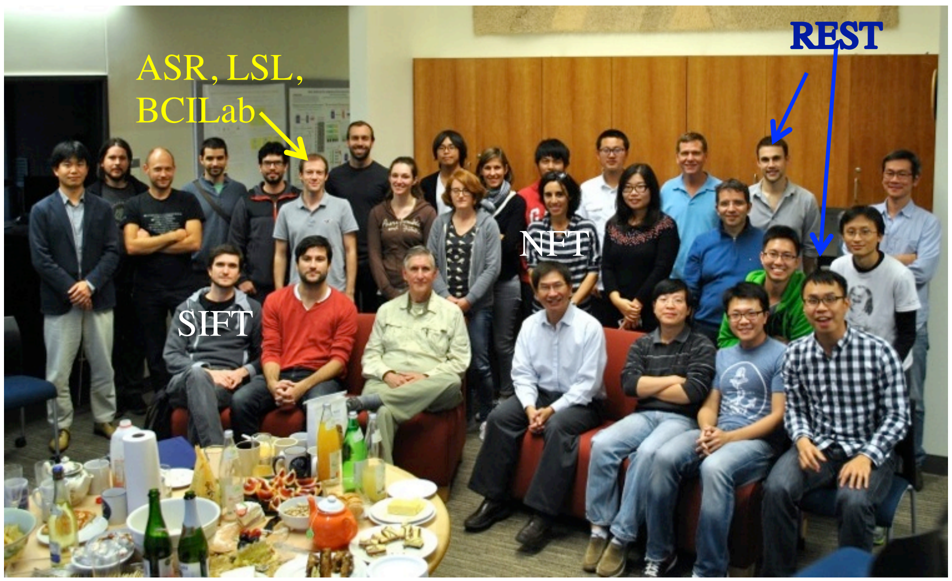
Real-world MoBI and BCIs

Tzyy-Ping (TP) Jung



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Hsinchu, Taiwan

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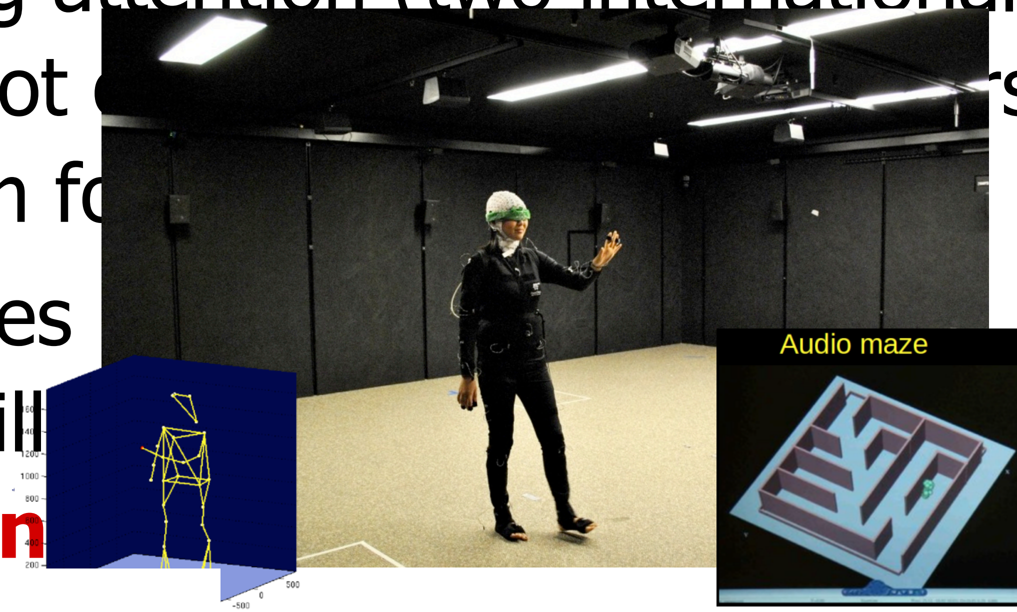
Tianjin University, Tianjin, China

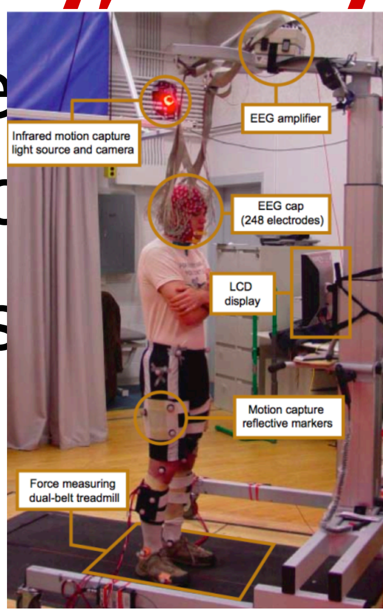
Motivations

MoBI has gained increasing attention (two international conferences) and made a lot … s. However, there is still room fo…

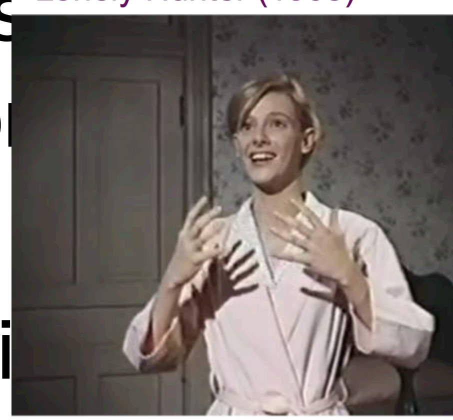
- The bio-sensing modalities … skin GSR, eye-gaze, pupil… **bulky, costly, inconven…** .
- The … y is … well-controlled labo… iro…
- Exis… ns … lly tag cog… ani…

Spatial Navigation

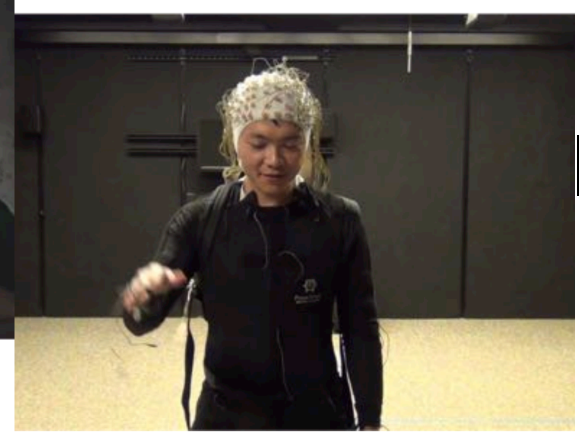




The Heart is a Lonely Hunter (1968)



Conducting Experiment (2013)



Outline

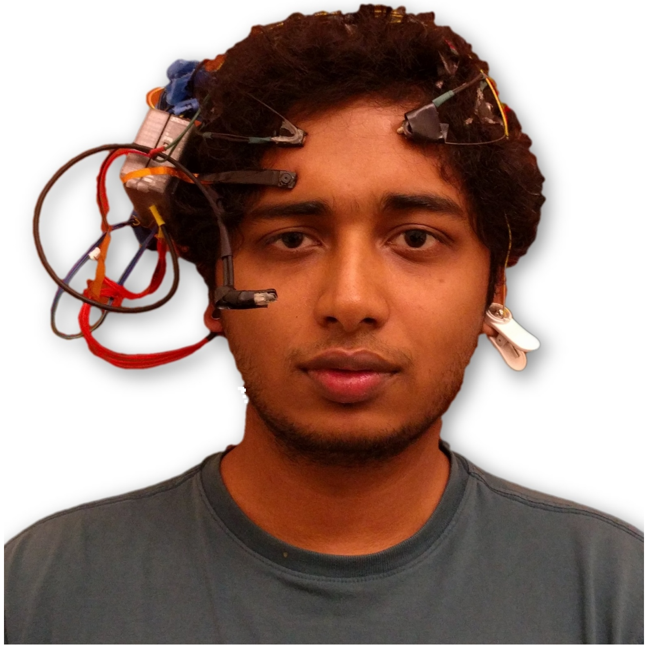
- Advanced sensors and apparatuses for measuring neural, physiological, and behavioral data from unconstrained subjects in virtual and real-world environments.
- Signal-processing techniques to automatically remove artifacts or noise in the neural and physiological recordings.
- A sample study uses a multi-modal approach (e.g. eye-gaze tracking and EEG) to explore students' underlying cognitive processes and brain dynamics during science learning.

A Truly Wearable Multi-modal Biosensing Platform for Real-World Neuroimaging

We have developed a low-cost wearable multi-modal bio-sensing system capable of recording (neuro)physiological signals, eye-gaze overlaid on world view, and motion capture in real-world settings.

