Neural Correlates of Human Performance

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Outline

- Introduction
- Independent components of the EEG
- Tonic and phasic EEG correlates of task performance
- Independent neuromodulators of components
- The effects of arousing feedback on subject behaviors and the EEG
- Cognitive-state monitoring and management

EEG Correlates of Neurocognitive Performance

- Lapses of attention or drowsiness can lead to catastrophic incidents for ship, air, truck, rail, or plant operators, air traffic controllers, security officers, and workers in many other occupations.
- The US National Highway Traffic Safety Administration (NHTSA) reported that ~25% of police-reported accidents were related to driver inattention.
- National Sleep Foundation (NSF) reported that 60% of adult drivers had driven a vehicle while feeling drowsy and 37% had actually fallen asleep.

EEG Correlates of Human Performance during Sustained Attention Tasks

Study	Task(s); Measure(s)	Electrode Sites or Brain Regions	δ	θ	α	β
Badia et al. (1994)	Sleep onset	F3, C3, O1		+	+/-	
Baulk et al. (2001)	Simulated driving task in an immobile car, secondary auditory detection task; lane crossing incidents, RT, Karolinska Sleepiness Scale (KSS)	C3-A1		+	+	
Beatty et al. (1974)	Radar monitoring task; target detection time	O1-P3		+		
Belyavin and Wright (1987)	Visual vigilance and letter discrimination tasks; RT, error/missing rate	P3-O1, P4-Oz	+	+	+	-
Campagne et al. (2004)	Simulated driving on mobile platforms; running-off-road incidents, speed variations	F3, C3, P3, O1 (C3, P3 shown)		+	+	
Cantero (1999)	Sleep onset	19 EEG channels		*		
Eoh et al. (2005)	Simulated driving task (static); number of accidents and lap time per cycle	Fp1, Fp2, T3, T4, P3, P4, O1, O2		+	+	-
Gillberg et al. (1996)	Simulated truck driving; mean speed, S.D. of speed, S.D. of lane position, KSS, RT	C3-A2, O2-P4		*	*	
Harrison and Horne (1996)	Multiple sleep latency test (MSLT)	(C3-A2)		+	*	
Hasan and Broughton (1994)	Sleep onset; MSLT	19 EEG channels		*	*	
Horne and Baulk (2004)	Simulated driving task in an immobile car; KSS, lane drifting	(C3-A1)		+	+	
Huang et al. (2001)	Auditory and visual vigilance tasks; correct rate	C3, C4		+	+	
Huang et al. (2008)	Compensatory tracking task; tracking error, reaction time	70 EEG channels; occipital independent components	+	+	+	
Huang et al. (2009)	Event-related lane departure during simulated driving (static); reaction time	256 EEG channels; occipital and parietal independent components	+	+	+	
Jung et al. (1997)	Auditory oddball task; error rate	Cz, Pz/Oz		+	-	*
Kecklund and Åkerstedt (1993)	Real truck driving; KSS, self-rated performance capacity	Cz-Oz		+	+	
Lal and Craig (2002, 2005)	Simulated driving in a static car frame; facial features (from video) of the driver	19 EEG channels	+	+		
Lowden et al. (2009)	Simulated driving on a moving base; speed, lateral position, steering wheel angle, KSS	Fz-A1, Cz-A2, Oz-Pz			+	+
Makeig and Inlow (1993)	Auditory oddball task; local error rate	13 EEG channels	+	+	-	
Makeig and Jung (1995, 1996)	Auditory oddball task, visual target detection; local error rate	Cz, Pz/Oz	+	+	-	*
Makeig et al. (2000)	Compensatory tracking task; tracking error	F3, C4, P4, O1 (C4 shown)	+	+		
Ogilvie and Wilkinson (1984)	Auditory response task; reaction time	Cz, Pz				
Ogilvie et al. (1991)	Auditory response task; reaction time	14 EEG channels (C3, C4 shown)	+	+	-	-
Ota et al. (1996)	Auditory response task; reaction time	18 EEG channels (F1, F2, O1, O2 shown)		+	+/-	
Otmani et al. (2005)	Simulated driving on a mobile base; S.D. of lateral position, steering wheel angle, KSS	F3, C3, P3, O1		+	+	

Many studies have demonstrated EEG correlates of fluctuations in performance during sustained attention task on the order of one second to several minutes.

Objectives of this Study

- To investigate tonic spectral changes during continuous sustained-attention tasks in a realistic environment.

Brain Dynamics

- To explore phasic EEG and behavioral changes induced by land-deviation events, subject responses, or arousing feedback presented to drowsy participants.

- To build a brain-machine interface that can continuously monitor brain dynamics and cognitive states of participants actively performing ordinary tasks in natural body positions and situations within real operational environments.

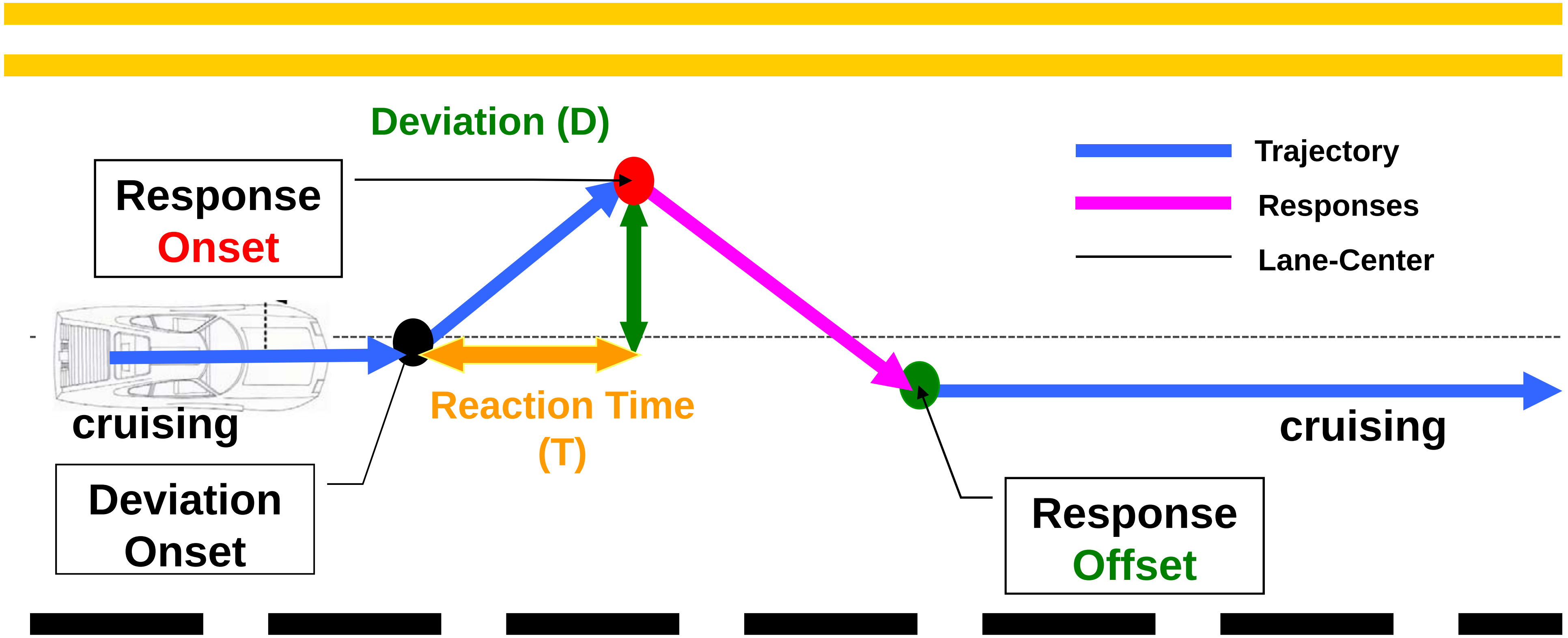
EEG/BCI Application

Driving is a Complicated Task

- Visual Motion Processing (Sensory)
- Visual Spatial Attention
- Sensory-motor coordination
- Vigilance/Alertness
- Error Detection/Correction; Response Selection
- Goal Planning/ Expectation/ Uncertainty
- Navigation (Cognitive Map)
- Divided Attention (Dual- / Multi-Task)
- Vestibular/Kinetic Processing

A VR-based Dynamic Driving Simulator

Paradigm: Single Trials Embedded in Continuous Driving

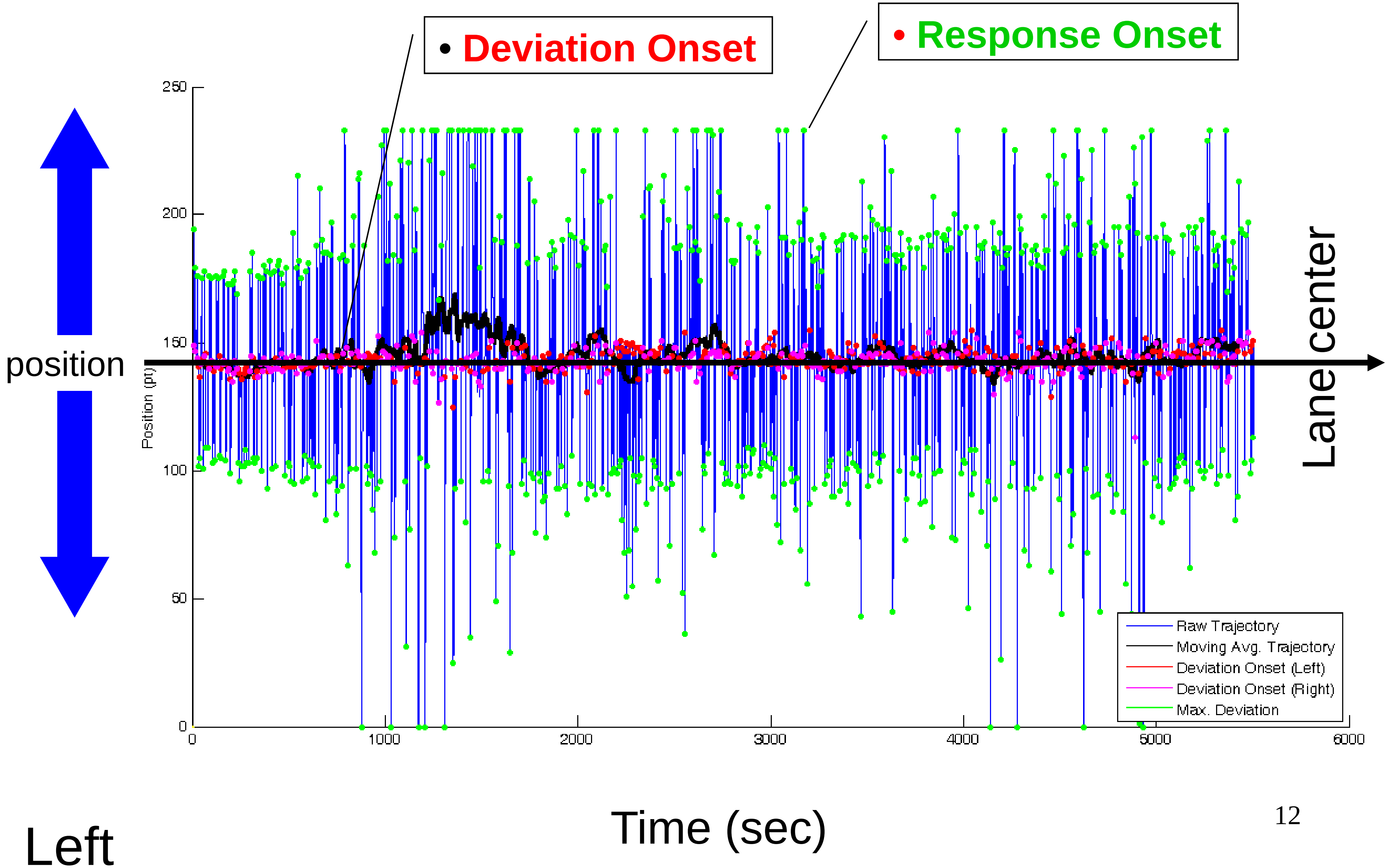


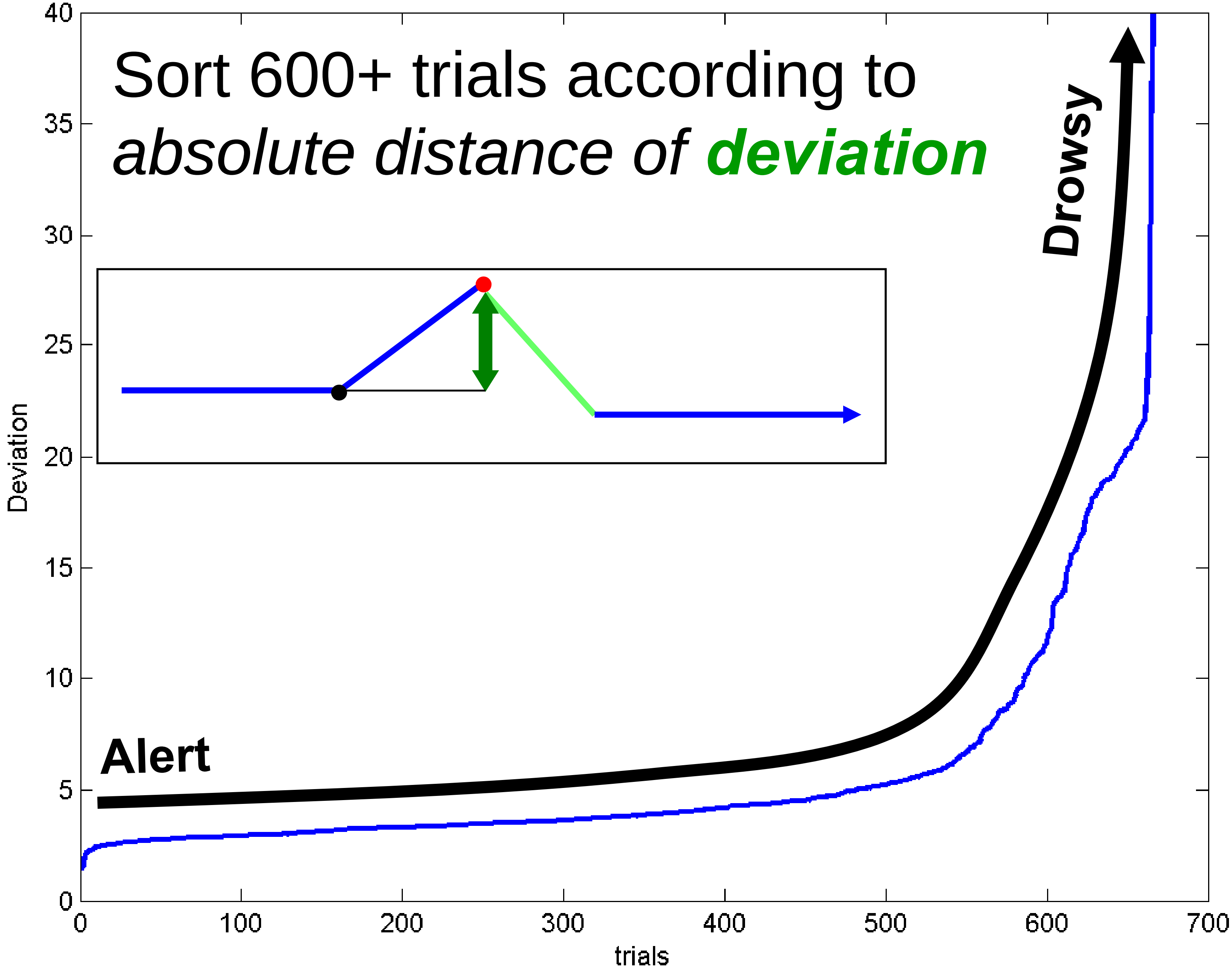
Cruising Speed: 100 km/hr
Linear deviation (D=c T)
Inter-Deviation-Interval: 5 ~ 10 sec
Deviation: 50% leftward, 50% rightward deviation

From Huang et al., 2005, 2007.

