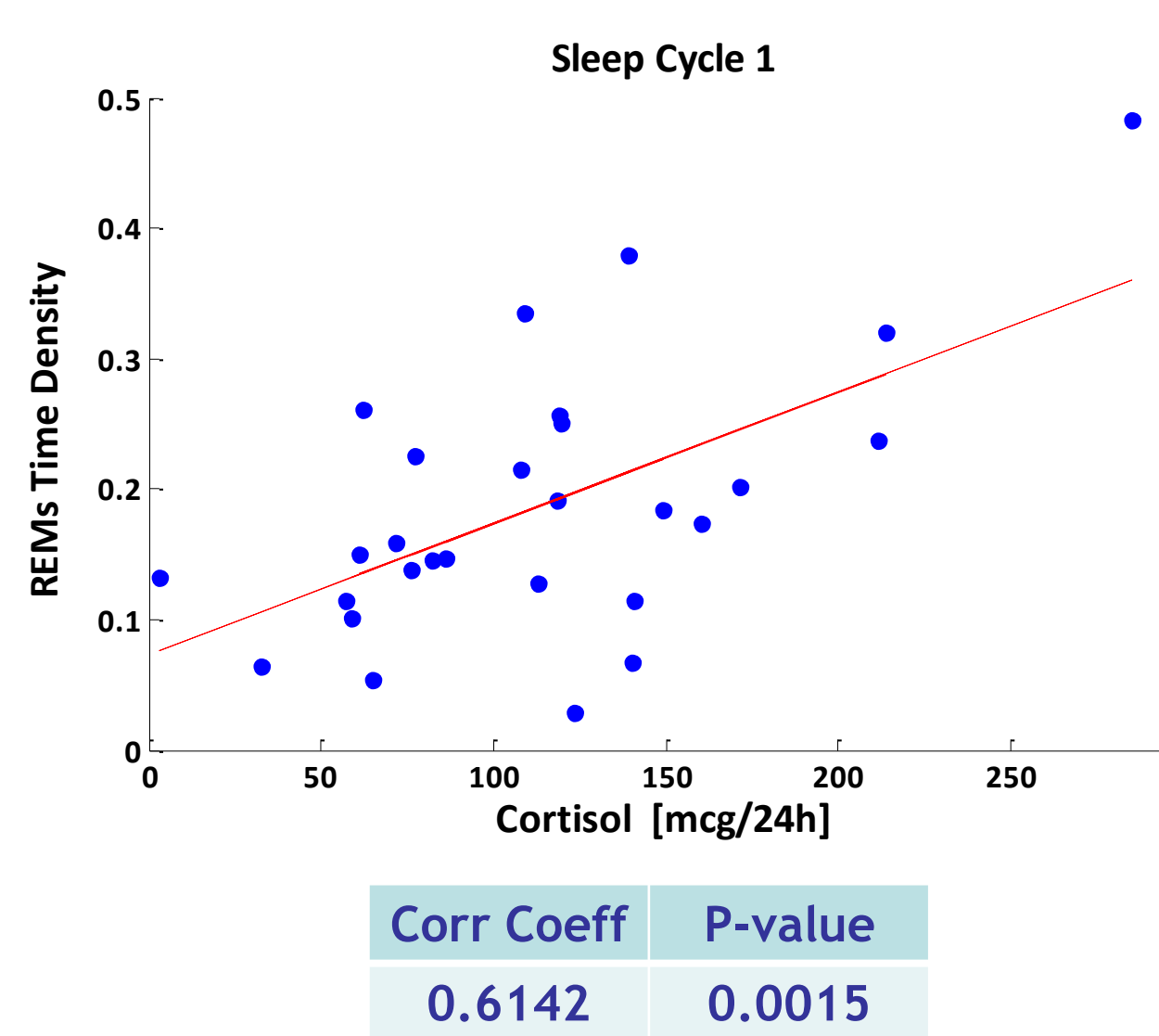
#### Percentages of Power Removed



Channels	Frequency Band					Channels	Frequency Band				
	$\delta$	$\theta$	$\alpha$	$\sigma$	$\beta$		$\delta$	$\theta$	$\alpha$	$\sigma$	$\beta$
Frontal	0.19222	0.05291	0.03975	0.04145	0.04257	Frontal	0.17411	0.04850	0.03645	0.03429	0.04033
Occipital	0.06272	0.00355	0.00305	0.00481	0.00499	Occipital	0.04453	0.00358	0.00314	0.00435	0.00531