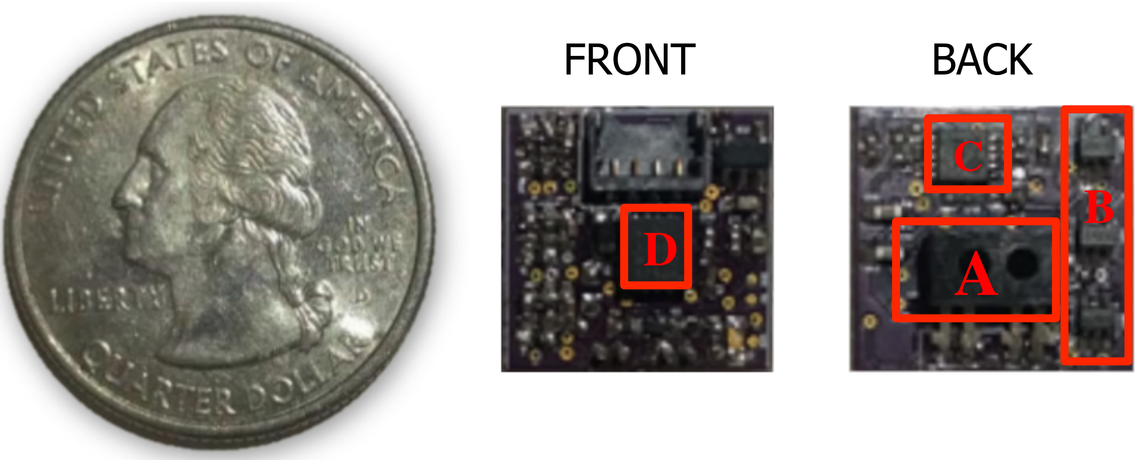
Wearable sensors

- World camera- Subject's visual perspective
- Eye Camera: Tracking subject's pupil
- EEG: Subject's brain activity
- ECG: Subject's Heart Rate and Heart-Rate Variability
- PPG: Photoplethysmogram
- Any other biosensors as per need such as GSR, HRV.



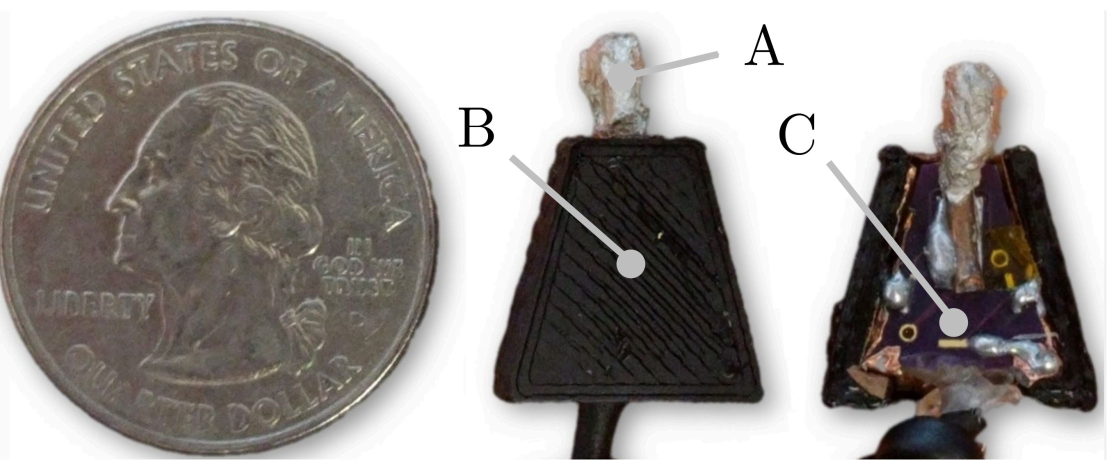
Sensors

Earlobe Photoplethysmogram (PPG) Sensor (1.6cm x 1.6cm x 0.6cm)



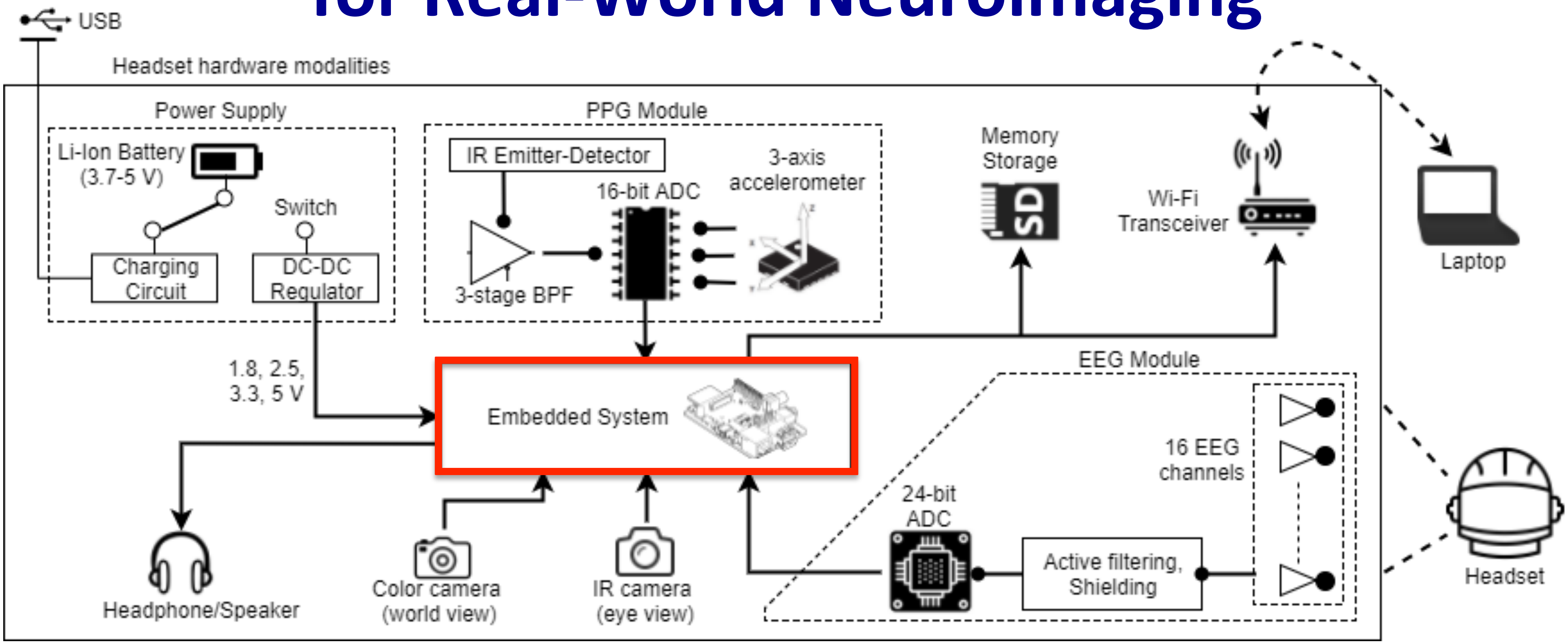
A. IR emitter & detector
B. A third-order analog high-gain band-pass filter (0.8 - 4 Hz)
C. A 100Hz 16-bit ADC (TI ADS 1115)
D. A 3-axis accelerometer measures motions of the sensor and removes it from the PPG signal using an adaptive noise-cancellation filter.

Non-prep EEG Sensor



A. Silver-epoxy-based (Ag) EEG sensor
B. A 3D-printed case housing a conductive element for shielding.
C. An on-board OpAmp (TI TLV 2211) as a voltage follower to improve SNR of the EEG data.

A Truly Wearable Multi-modal Biosensing Platform for Real-World Neuroimaging



A wearable embedded system (Broadcom BCM2837)

- Data acquisition from sensors
- Control the sampling rate of each sensor
- Using a digital filter on the sensor data if analog filtering has not been done.
- Time-stamping the sensors' data for synchronization
- Record the data on itself or send the time-stamped data using Wi-Fi to a remote machine.