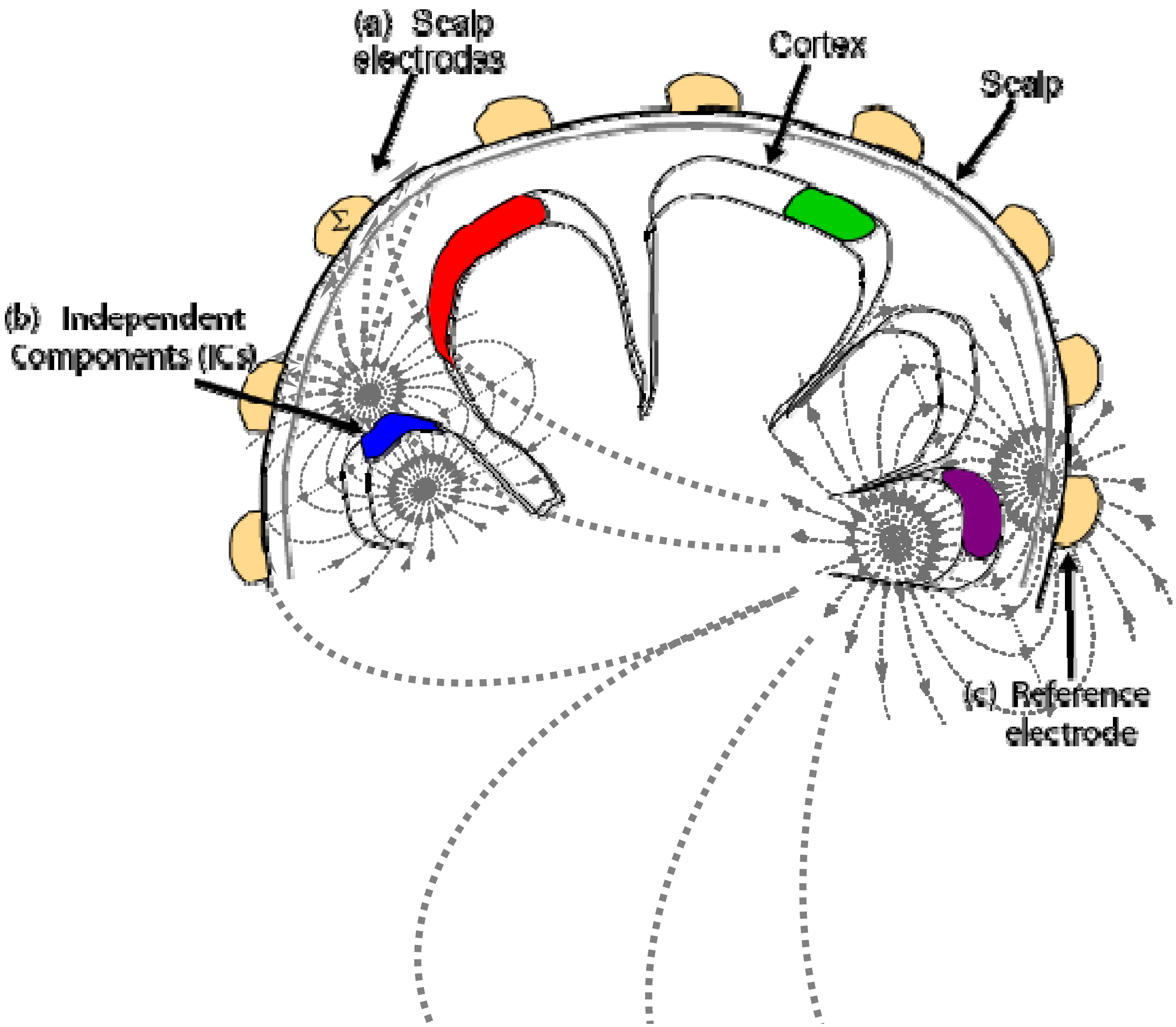
- Data Acquisition: 256-channel (Biosemi system)
- Sampling rate: 256 Hz
- 4 infrared cameras
- Driving simulator (OPEN GL/Performer)
- Scene: An endless straight road at night
- 10 subjects, two 1-hour sessions per subject
- Response: Arrow keys
- Behavioral log: 256 Hz

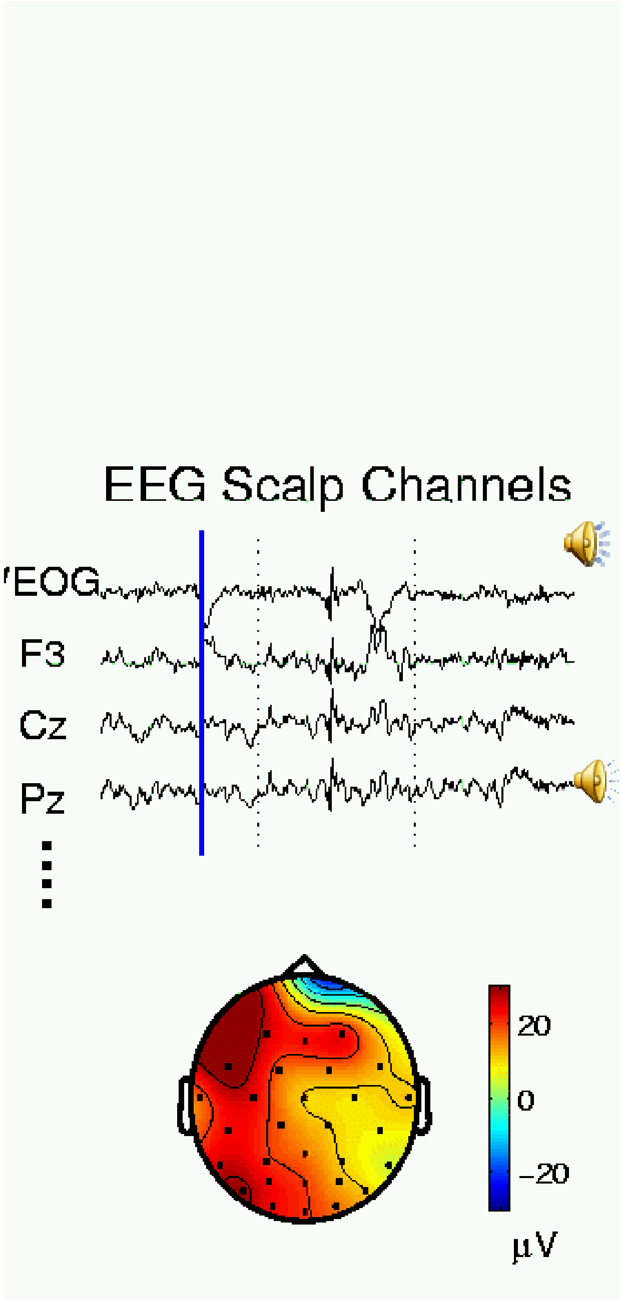
Deviation Trajectory




Sort 600+ trials according to
absolute distance of ***deviation***
Drowsy
Alert
Deviation
trials
0
5
10
15
20
25
30
35
40
0
100
200
300
400
500
600
700

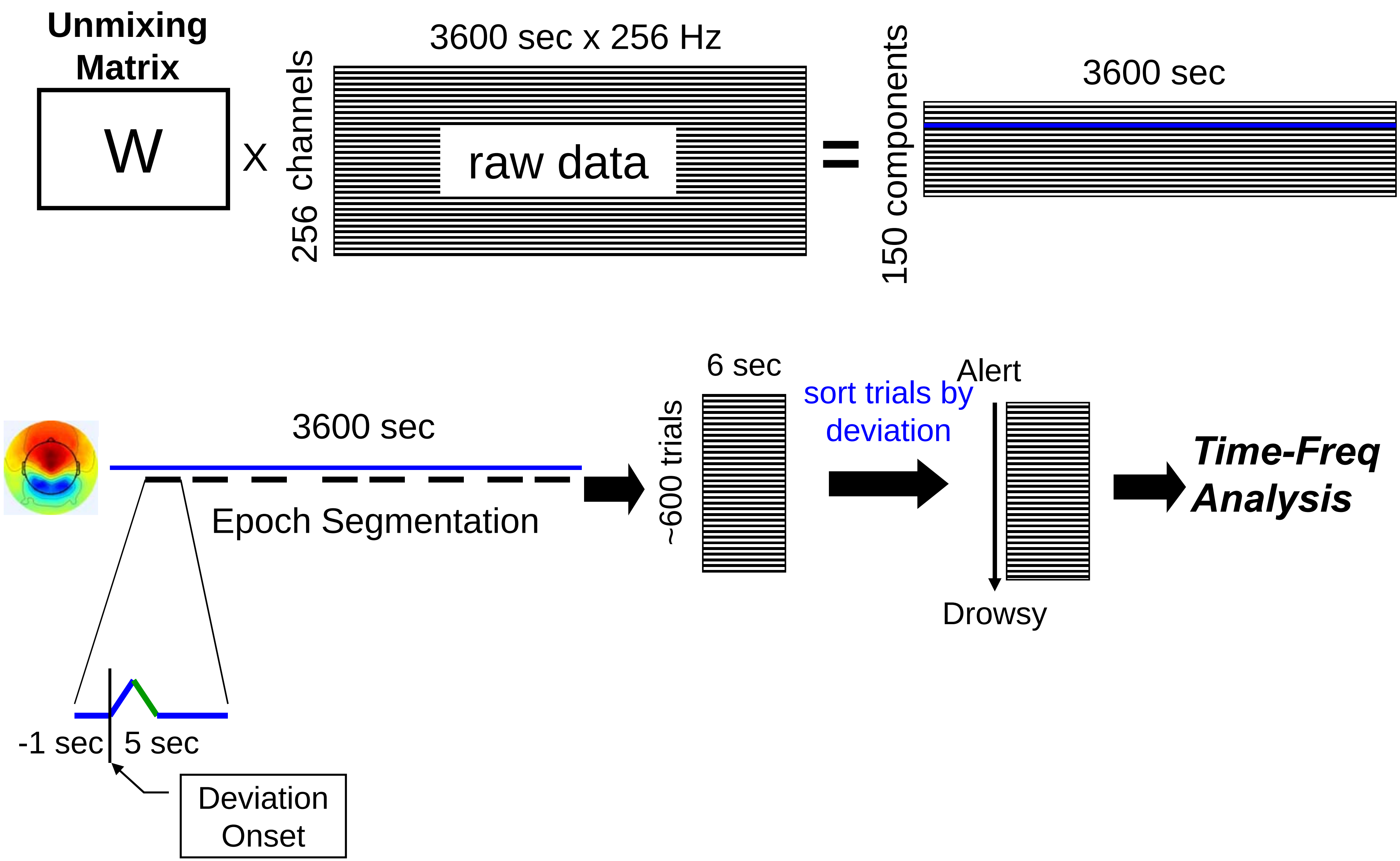
Signal Mixing



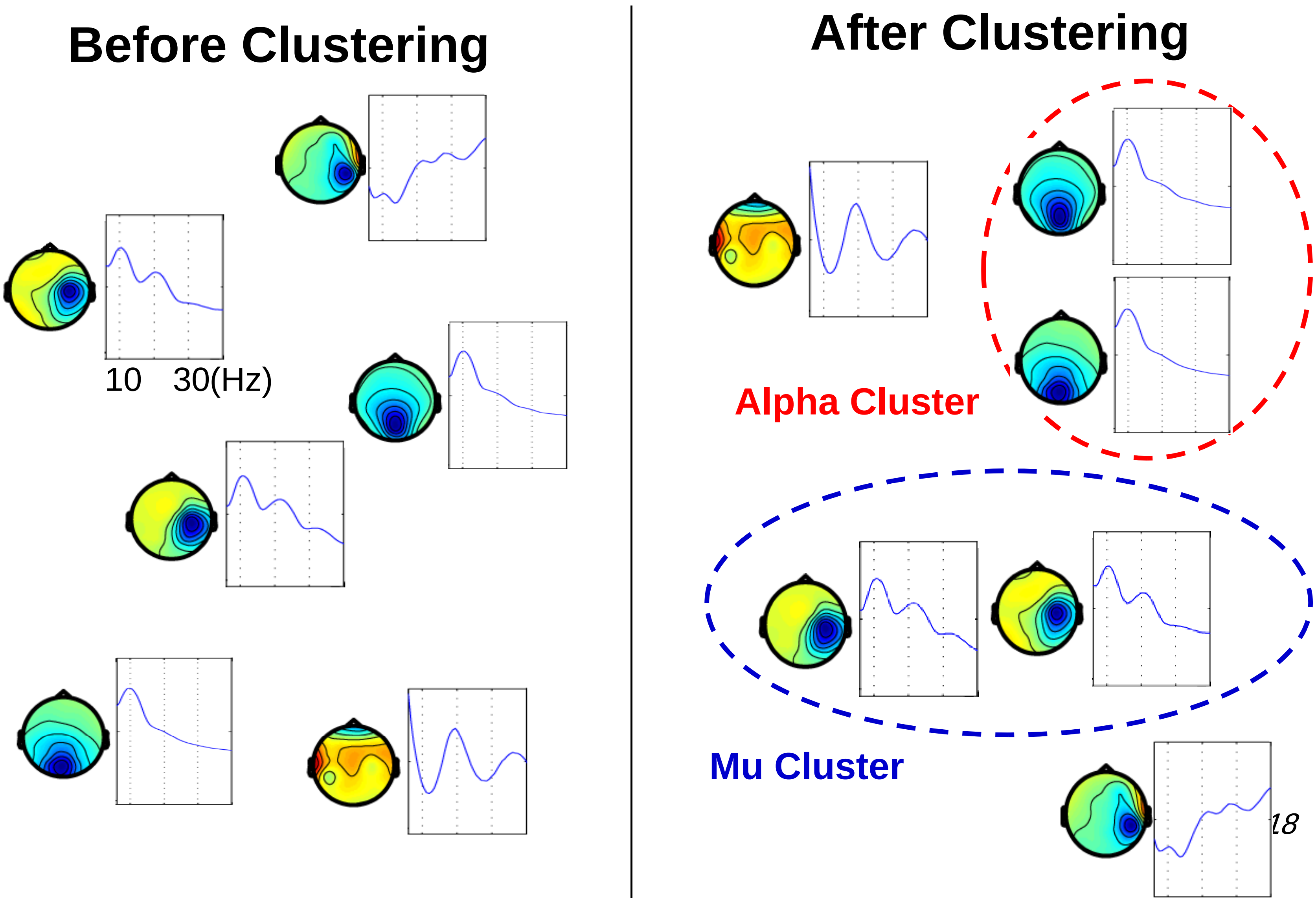


From Jung et al., 2000.