✓ Evaluation of the actual Distortion induced by REMs artifacts on brain activity spectrum

#### Correlation with Stress (24h-Cortisol)



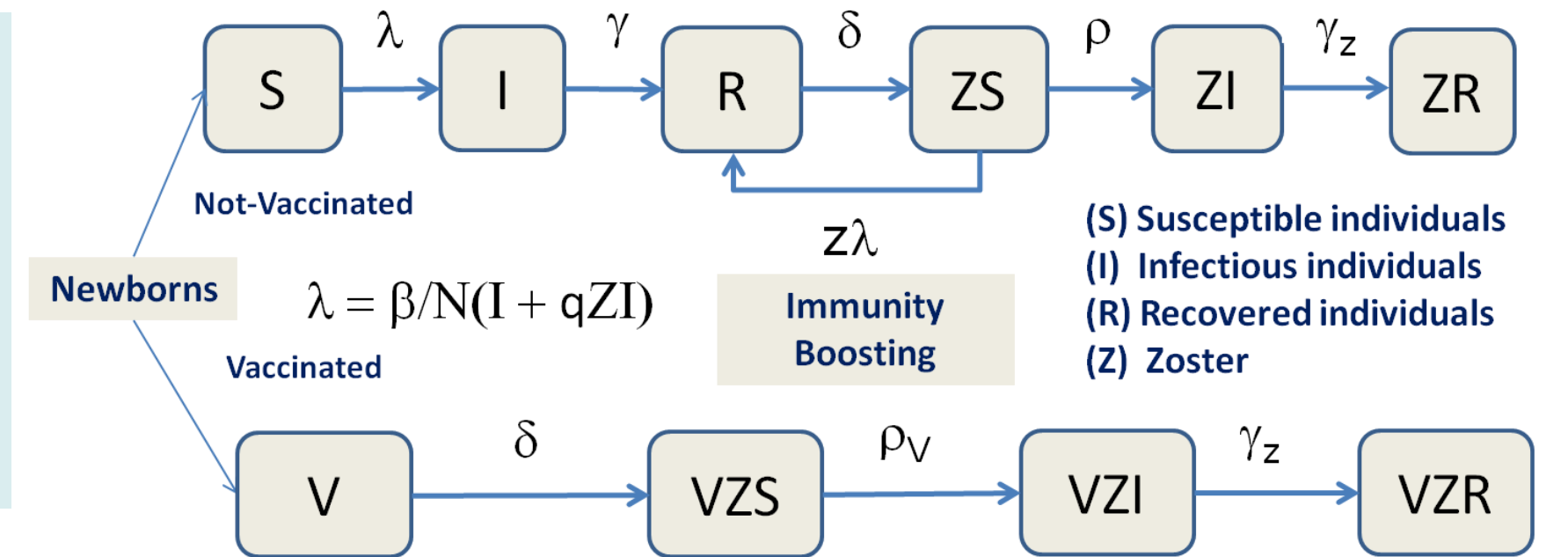
## Future Work:

### Analysis of Functional Connectivity from multi channel EEG (Main Problem-> “Volume Conduction”):

- Analysis of methods using EEG simulated signals derived from artificial networks
- Time evolution of functional connectivity during REM sleep episodes
- Comparison with results during wakefulness
- Cortical connectivity correlation with autonomic activation during REM sleep

## Other Activities:

Optimal Control of Varicella and Herpes Zoster disease by mass routine Varicella Vaccination



Box Modeling via ACE/ASE model for Glycemic Control in diabetes