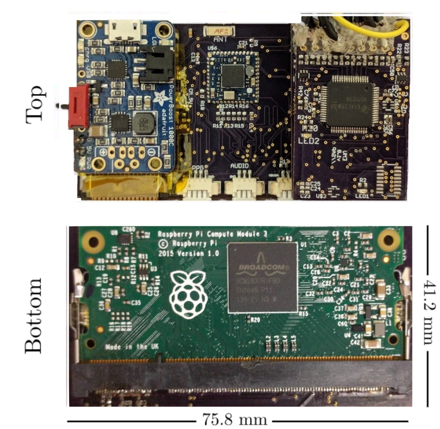
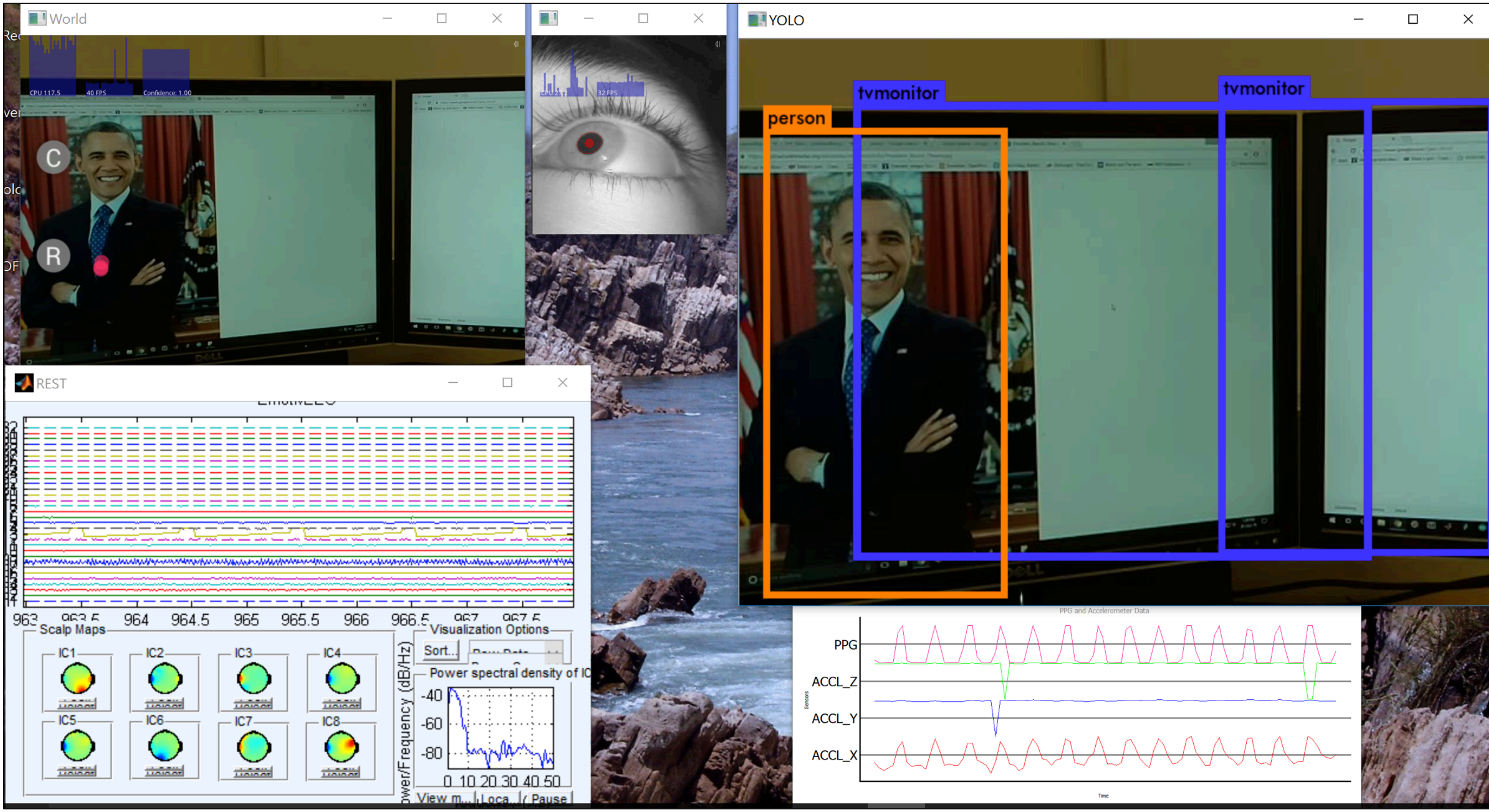


Fig. 5. Embedded System (A) Power circuitry, (B) World camera connect (C) PPG connector, (D) Audio jack connector, (E) Eye camera connect (F) EEG sensors connector and ADC module, (G) Wi-Fi module, and (Raspberry Pi Compute Module 3

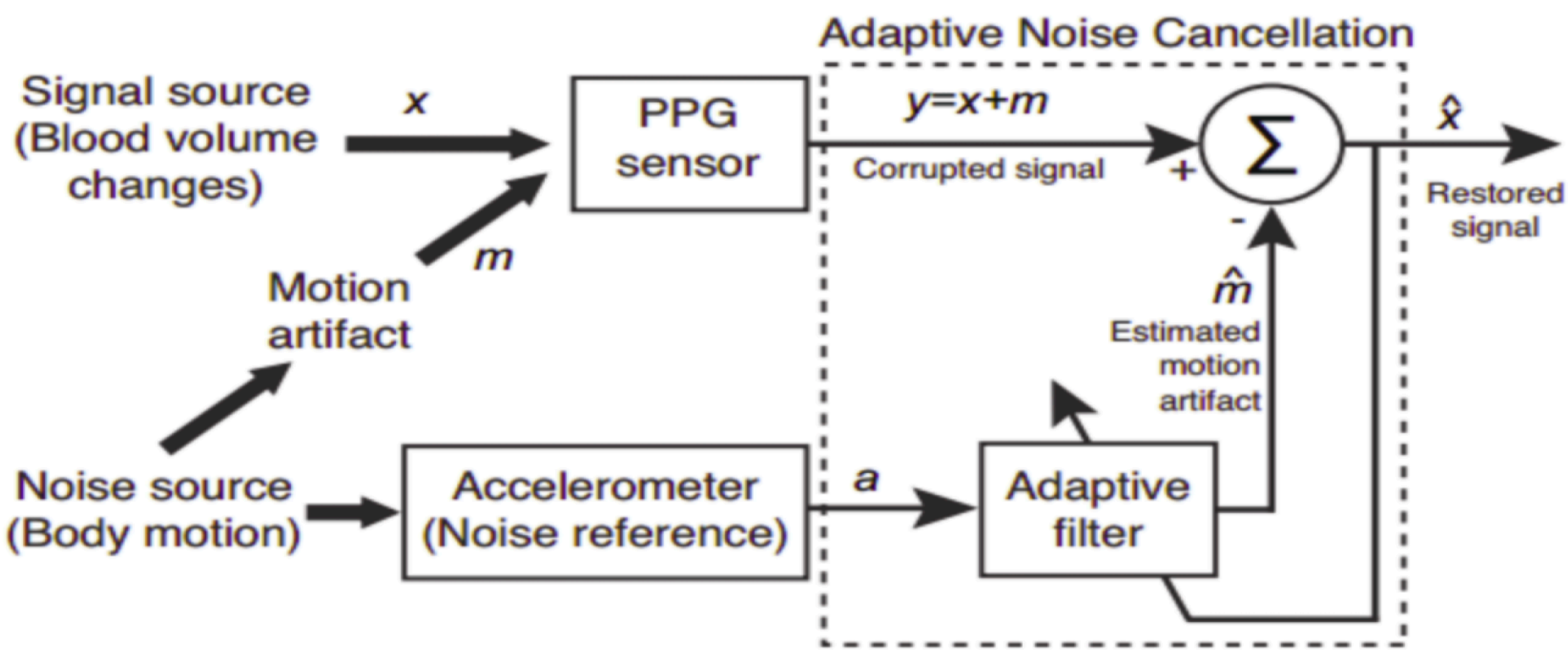
Software on a Host Computer



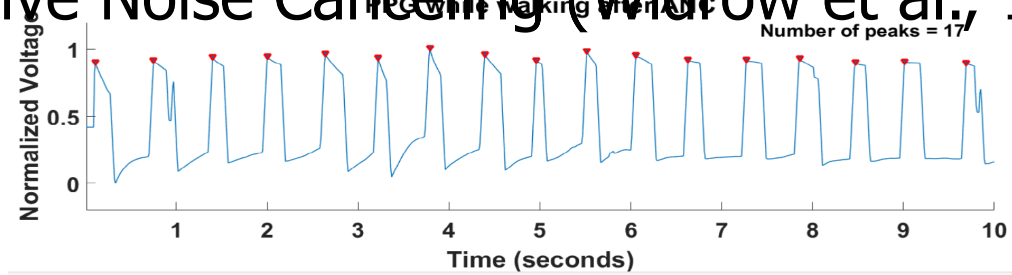
Evaluation of the Multi-modal Sensors

Earlobe Photoplethysmogram (PPG)

Heart rates were measured while subjects were sitting and walking in-place.