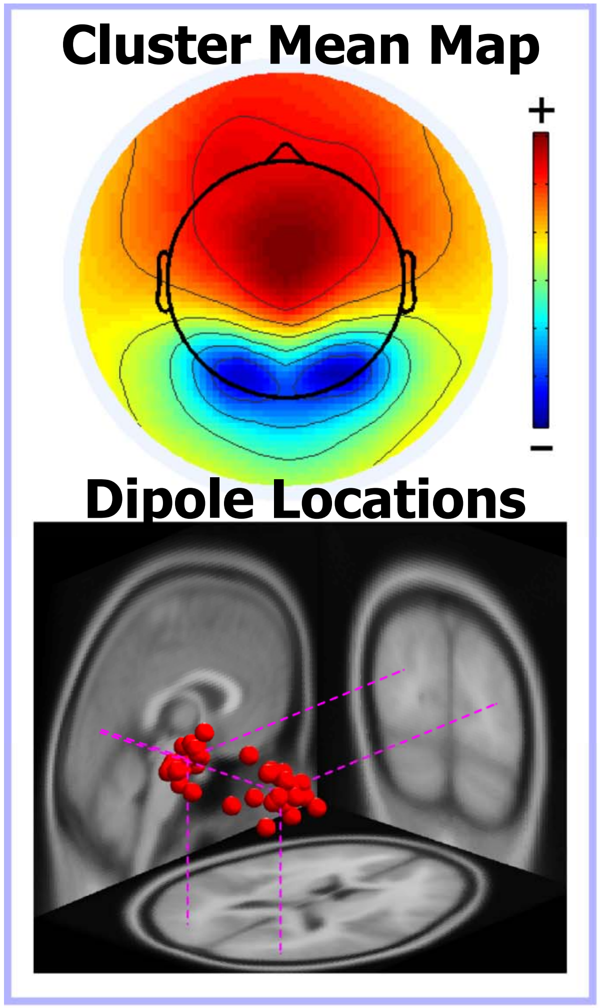
Data Analysis using ICA

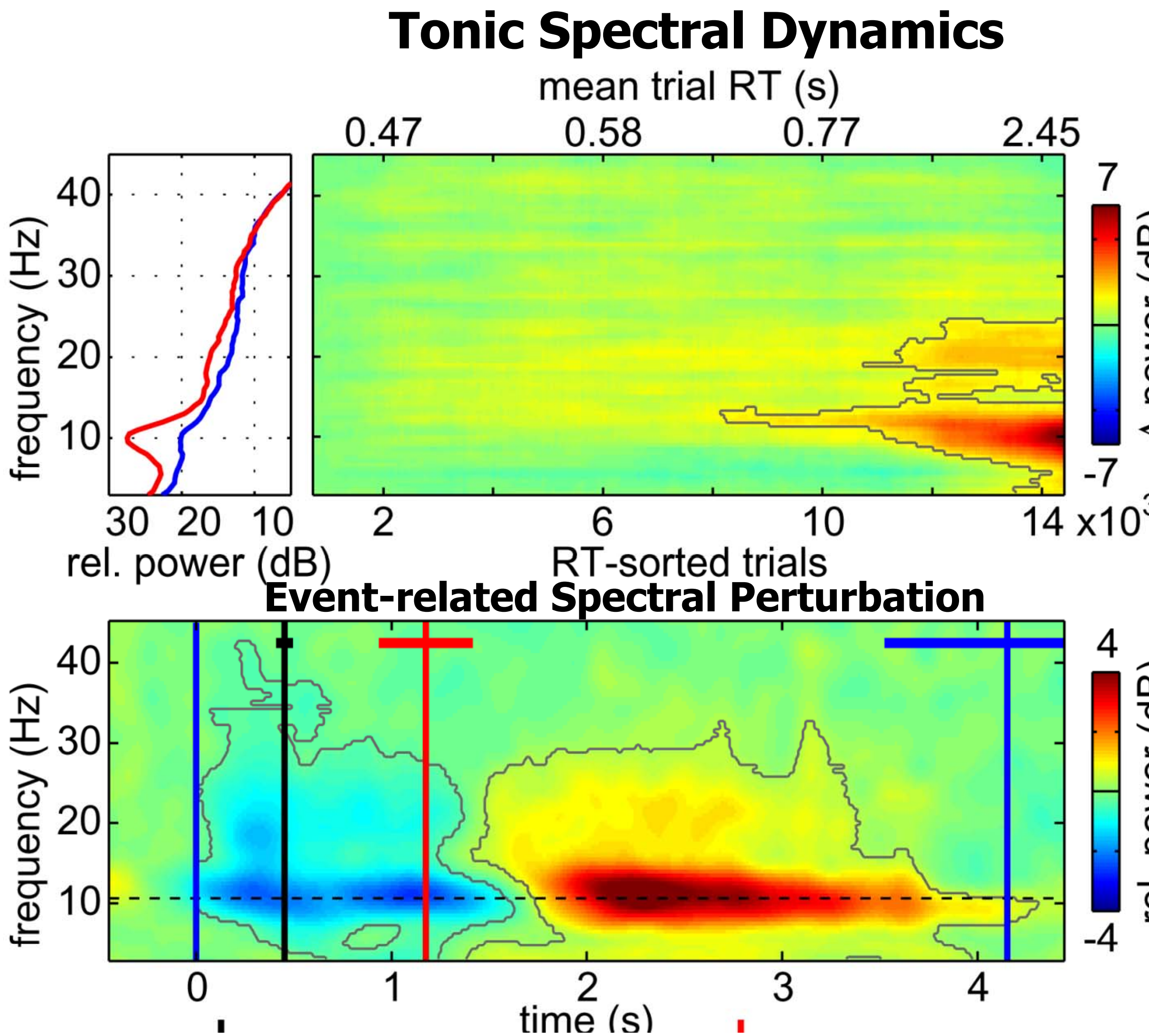


Component Stability: Cross-subject clustering analysis of ICA components



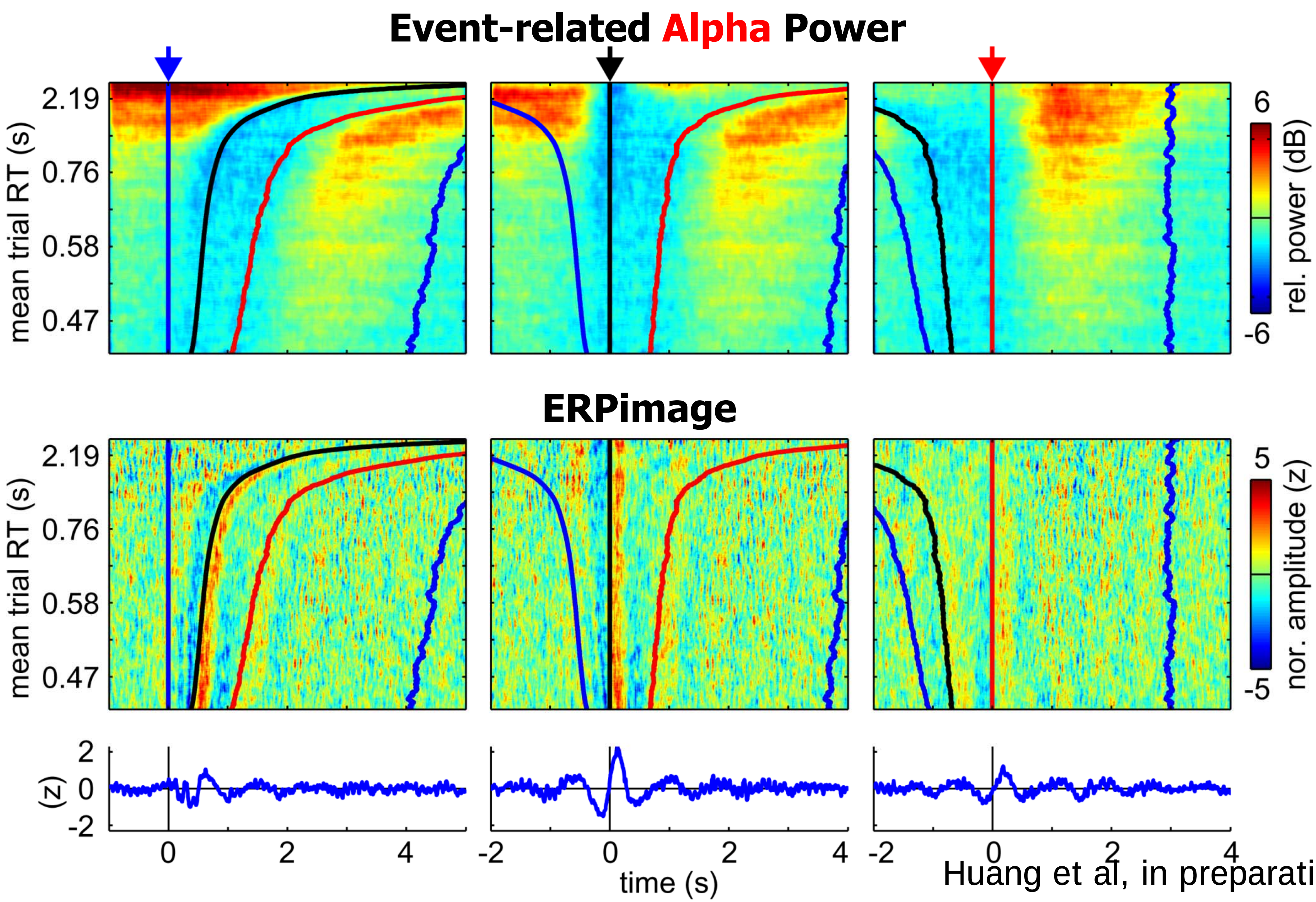
Deviation-induced Brain Dynamics



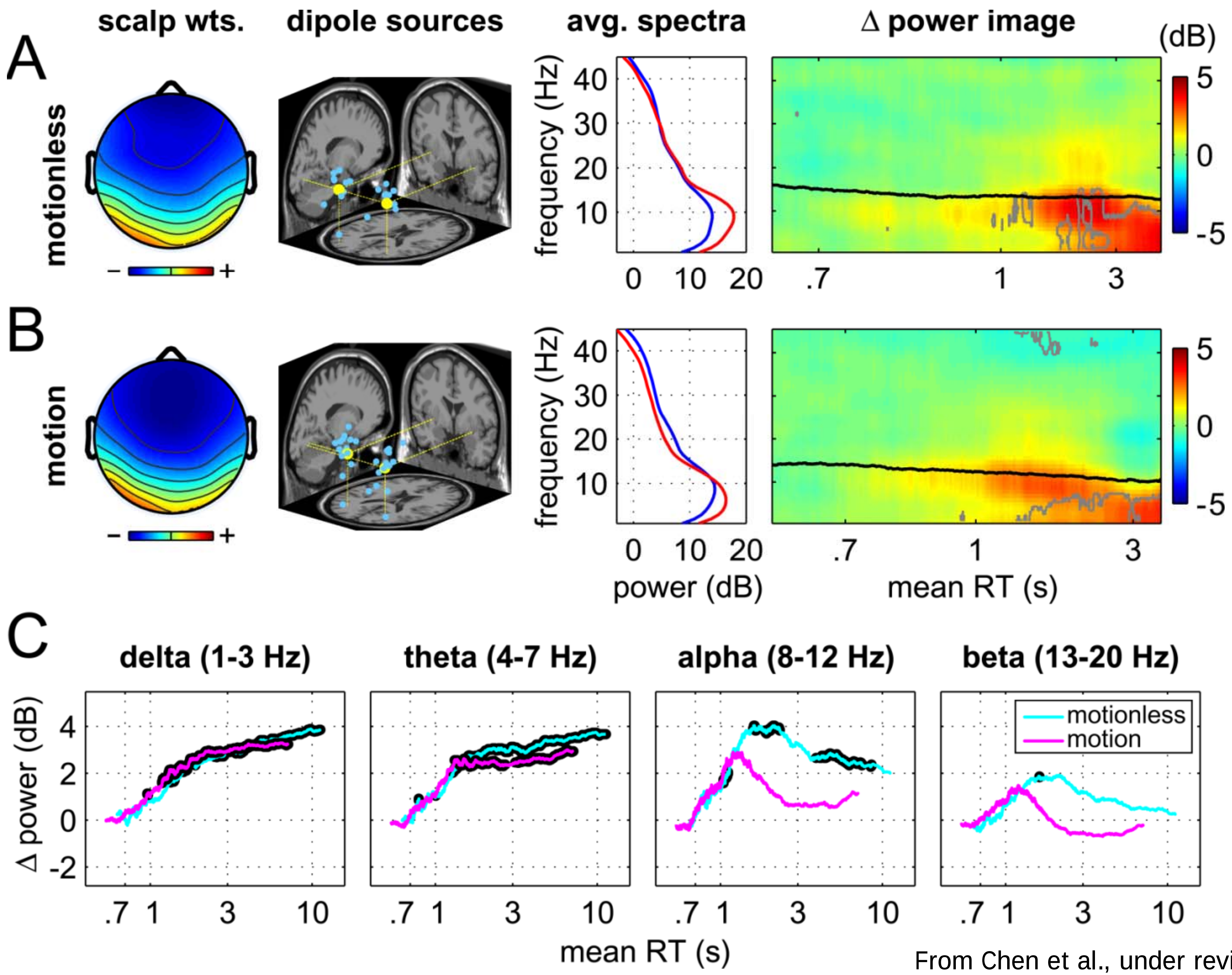


Huang et al, in preparation

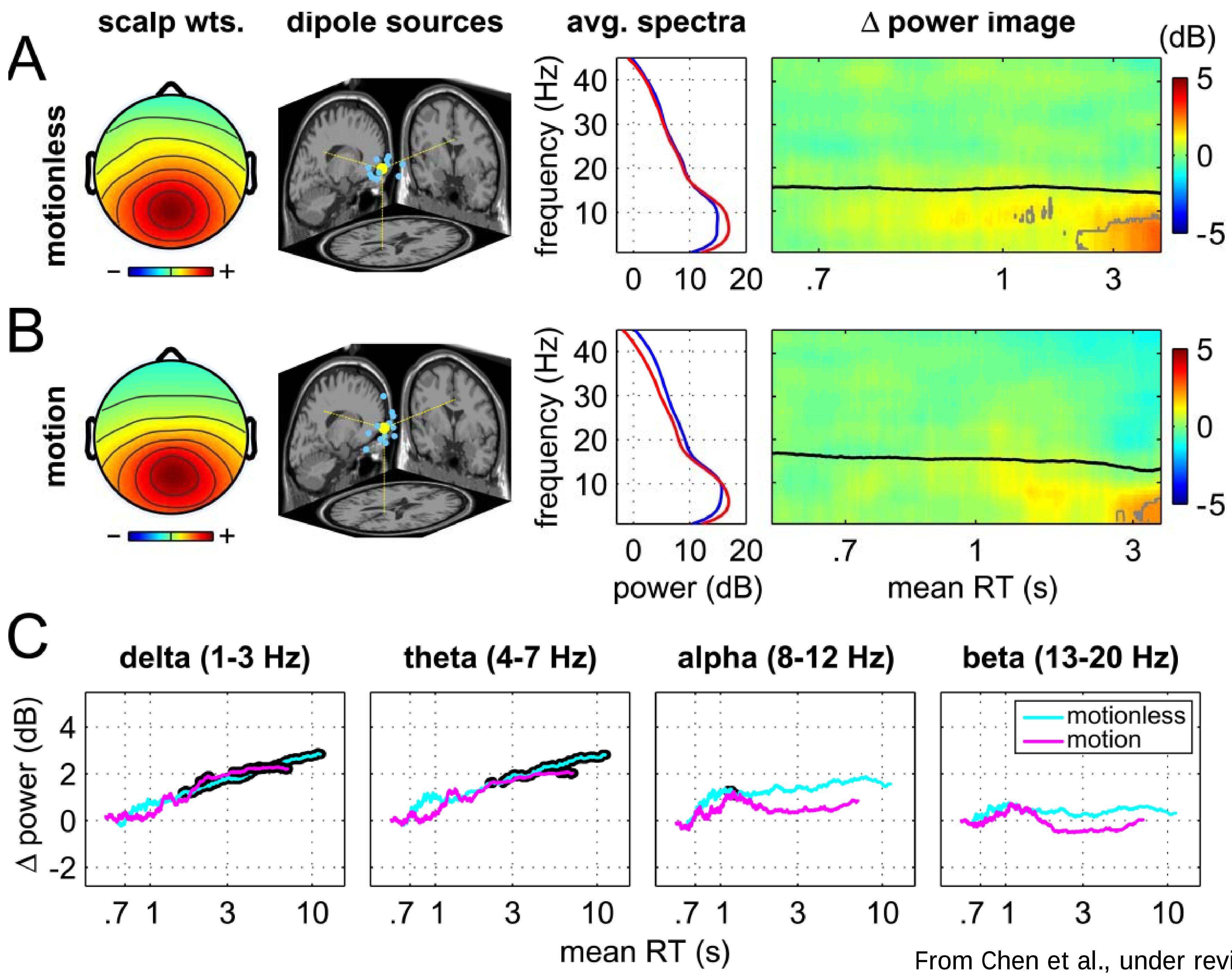
Deviation-induced Brain Dynamics



Huang et al, in preparation

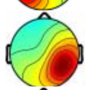
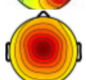


From Chen et al., under review.



From Chen et al., under review.

Spectral Perturbations as a Function of RT

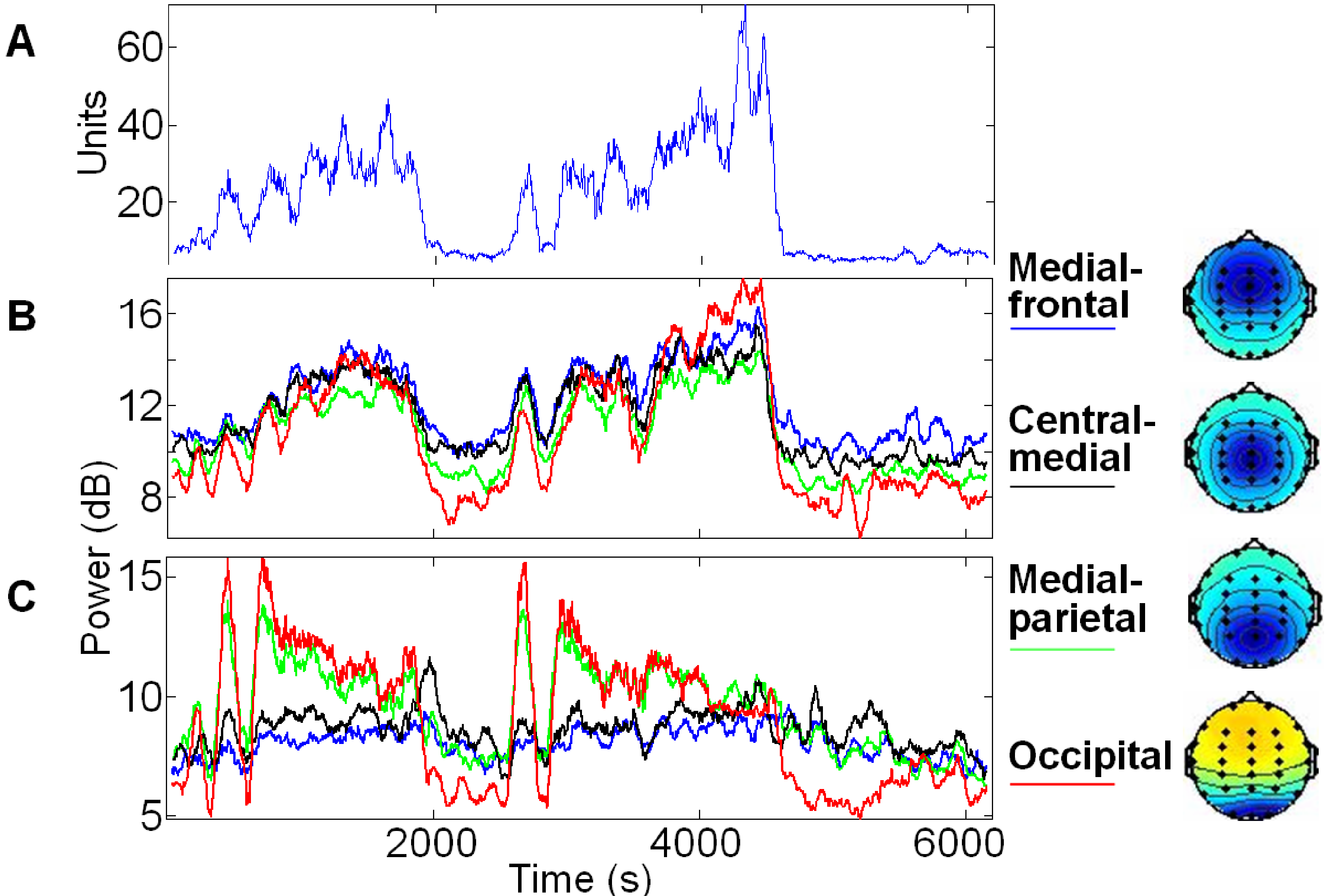
	Trends								
		Motionless				Motion			
	Cluster / Figure	δ	θ	α	β	δ	θ	α	β
	Occipital (bilateral) / Fig. 3	↗*	↗*	↗↘	↗↘	↗*	↗*	↗↘	↗↘
	Occipital (medial) / Fig. S6	↗	↗	↗↘	↗↘	↗*	↗*	↗↘*	↗↘