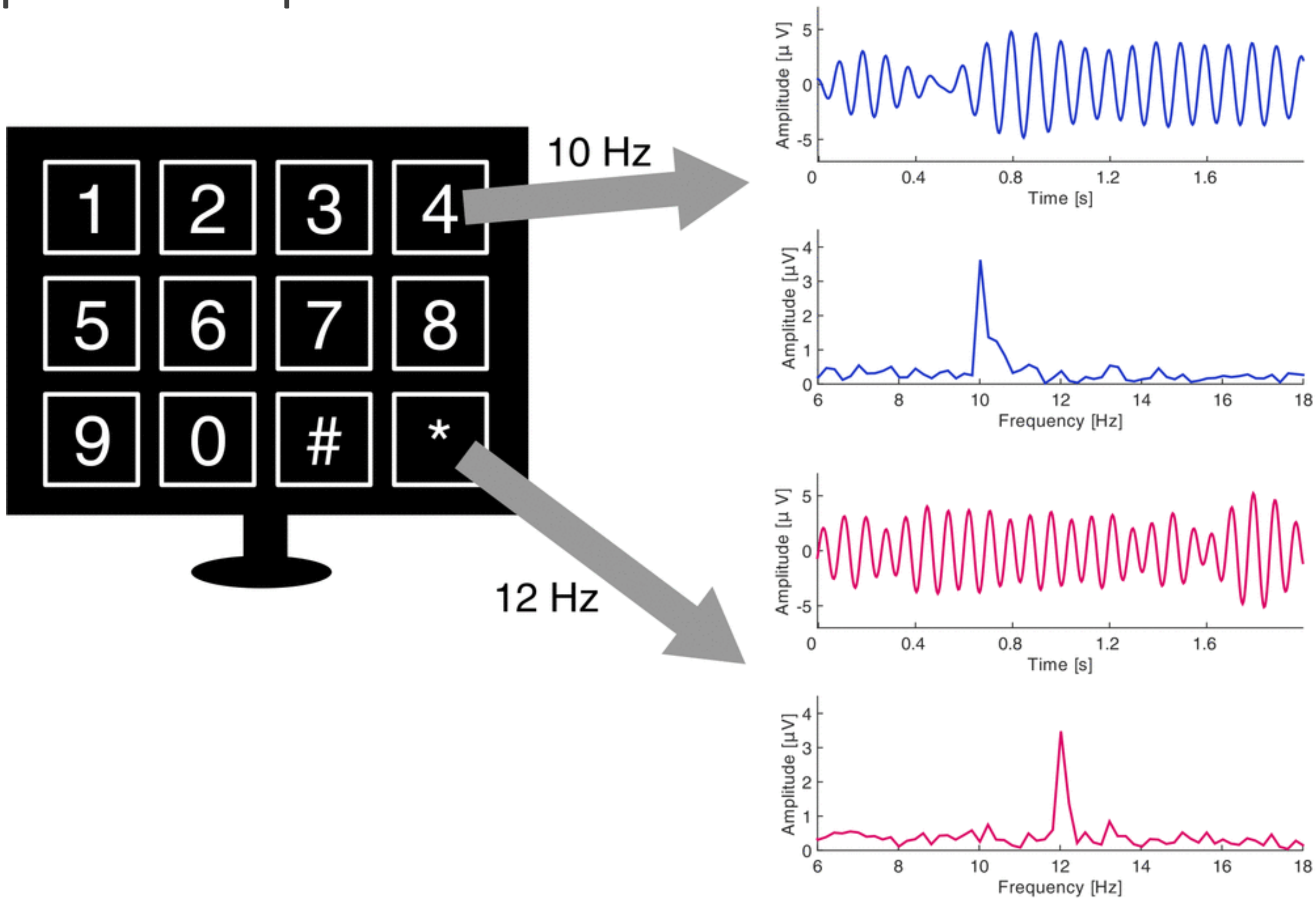


Adaptive Noise Canceling (Widrow et al., 1975)



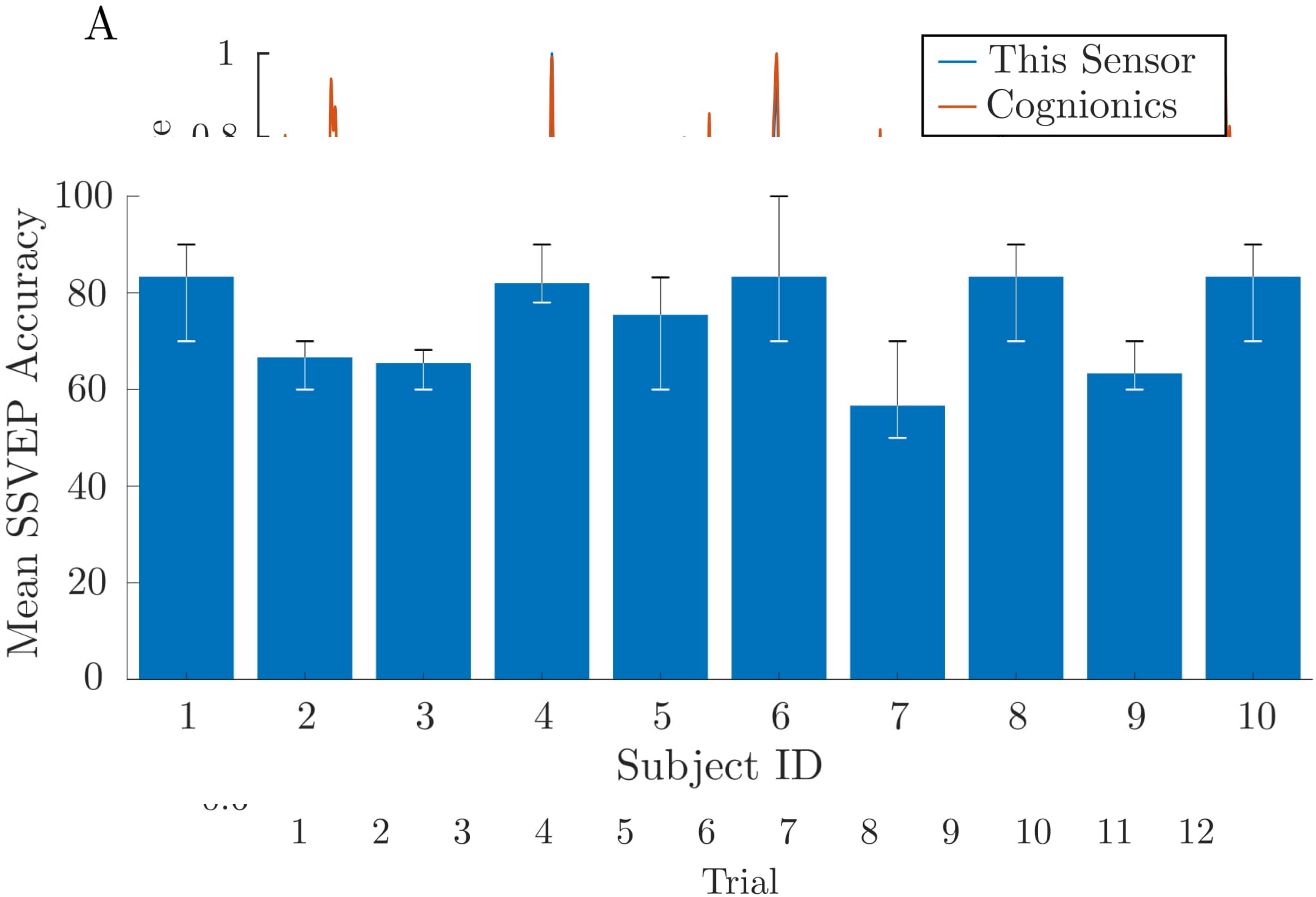
Evaluation of the Multi-modal Sensors

- **Steady-state visual evoked potential (SSVEP)**: Brain's electrical response to repetitive visual stimulation



Wei et al., IEEE SMC 2018

Evaluation of the Multi-modal Sensors

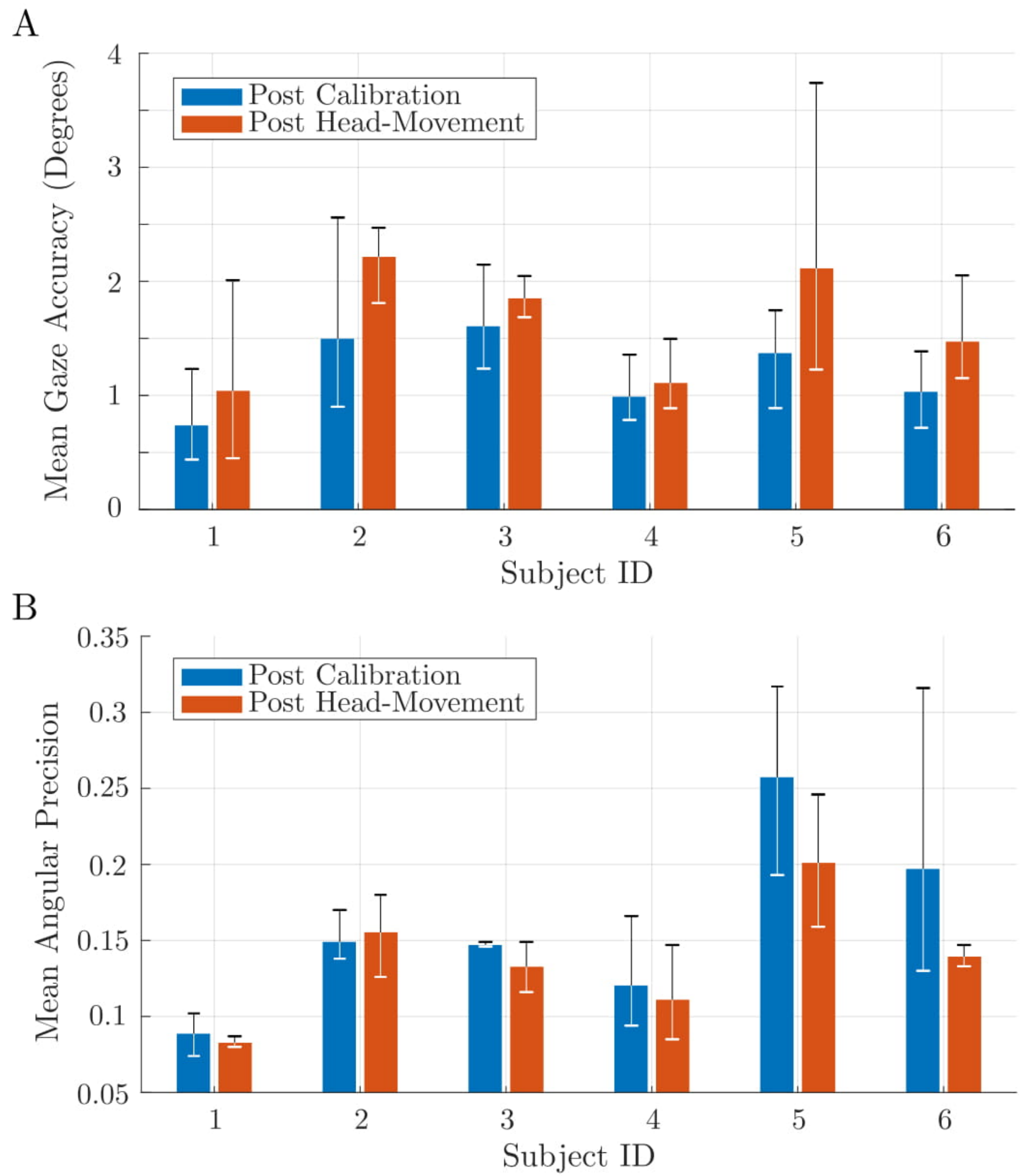


Evaluation of the Multi-modal Sensors

Eye tracking

Precision: the RMS of the angular distance between successive samples during a fixation.

Accuracy: the average angular offset distance in degrees of the visual angle - between fixation locations and the corresponding targets.

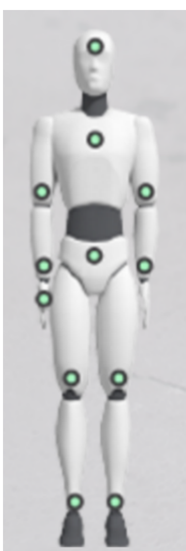


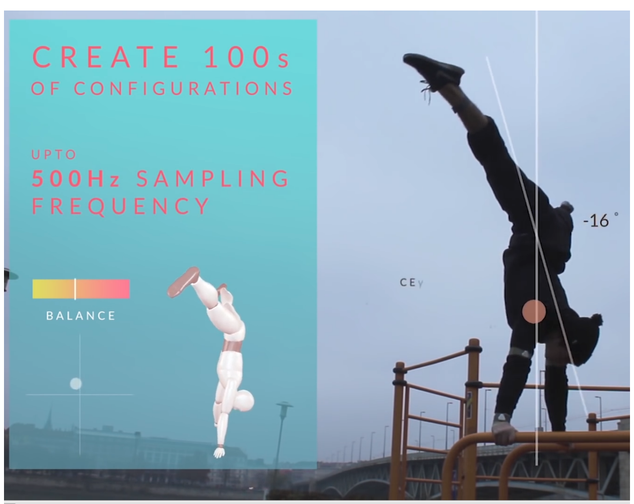
A Truly Wearable Multi-modal Biosensing Platform for Cognitive Experiments

We have developed a low-cost wearable multi-modal bio-sensing system capable of recording (neuro)physiological signals, eye-gaze overlaid on world view, and motion capture in real-world settings.

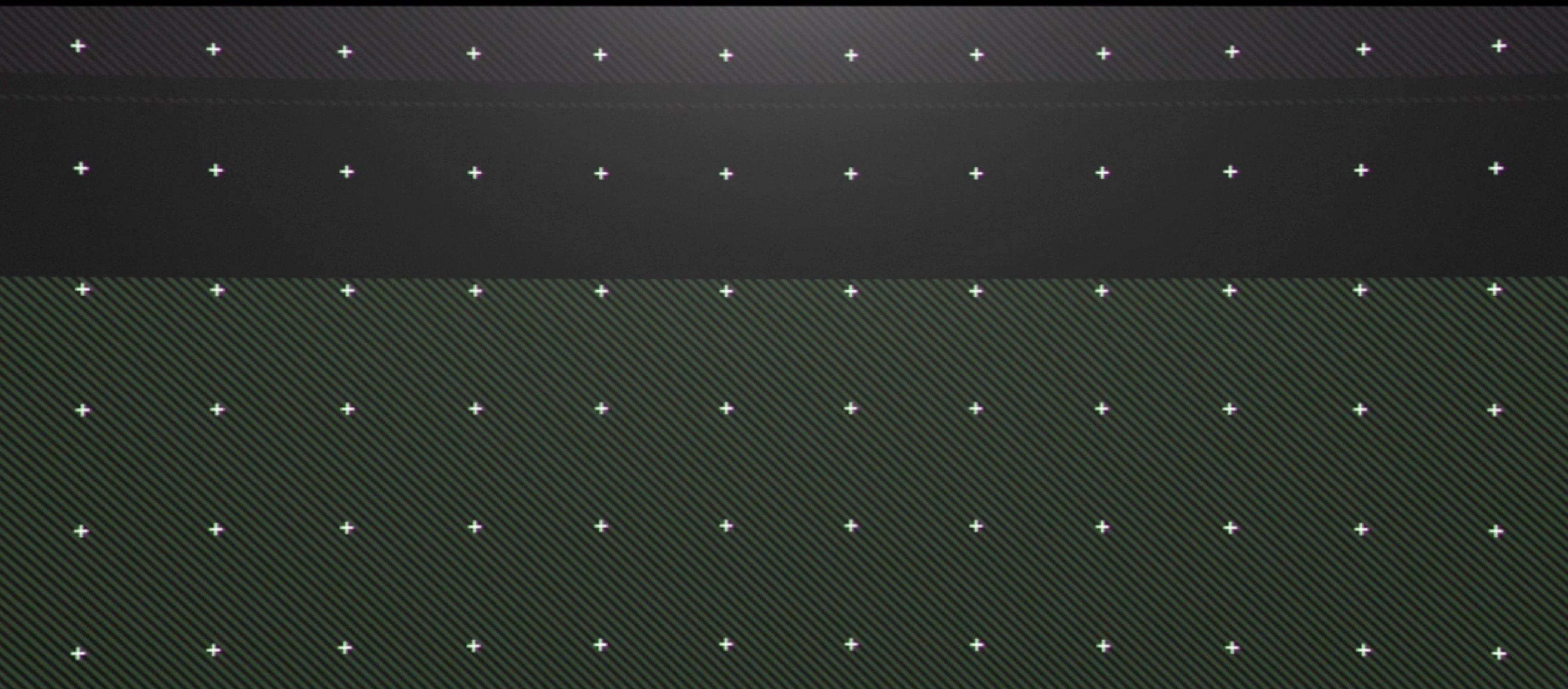
Wearable sensors

- World camera- Subject's visual perspective
- Eye Camera: Tracking subject's pupil
- EEG: Subject's brain activity
- ECG: Subject's Heart Rate and Heart-Rate Variability
- PPG: Photoplethysmogram
- IMUs for full-body motion capture
- Any other biosensors as per need such as GSR, HR, HRV.





Multi-modal Bio-sensing During a Gameplay



Outline

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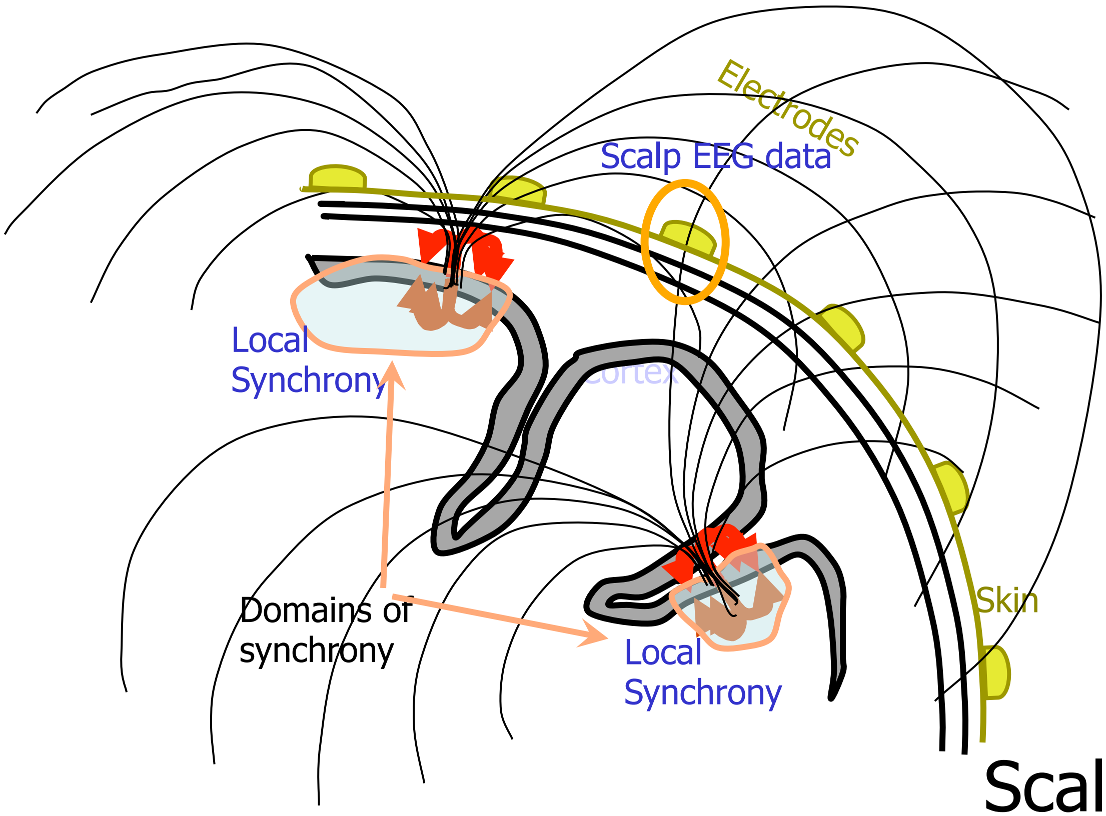
Difficulties in Observing Distributed EEG dynamics