	Occipital (tangential) / Fig. S8	↗*	↗*	↗↘*	↗↘	↗	↗	↗↘	↗↘
	Medial posterior parietal / Fig. 4	↗*	↗*	—	—	↗*	↗	—	—
	Left somatomotor / Fig. 5	↗	↗	—	—	↗	↗	—	—
	Right somatomotor / Fig. S10	↗	↗*	—	—	↗	↗	↘	↘
	Central medial / Fig. 6	↗*	↗*	↗*	↗	↗*	↗*	↗	↗
	Frontal medial / Fig. 7	↗	↗	—	—	↗	↗*	—	—

↗monotonic increase, ↘monotonic decrease, ↗↘ biphasic trend, — no difference, * power changes significantly different ($p < 0.01$) from mean reference power of each respective frequency band at 3-s RT.

From Chen et al., under review.

Temporal Dynamics of Component Spectra and Subject Performance

Temporal Dynamics of Component Spectra and Subject Performance



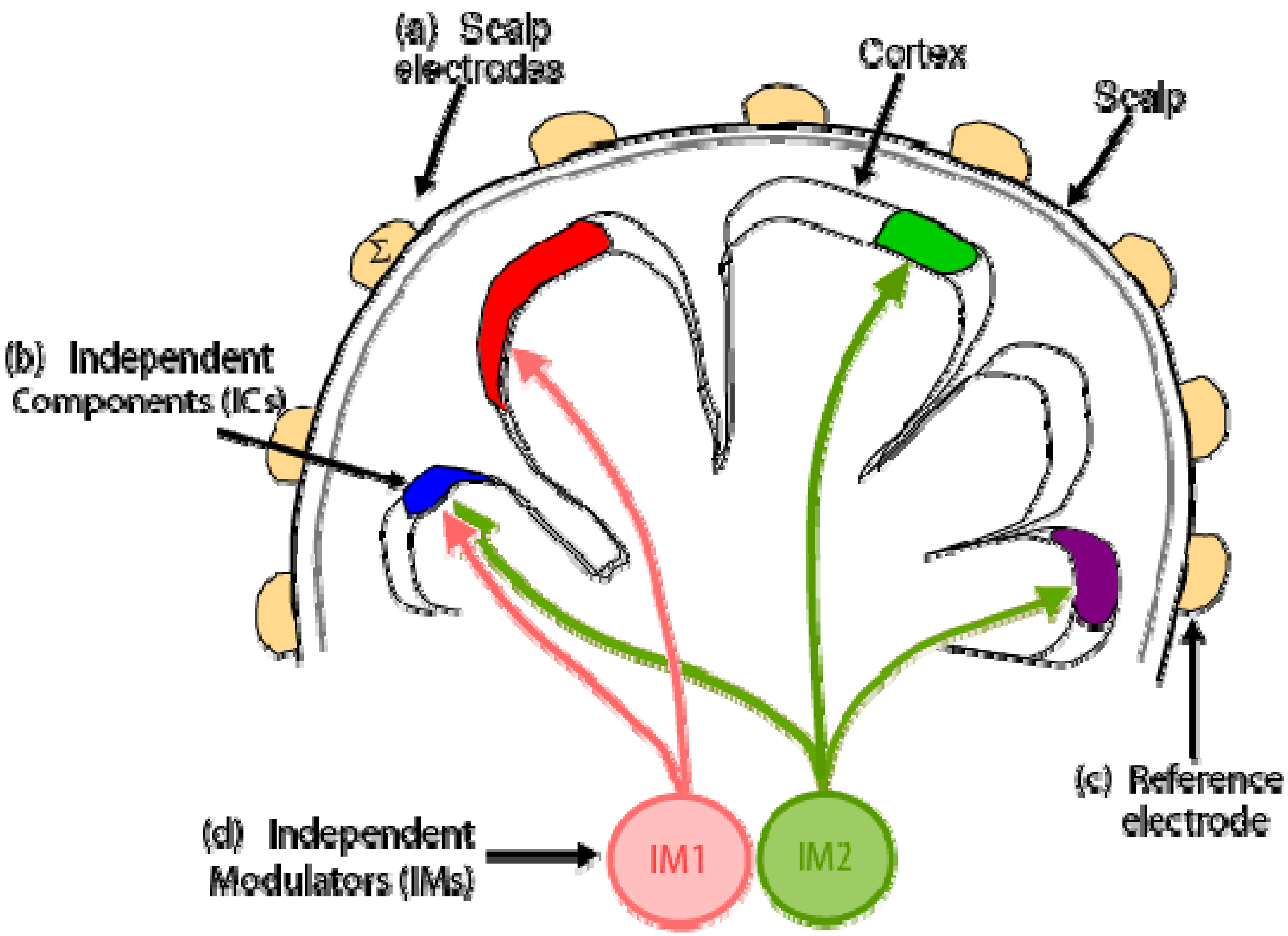
From Chuang et al., 2009.

Hypothesis

There are modulators that mediated spectral activations of the cortical areas by intra-cortical feedback loops, or controlled by thalamo-cortical feedback loops.