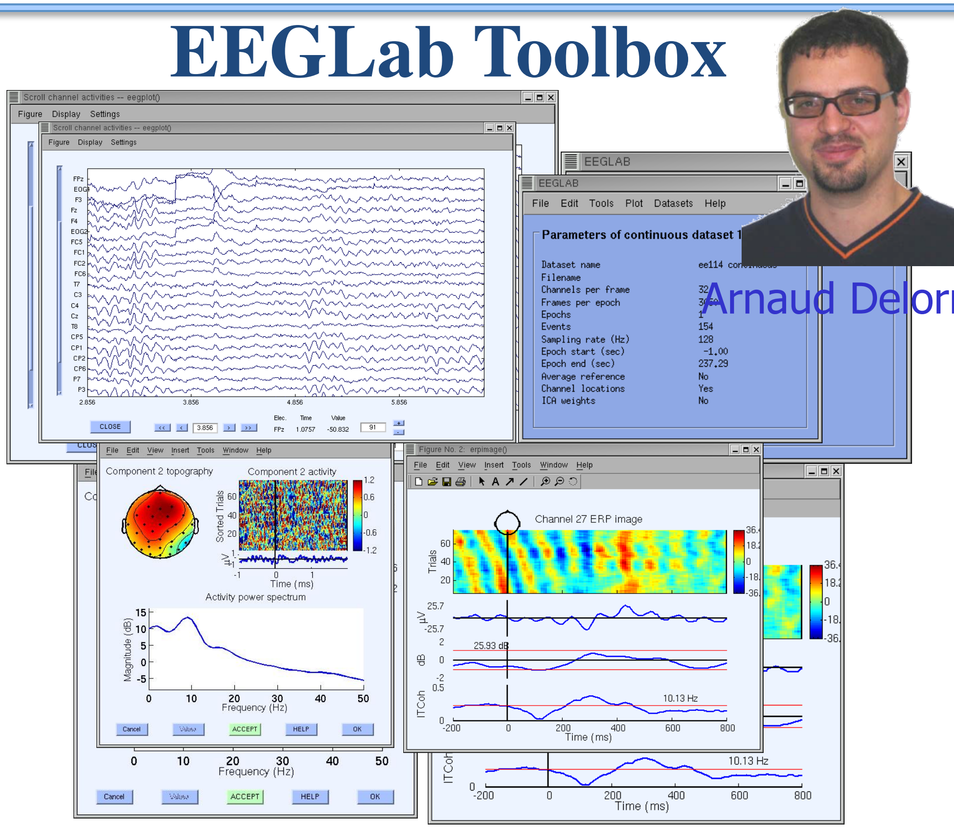
Scalp EEG signals appear to be noisy because they are a mixture of signals generated in many brain areas.

Independent Component Analysis

Courtesy of SoftMax, Inc

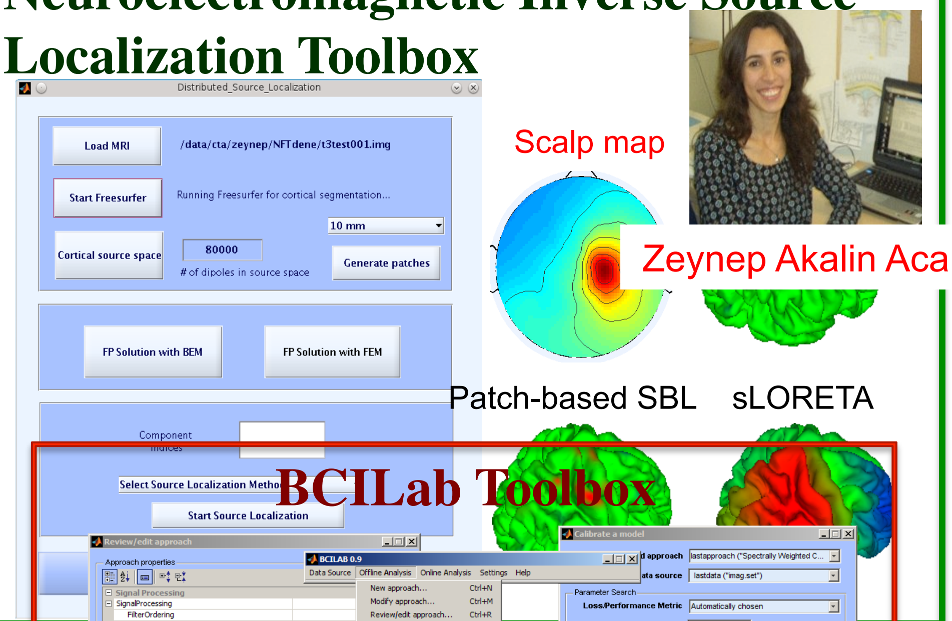
Off-line Analysis and Visualization of EEG Source Dynamics

EEGLab Toolbox

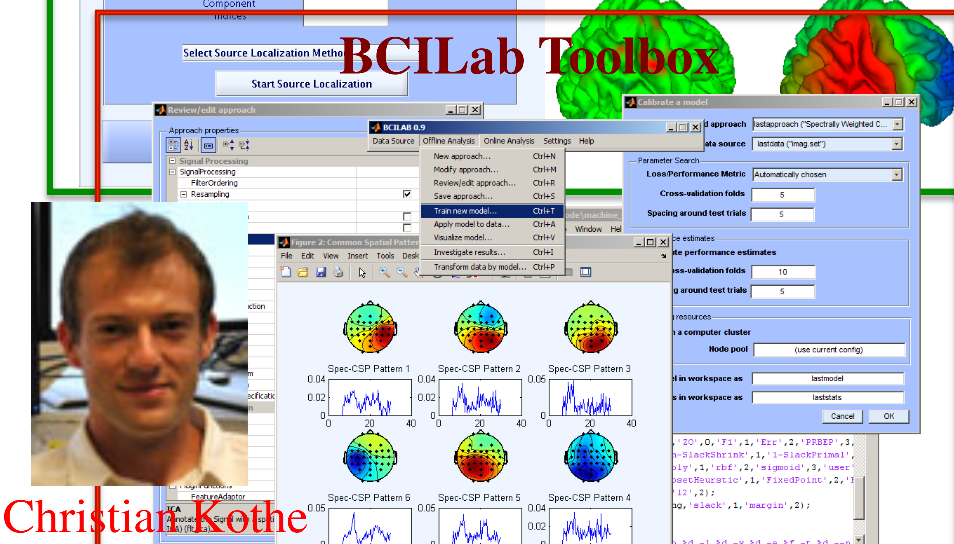


EEGLAB – An Open Source Environment for Electrophysiological Research

Neuroelectromagnetic Inverse Source Localization Toolbox

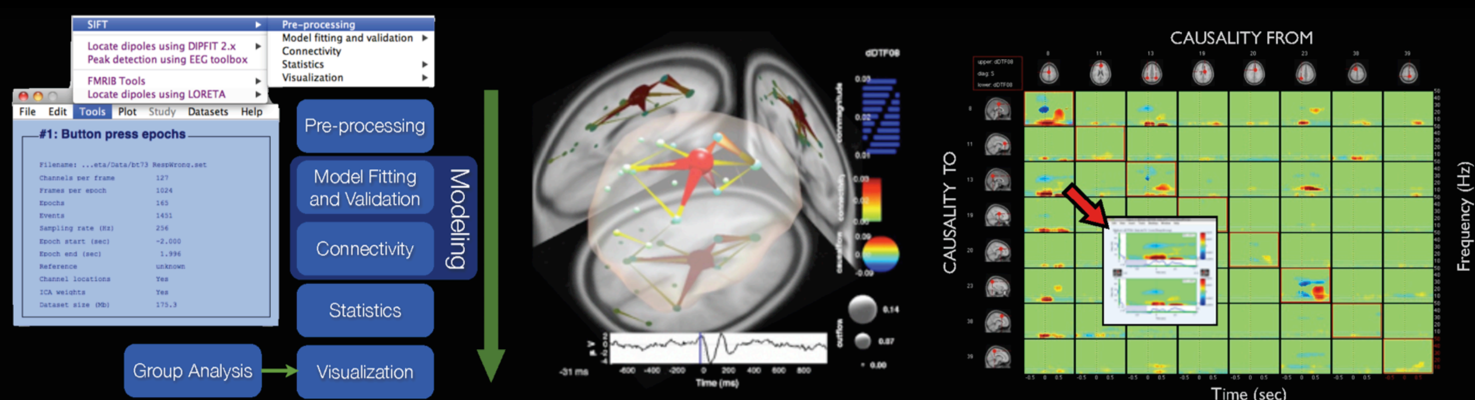


BCILab Toolbox



Source Information Flow Toolbox (SIFT)

Tim Mullen



Real-time EEG Source-mapping Toolbox (REST)

Luca Pion-Tonachini

Live streaming multi-channel data (LSL)