Independent Component Analysis

Modulator

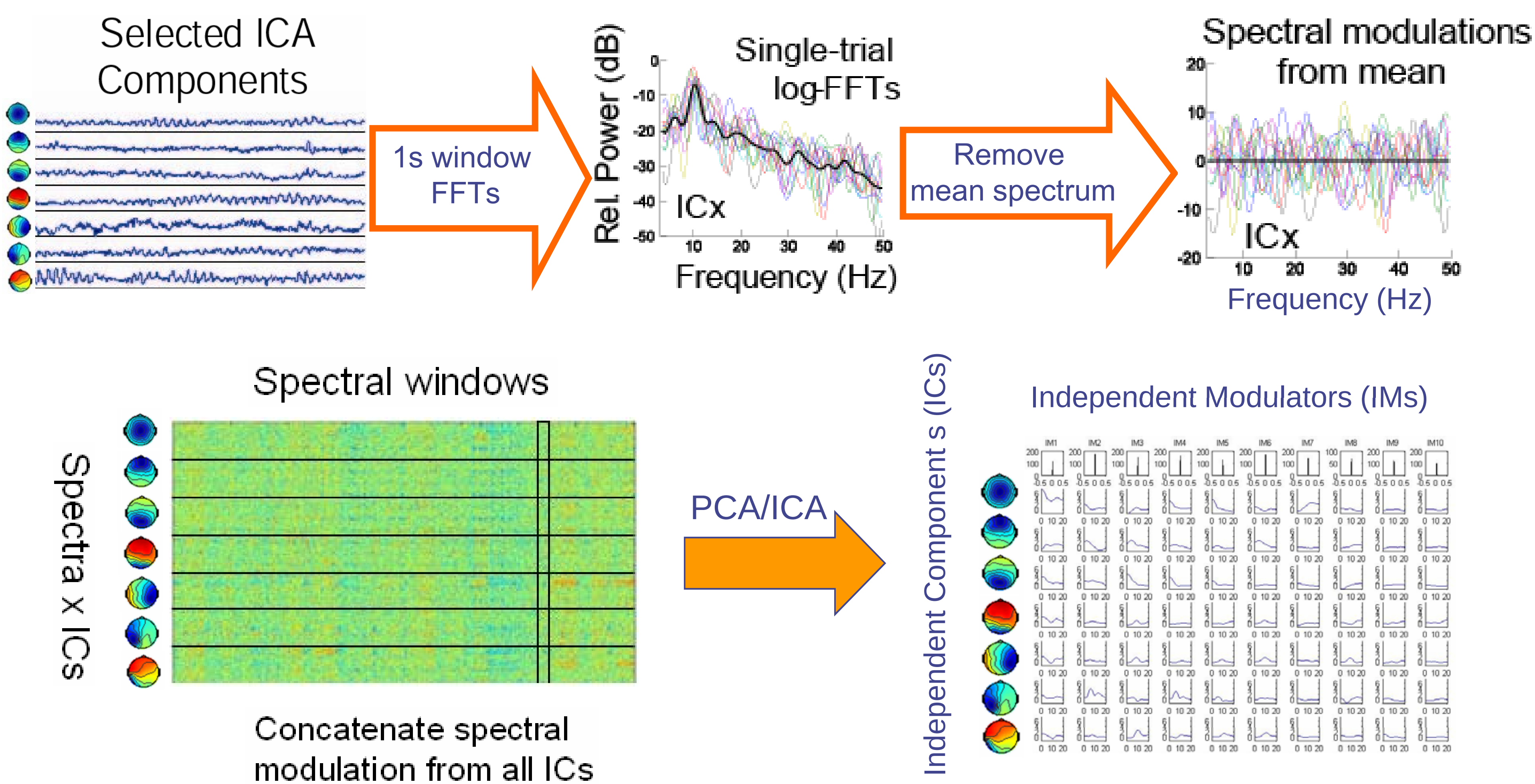


IM：Independent Modulator

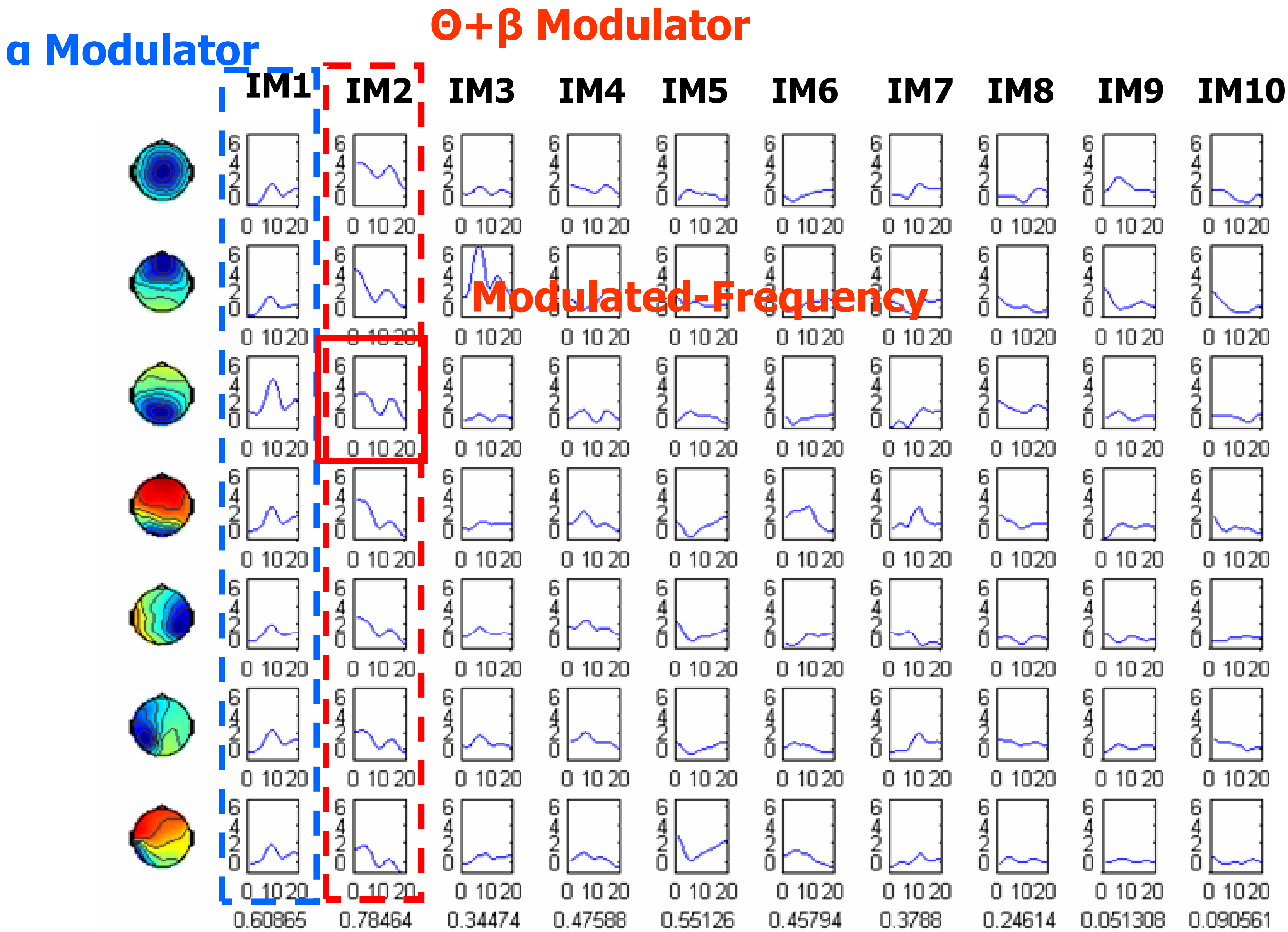
mediates spectral activations of multiple brain areas

From Onton & Makeig, 2006.

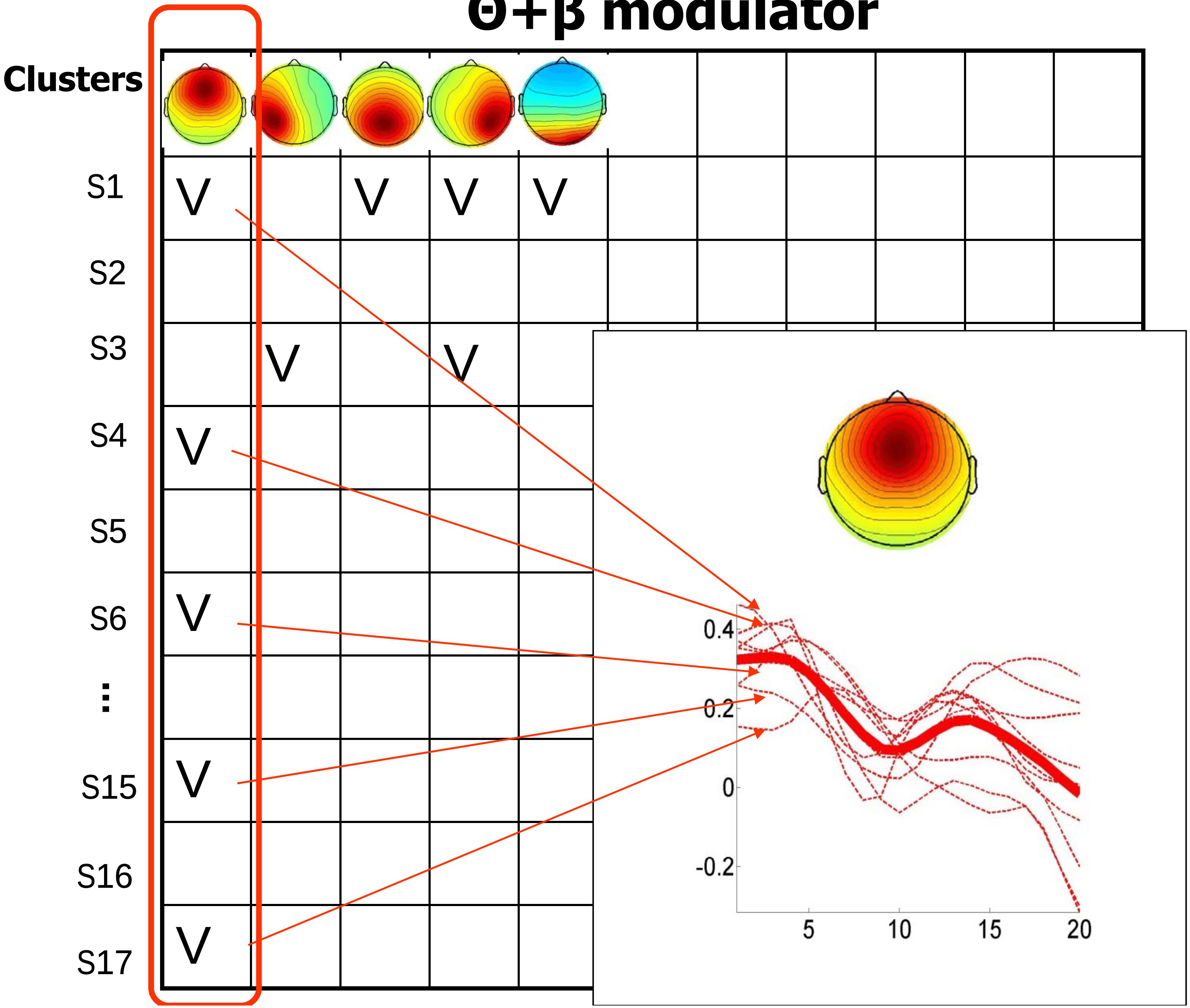
Independent Modulator Decomposition



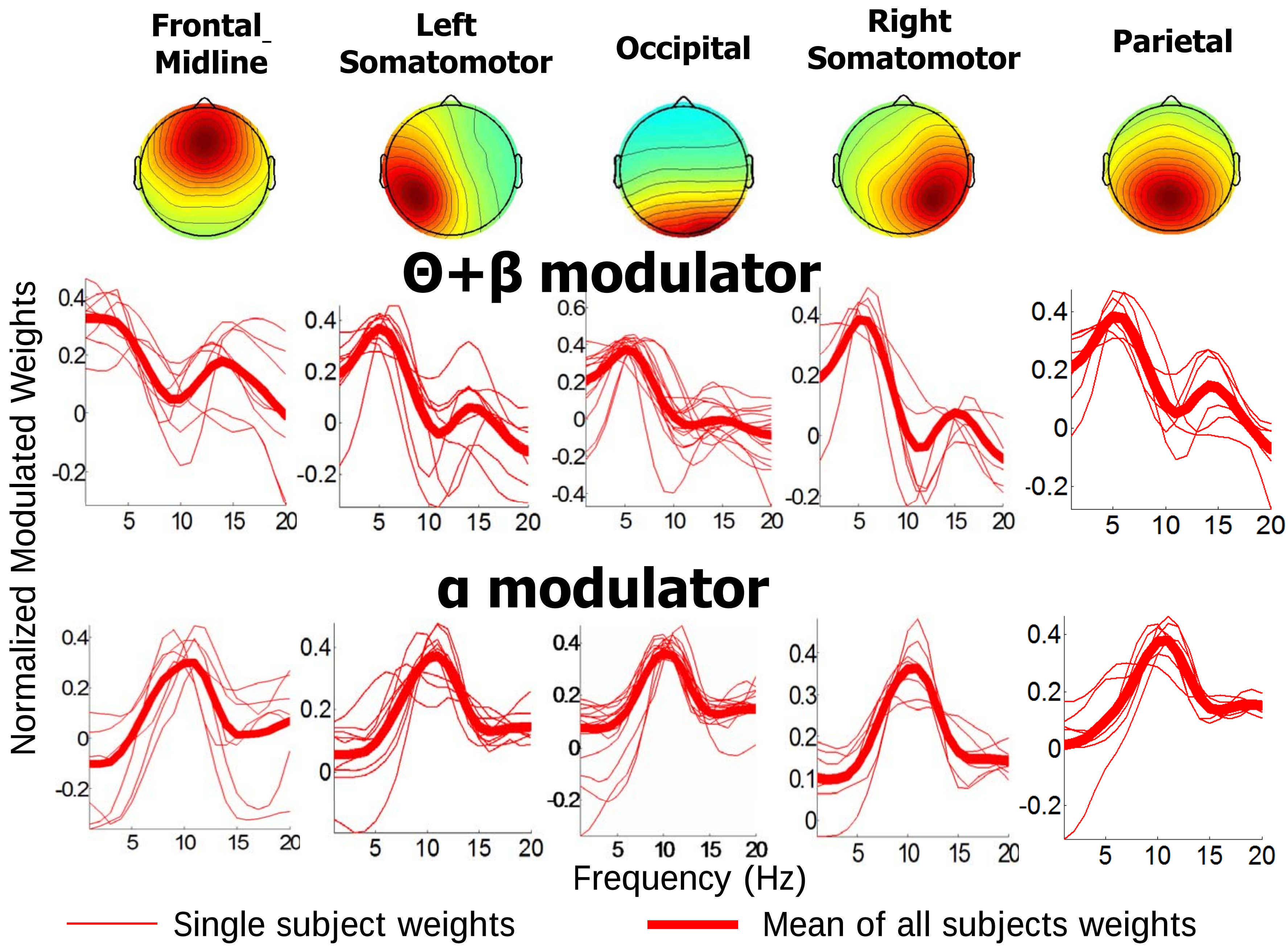
Single-Subject IM Decomposition



Θ+β modulator

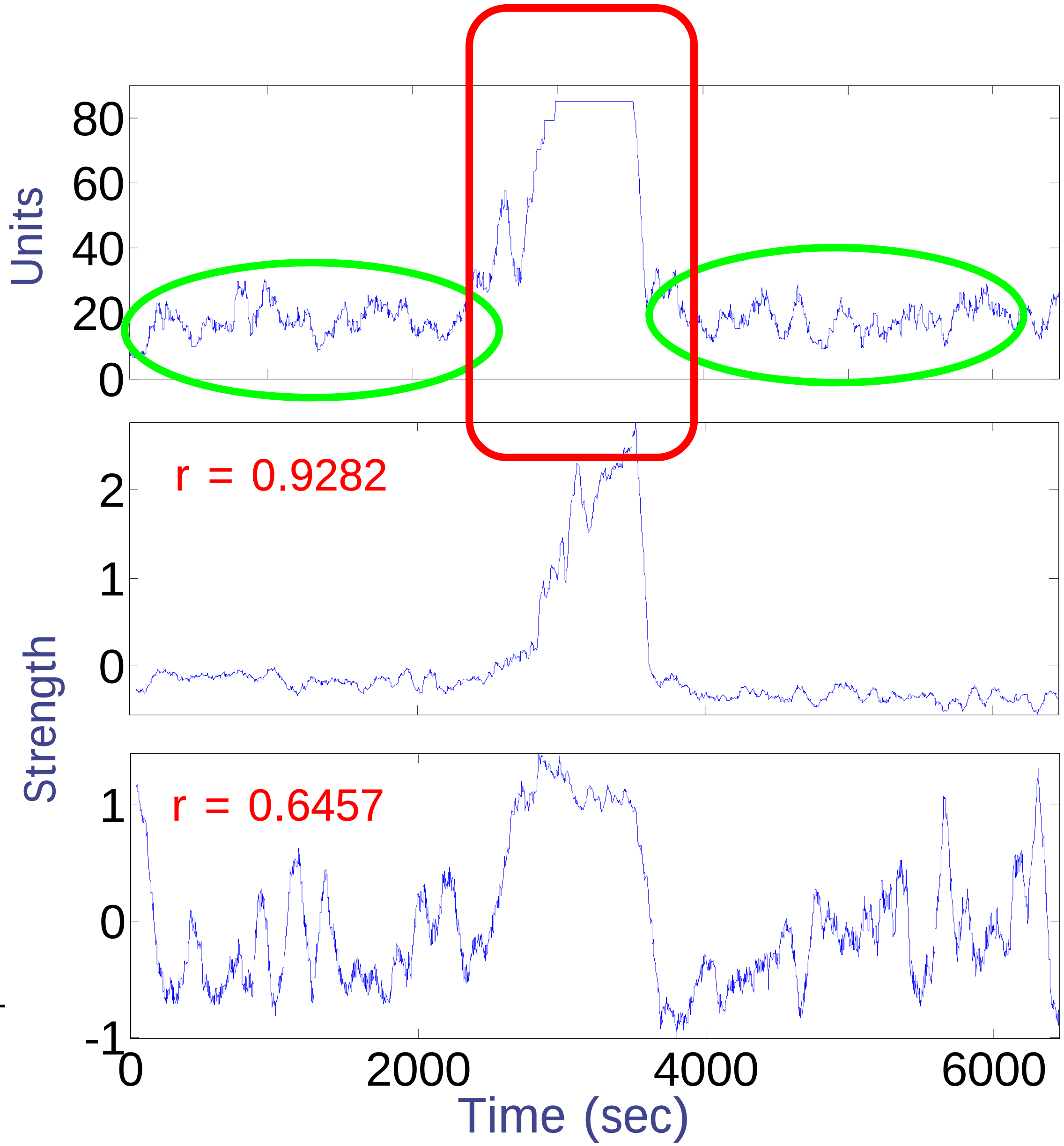


Neuromodulators Medicate Spectral Activations of ICs

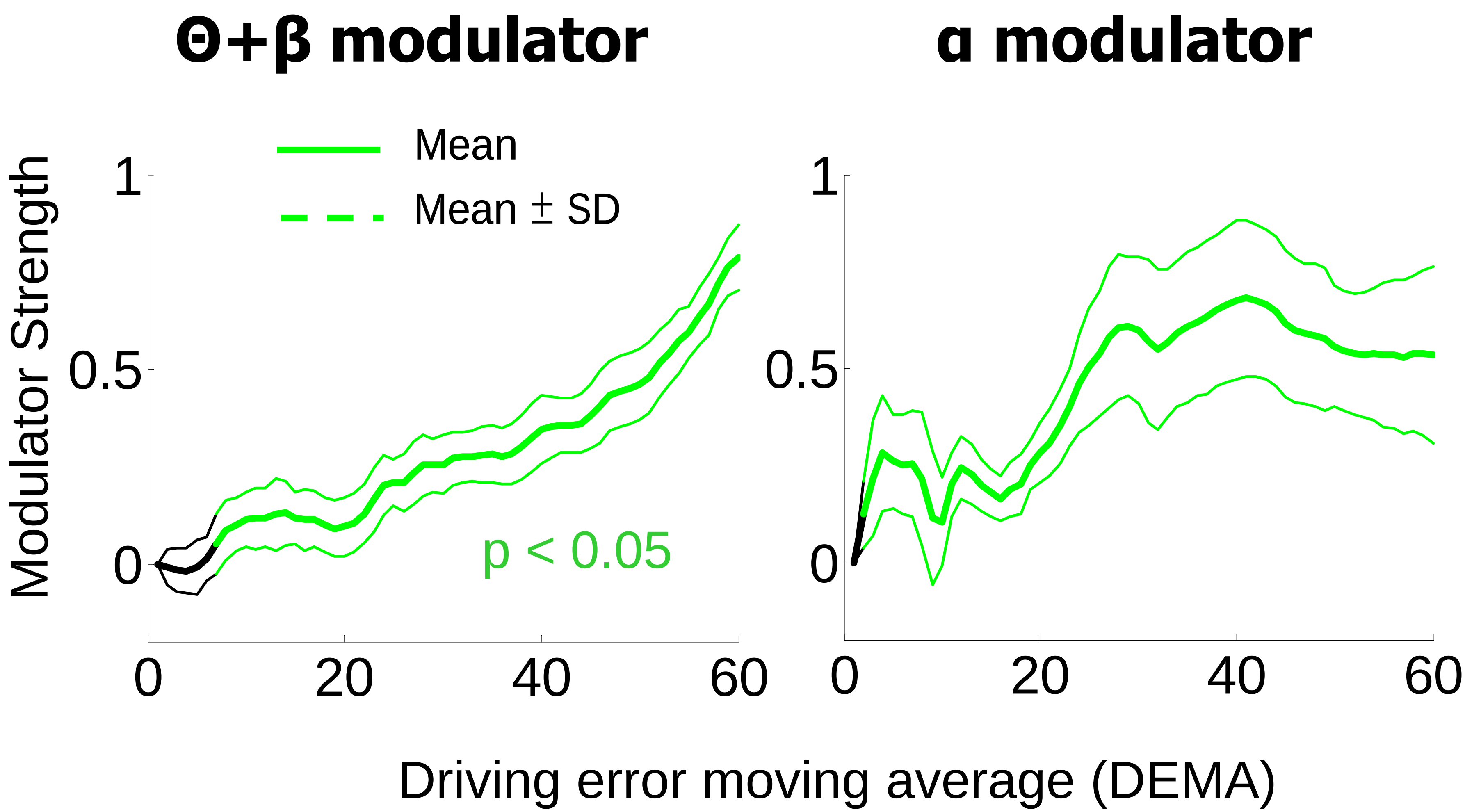


Modulator's Activity vs Driving Performance

	Theta-Beta Modulator	Alpha Modulator
S1	0.7861	0.5713
S2	0.7845	0.6093
S3	0.9433	0.2002
S4	0.8689	0.6619
S5	0.7783	0.5189
S6	0.8201	0.6162
S7	0.9228	0.029
S8	0.8715	0.2748
S9	0.7722	0.3341
S10	0.7957	0.2485
S11	0.8043	0.0831
S12	0.8427	0.683
S13	0.818	0.1898
S14	0.7174	0.5748
S15	0.9282	0.6457
S16	0.9337	0.6186
S17	0.7641	0.5353
Mean	**0.83246**	**0.43497**
SD	**0.06812**	**0.22137**



Modulator's Activity vs Driving Performance



Real-time Cognitive-State Monitoring

T.P. Jung[1,2], C.T. Lin[1], Scott Makeig[2] and Associates

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National Chiao Tung University, Hsinchu, Taiwan
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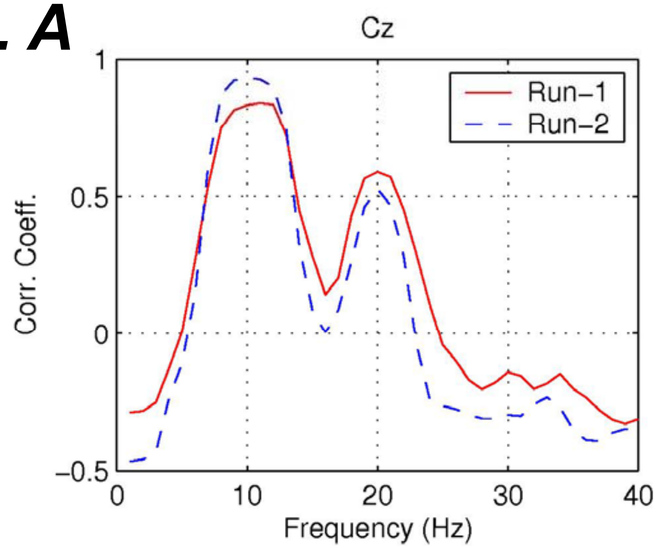
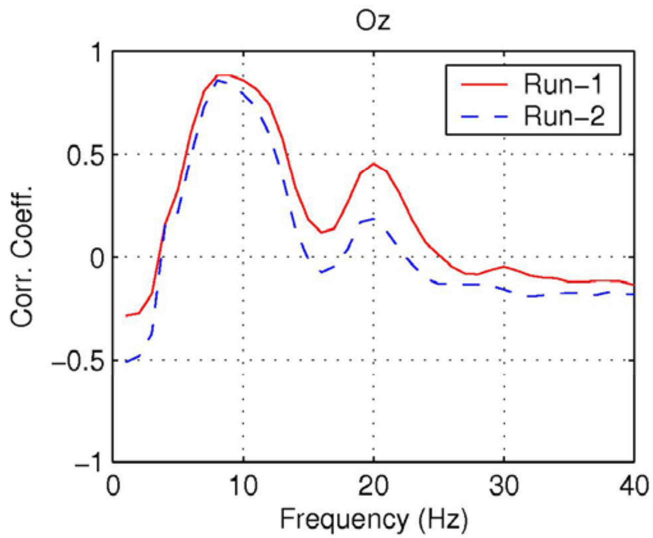
University of California San Diego, USA

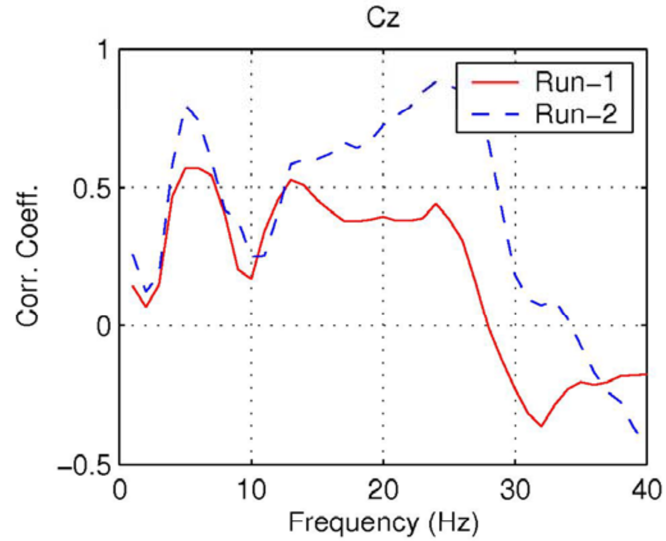
Correlation between Power Spectra and Driving Performance