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Preprocessing:
- Re-reference
- Band-pass filtering (IIR
- Data cleaning (ASR)

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Source separation:
- Online Recursive ICA

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Source-level analys
- Source localization
- Source classification

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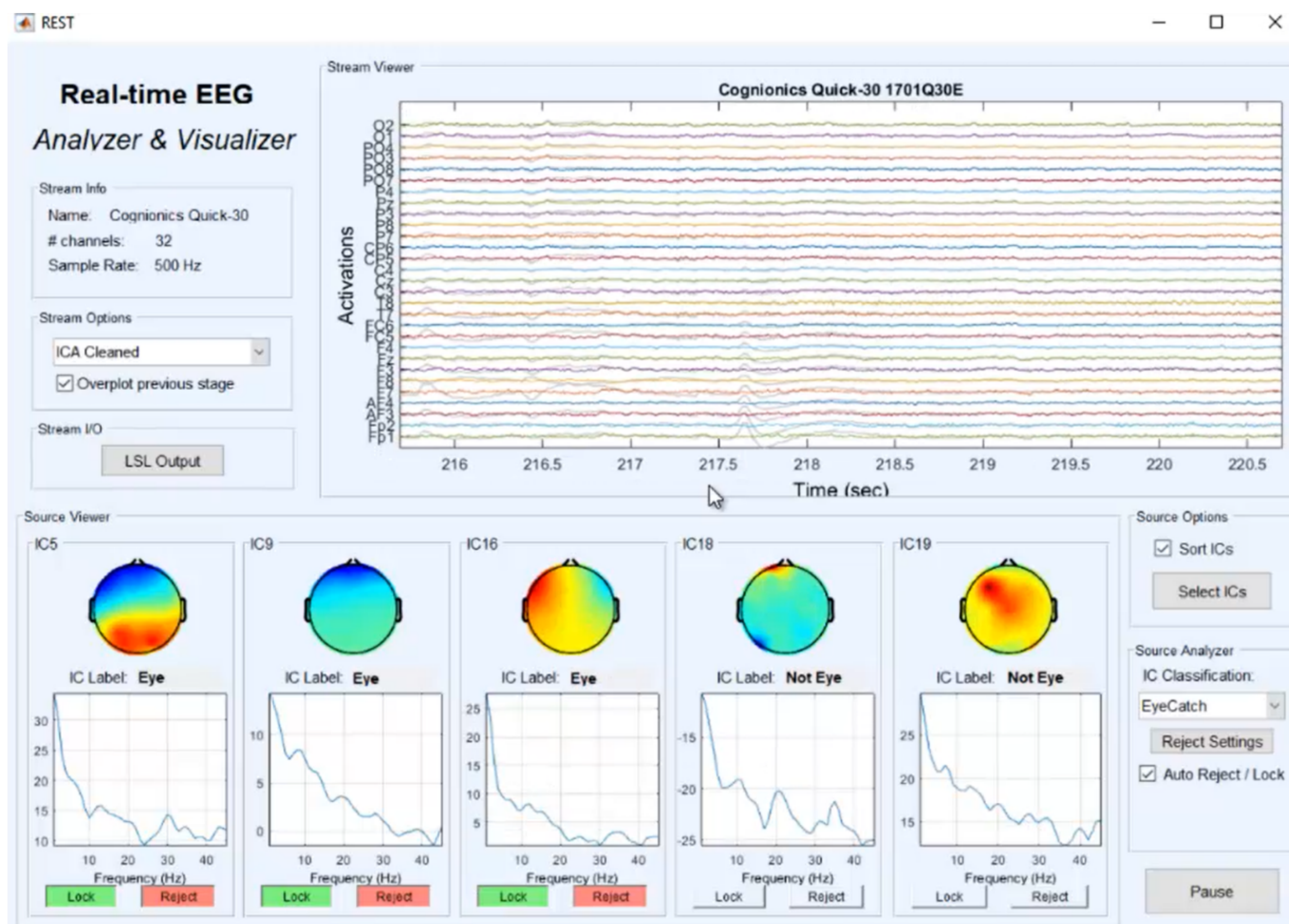
Real-time applications:
- Automatic artifact removal
- Brain-state monitoring

Graphical User Interface



Code: https://github.com/goodshawn12/REST

Pion-Tonachini & Hsu, *IEEE EMBC*, 2015
Hsu et al., *IEEE EMBC*, 2015
Hsu et al., *IEEE TBME*, 2016
Pion-Tonachini & Hsu et al., IEEE EMBC, 2018

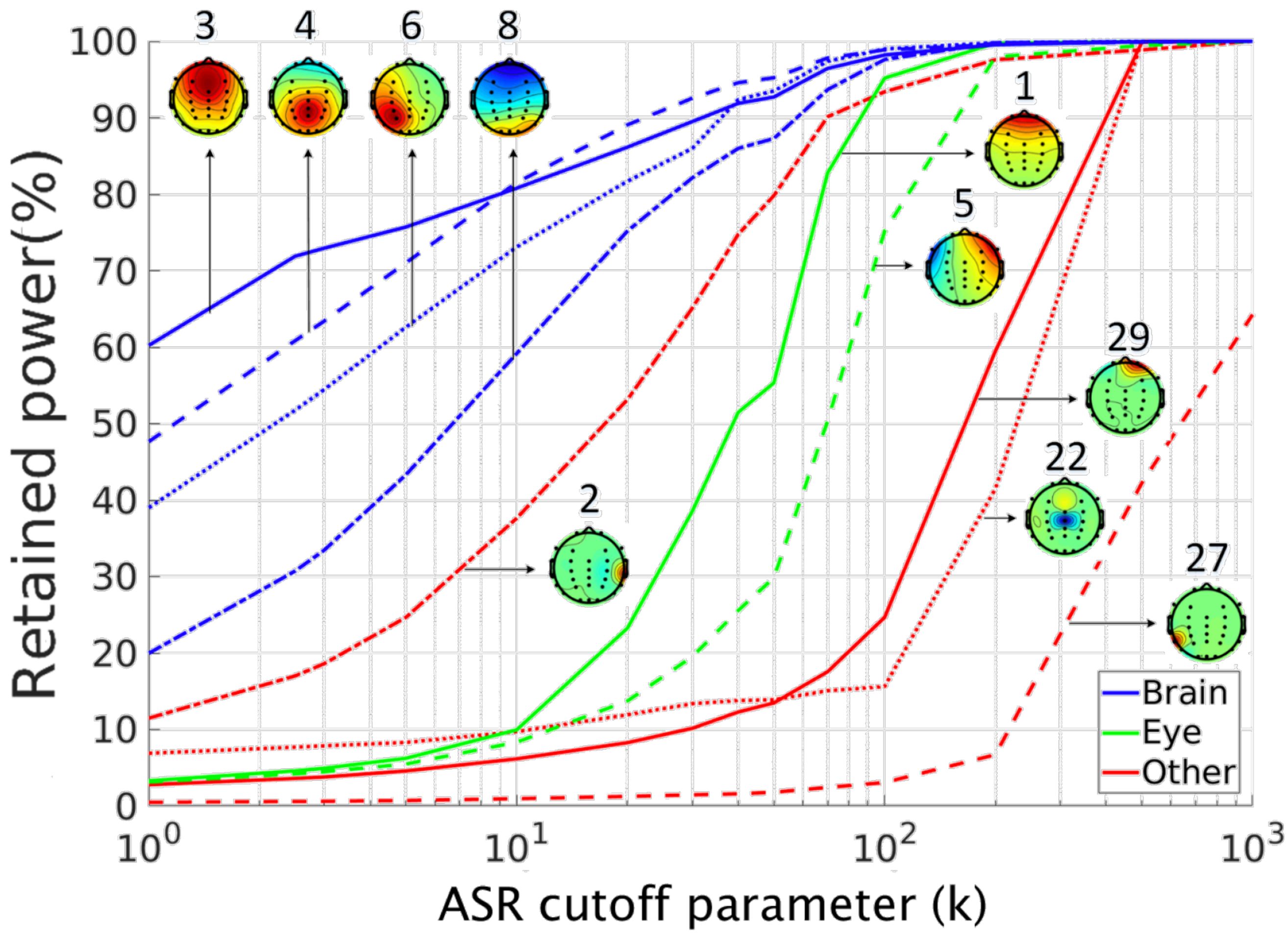
Real-time Automatic Artifact Rejection using REST