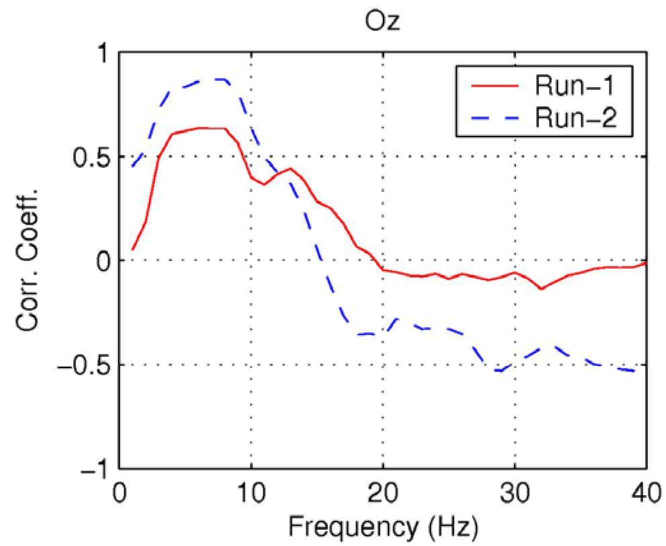
Subj. A





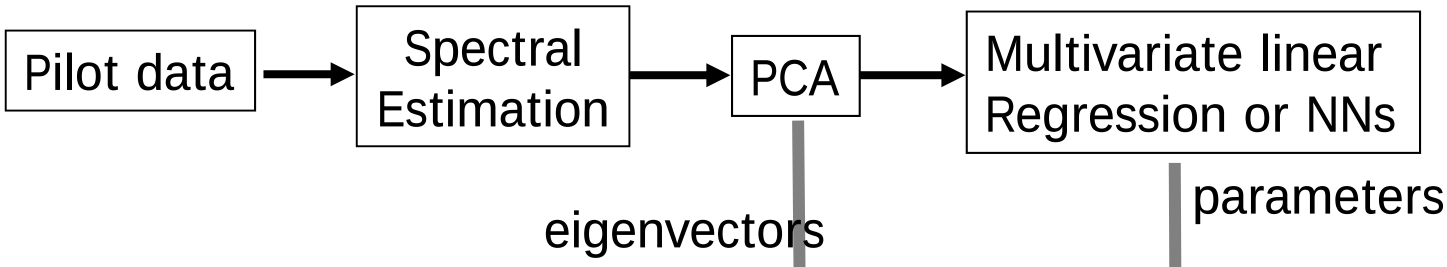
Subj. D



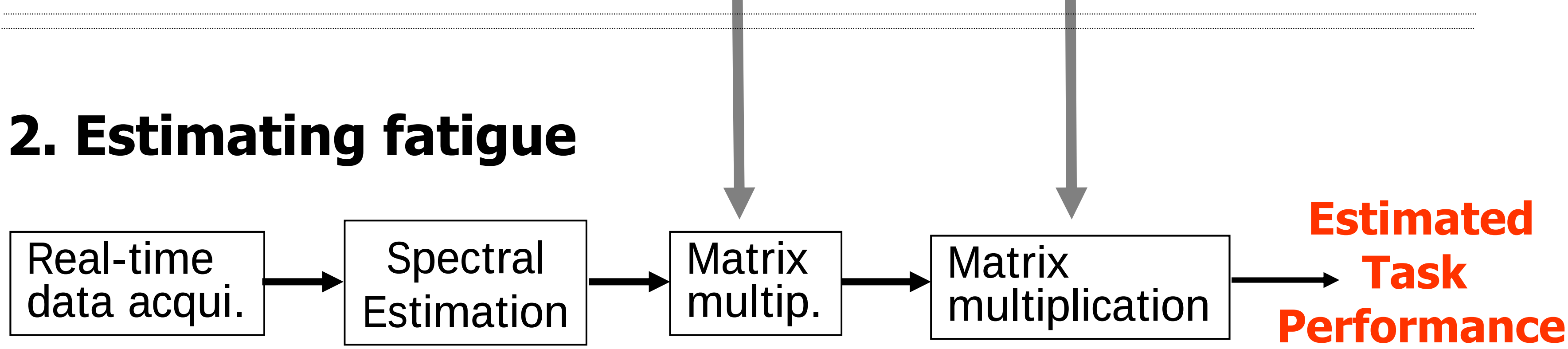


Real-time Drowsiness Monitoring

1. Training



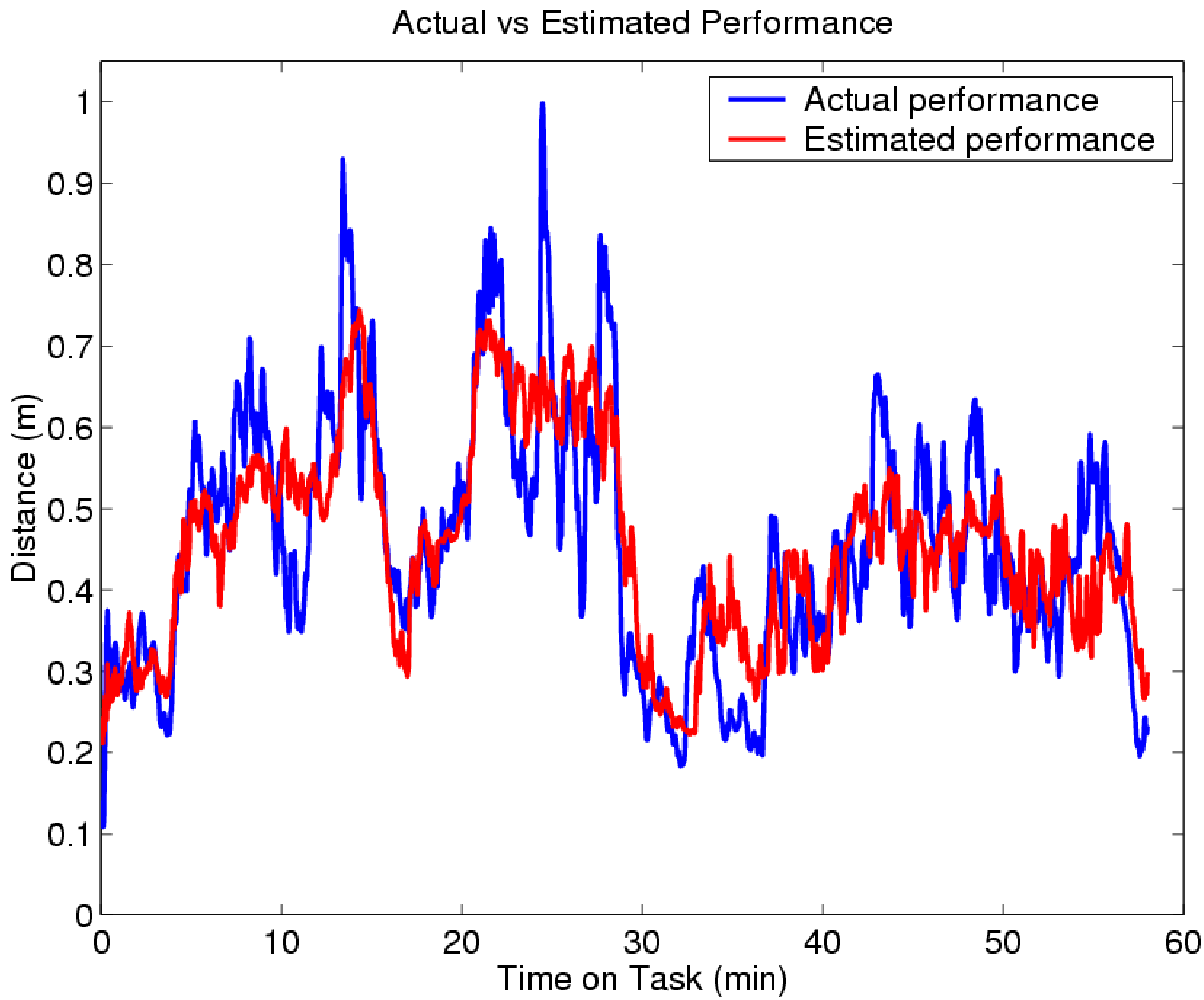
2. Estimating fatigue



References:

1. Jung, *et al*., *IEEE TBME*, 44:60-9, 1997.
2. Lin, *et al*., *EURASIP J Applied Signal Processing*, 19:3165-74, 2005.
3. Lin, *et al., IEEE TCAS* I, 52(12):2726-38, 2005.
4. Lin, *et al., IEEE TCAS* I, 53(11): 2469-76, 2006.
5. Lin, *et al., Proc. of the IEEE,* 96(7):1167-83, 2008.

Sample Results



Arousing Feedback Rectifies Lapse in Performance

C.T. Lin[1], T.P. Jung[1,2] and Associates

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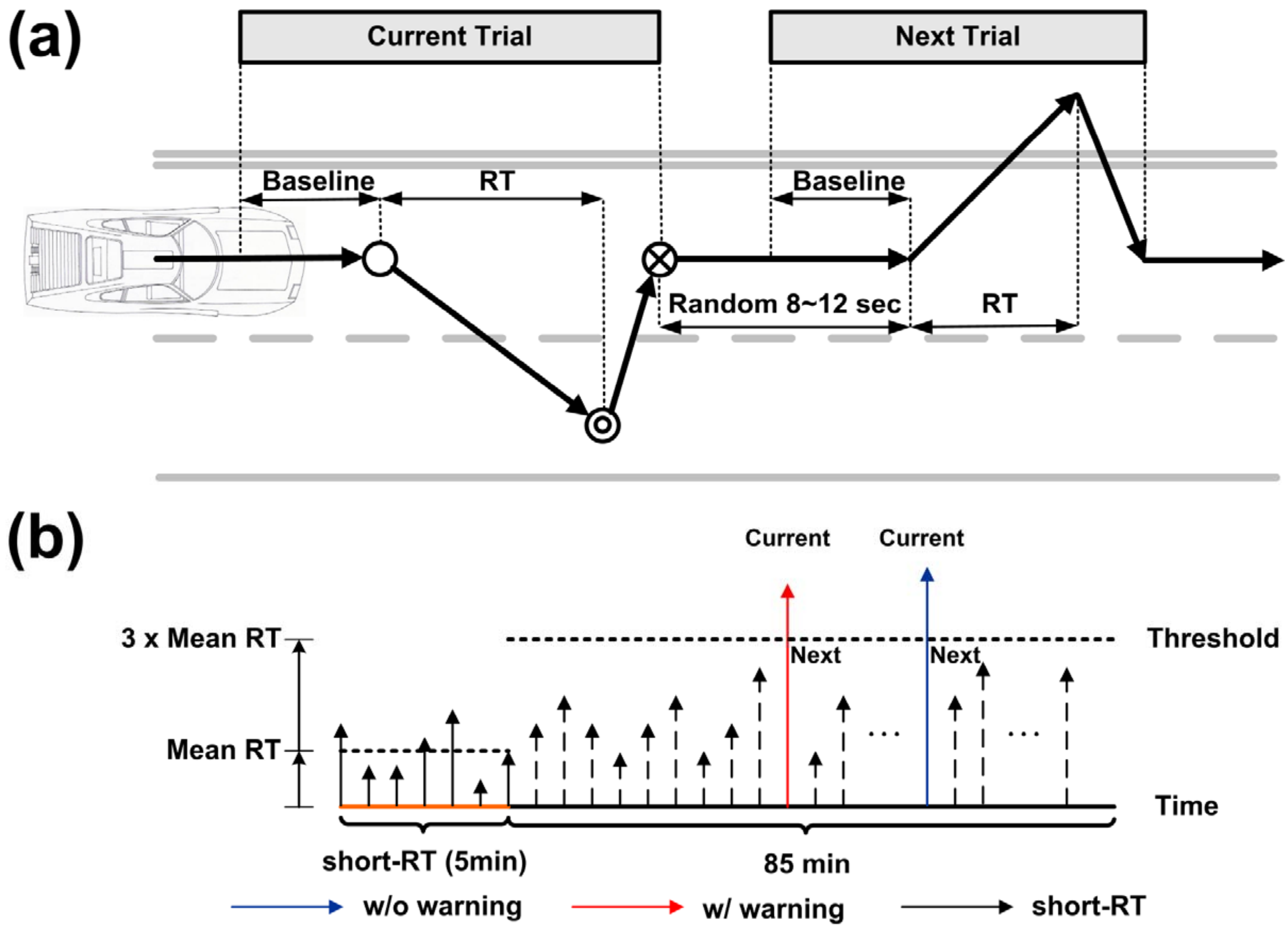
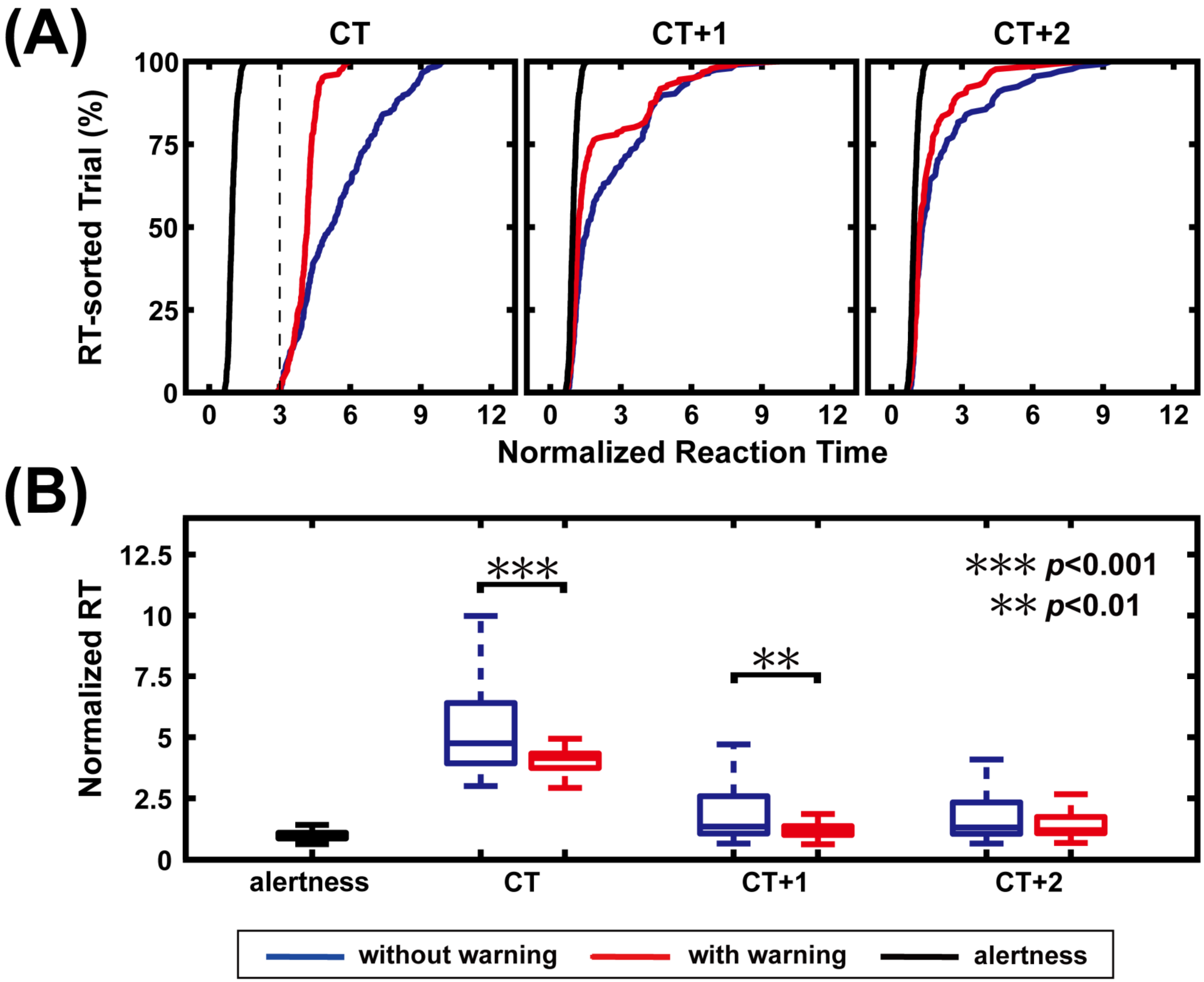
University of California San Diego, USA

Auditory Feedback to the Drowsy Brain



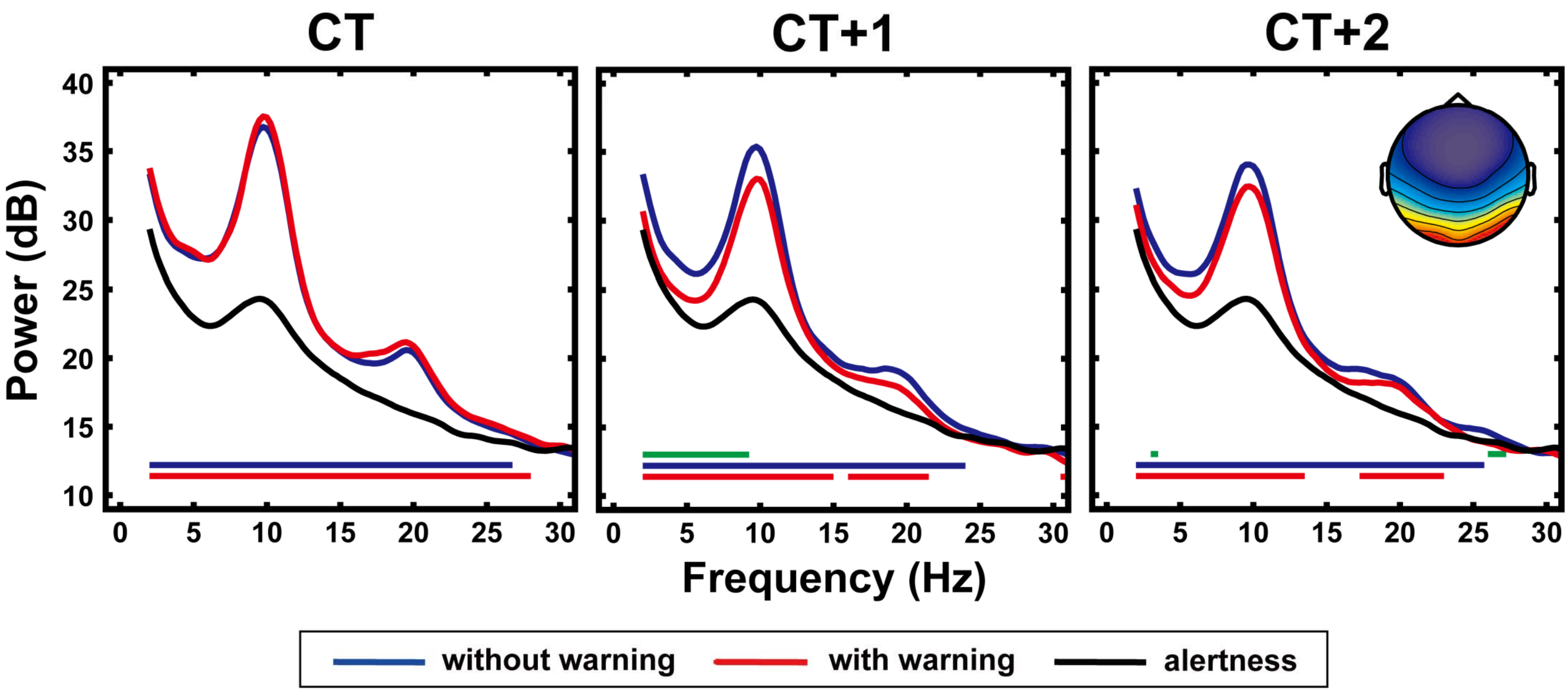
From Lin et al, *NeuroImage*, 2010.

Behavioral Responses to Feedback



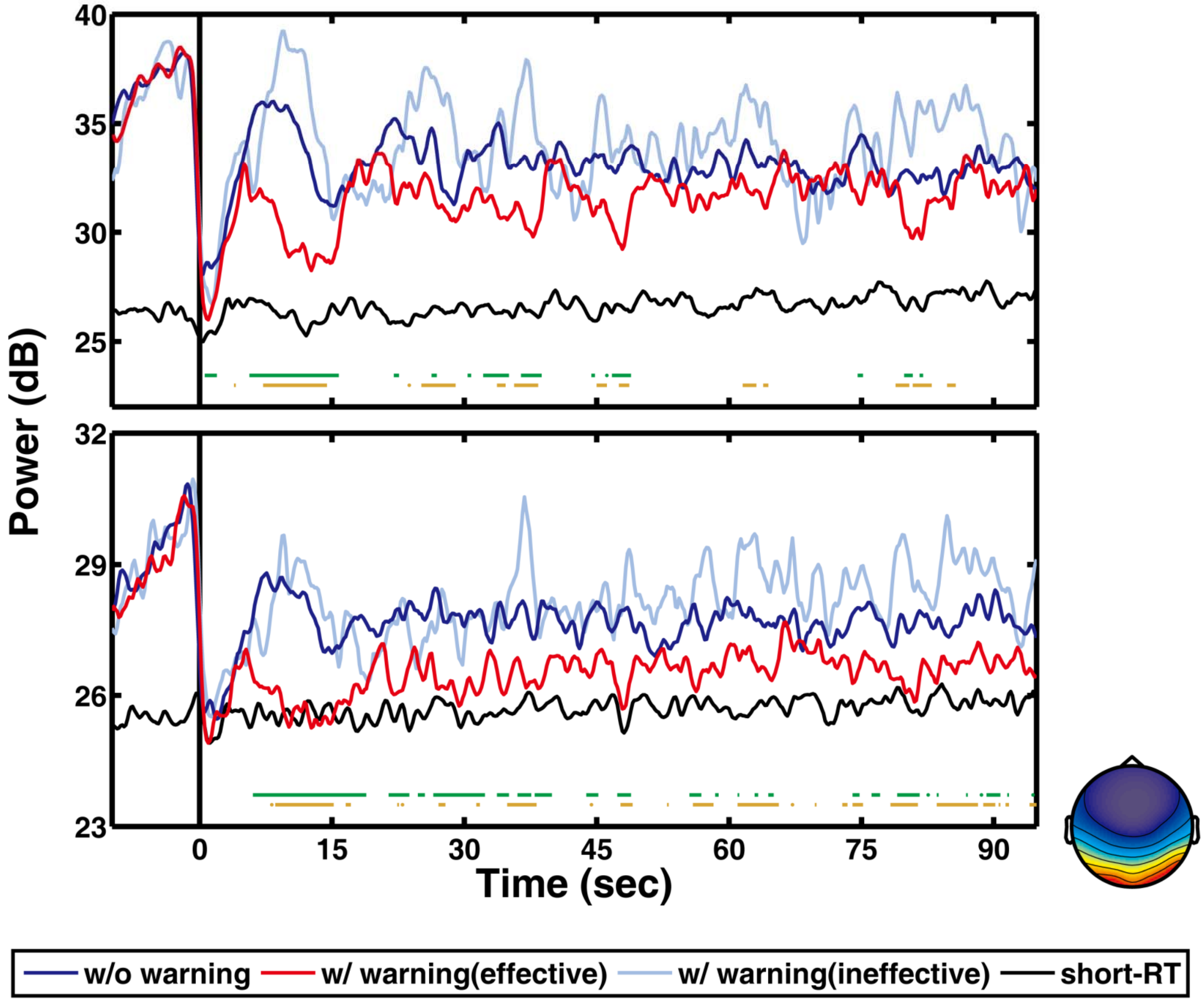
From Lin et al, *NeuroImage*, 2010.

EEG Dynamics following Feedback



From Lin et al, *NeuroImage*, 2010.

EEG Dynamics following Feedback



From Jung *et al*, IEEE *EMBC* 2010.

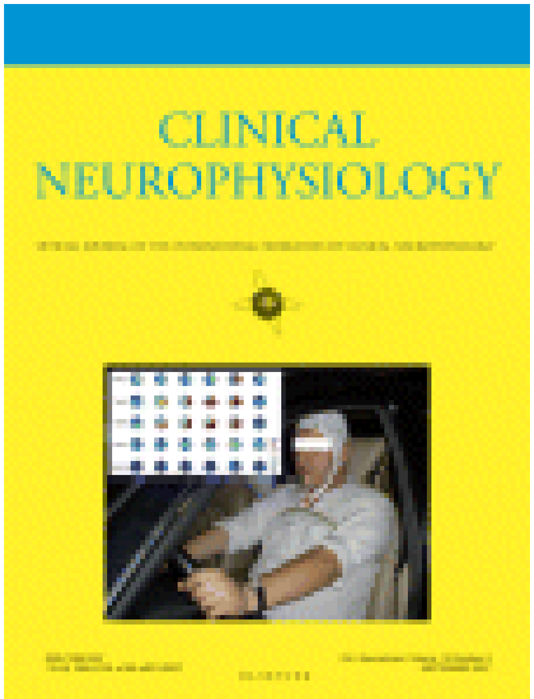
Estimating Efficacy of Arousing Feedback

	Trial type		Overall Accuracy (%)
Trials classified as	effective	ineffective	
effective	320	223	64.0%
ineffective	23	120	

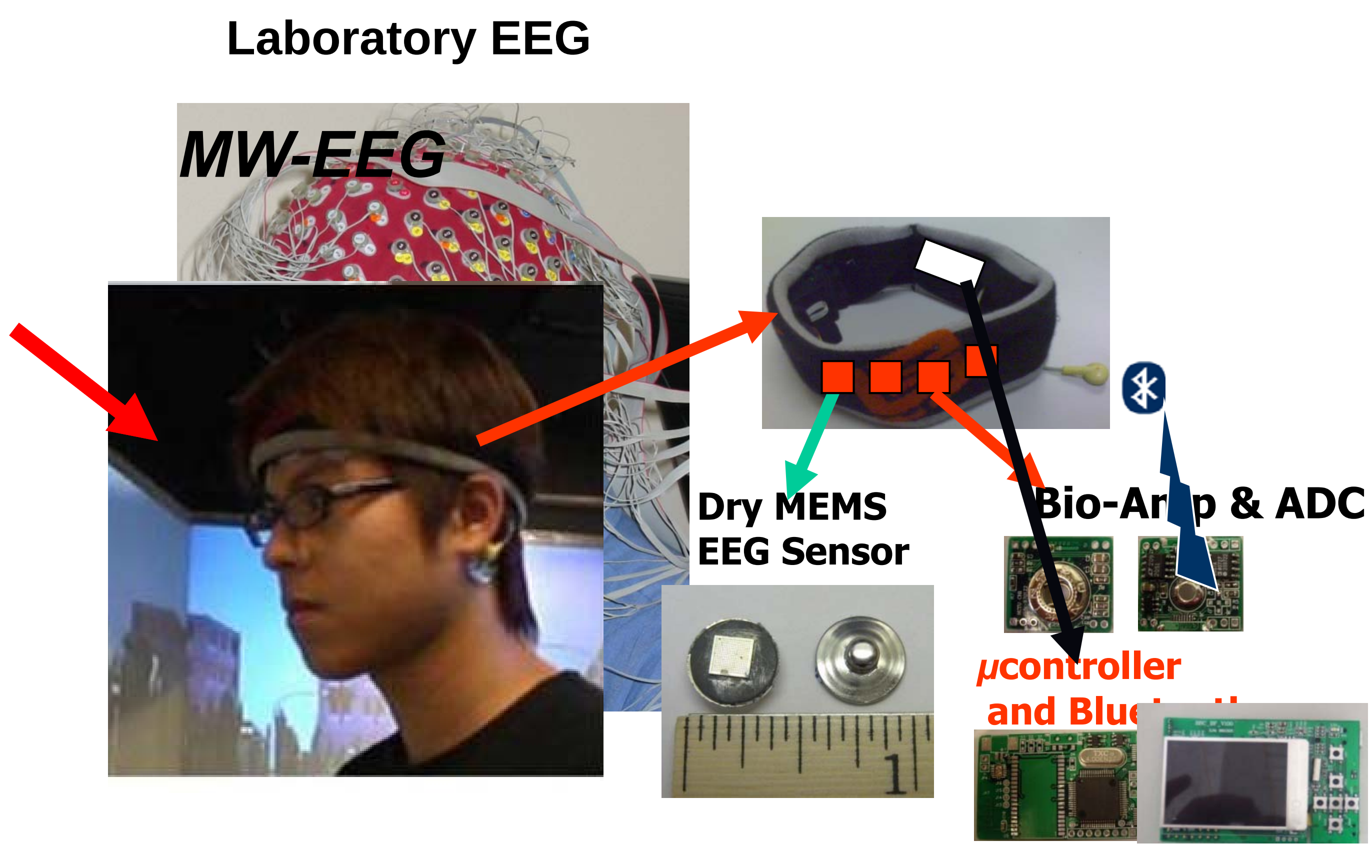
From Jung *et al*, *IEEE EMBC 2010*.

Missing Link

Clinical Neurophysiology
Volume 118, Issue 9, September 2007



Missing Link



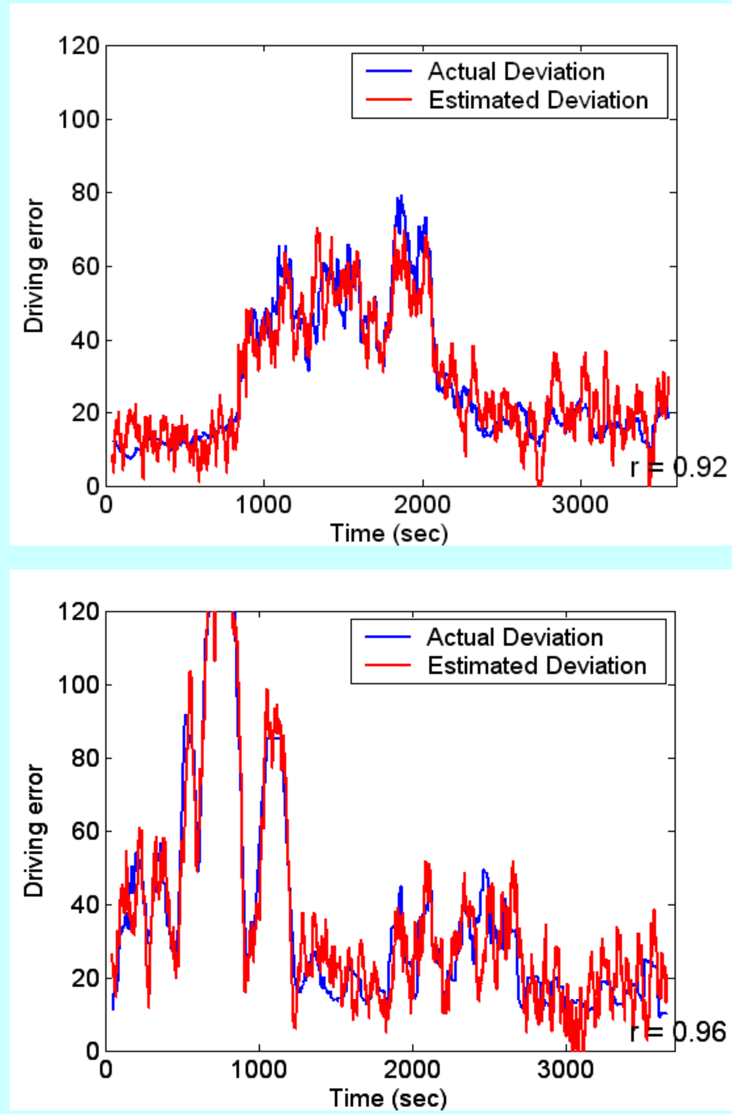
EEG-based Cognitive-State Monitoring

Estimating Cognitive states of the drivers

DSP and Display module

2.5 x 1.5 in

Sample Results



Lin at. al., *Proc. of the IEEE*, July 2008.

Summary

- This study has reported both tonic and phasic spectral dynamics of independent components in response to lane-deviations during a continuous lane-keeping driving task.
- Independent Modulator Analysis (IMA) separated spectra of statistically independent sources into the weighted sum of maximally temporally independent modulators (IMs).
- Across subjects, we found common modulators which mediated activations of the several cortical areas associated with subjects' task performance.
- The modulator activations were highly correlated with the driving performance in the realistic lane-keeping driving task.

Summary (cont.)

- Arousing auditory feedback delivered to the cognitively challenged subjects immediately agitated subject's responses to the events.
- The improved behavioral performance was accompanied by concurrent spectral suppression in the theta- and alpha-bands of a lateral occipital component.
- We also showed that continuous, accurate, noninvasive and near real-time estimation of subject's cognitive level is feasible in a realistic operational environment.
- It is feasible to integrate novel dry sensors, advanced signal-processing algorithms and miniature supporting hardware into a mobile & wireless cognitive-state monitoring and management system.