Luca Pion-Tonachini, Sheng-Hsiou Hsu,
Chi-Yuan Chang, Tzyy-Ping Jung

Swartz Center for Computational Neuroscience
University of California San Diego

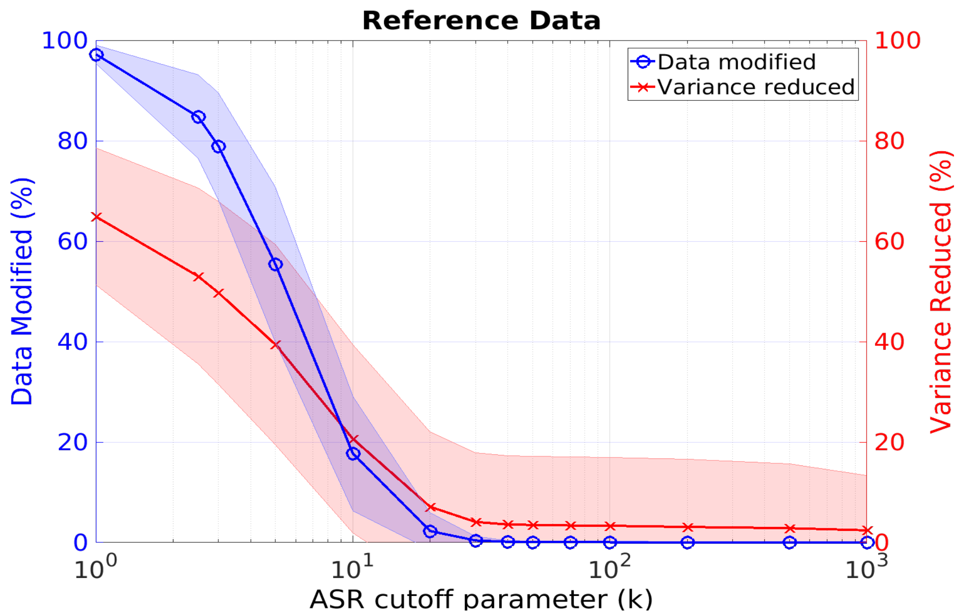
Evaluation of ASR: a general-purpose real-time automatic artifact rejection method

Artifact removal of the EEG data from a sample subject

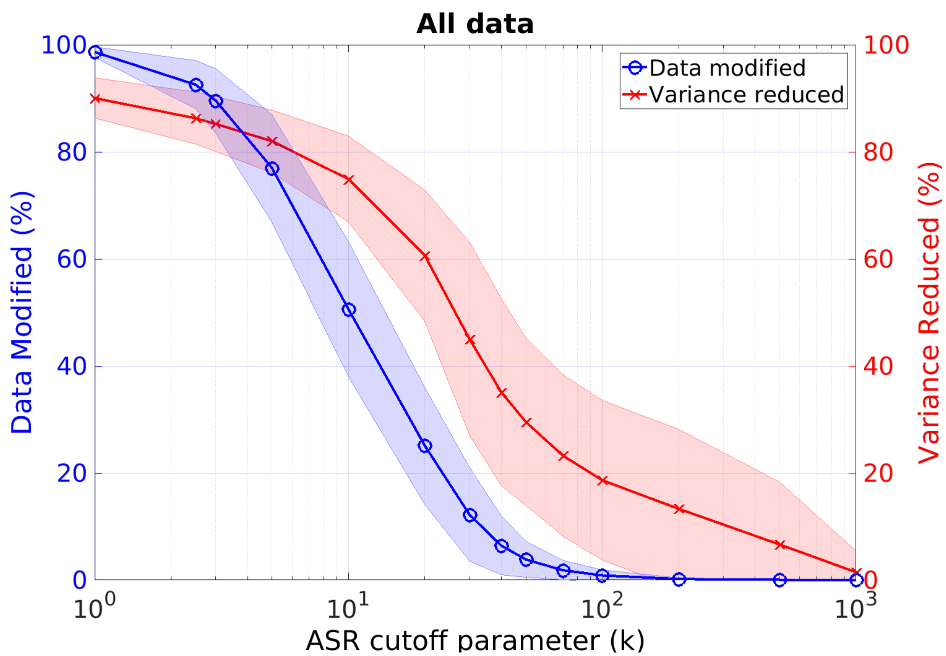


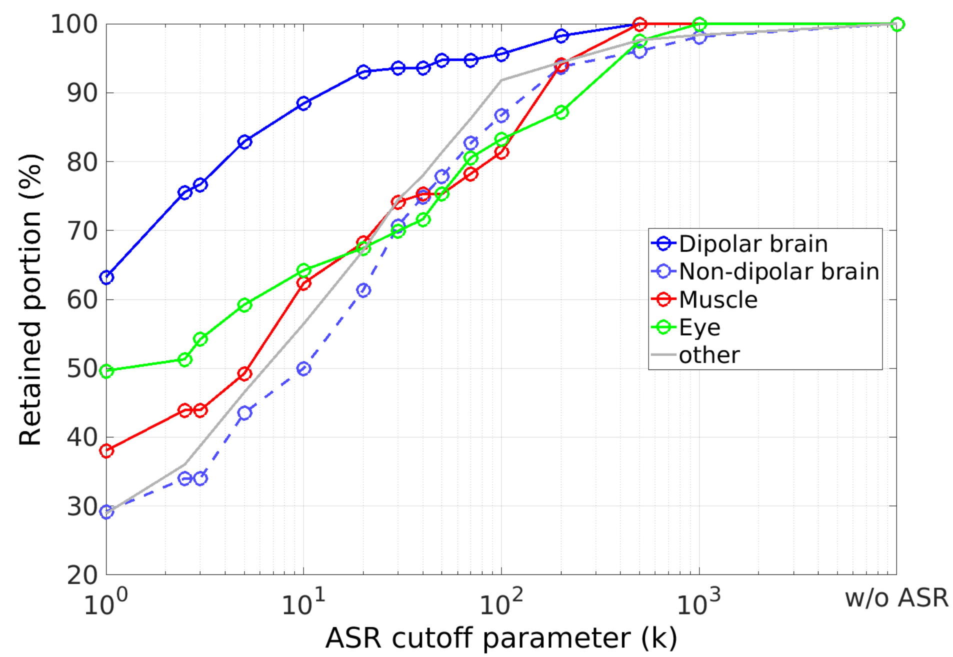
Chang, C. Y., Hsu, S.-H, Pion-Tonachini, L., and Jung, T. P., "Evaluating Artifact Subspace Reconstruction for Automatic Artifact Removal." *IEEE EMBC, 2018*

Evaluation of ASR: a general-purpose real-time automatic artifact rejection method



Subjects: 20 subjects
EEG Data: 30-channel EEG in a Lane-keeping driving task





Chang, C. Y., Hsu, S.-H, *et al.*, in preparation.

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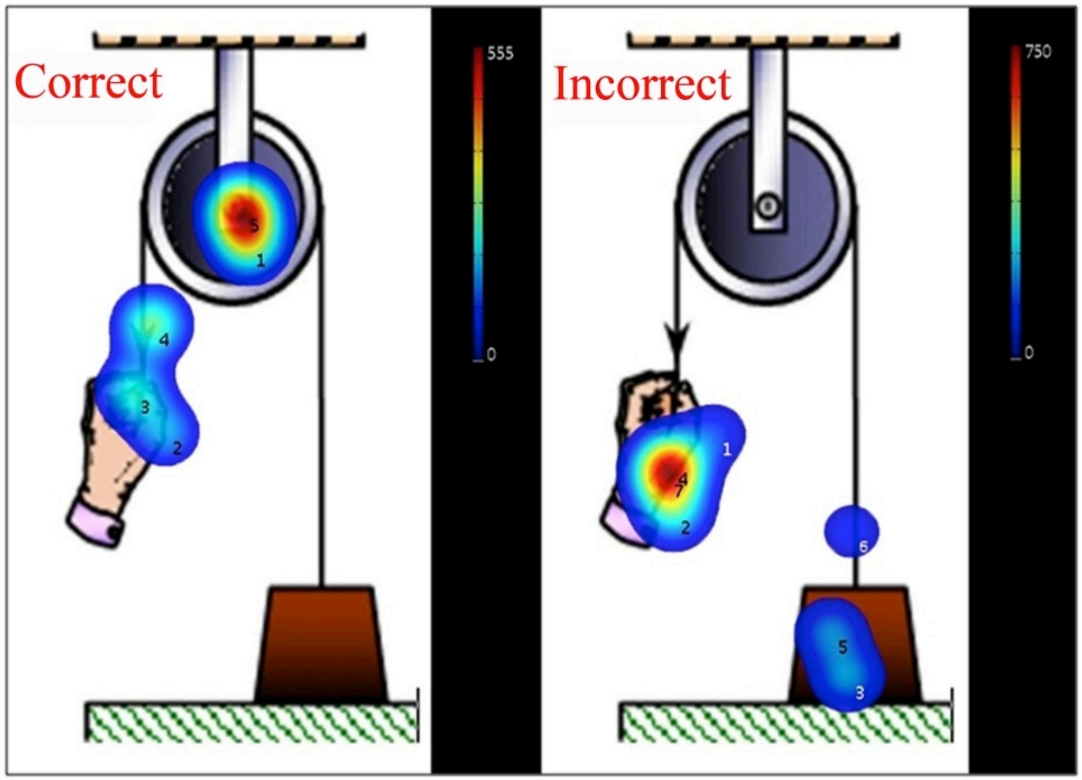
A Sample Multi-Modal Neuroimaging Study

This study uses a multi-modal approach (e.g. eye-gaze tracking and EEG) to explore students' underlying cognitive processes and brain dynamics during science learning.

Chen, She, et al. (2014). Eye movements predict students' computer-based assessment performance of physics concepts in different modalities. Computers & Education, 74 (61-72).

A Multi-modal Approach to Study Science Learning

N = 63 (undergraduate students)



Chen, She, et al. (2014). Eye movements predict students' computer-based assessment performance of physics concepts in different modalities. *Computers & Education*, 74 (61-72).

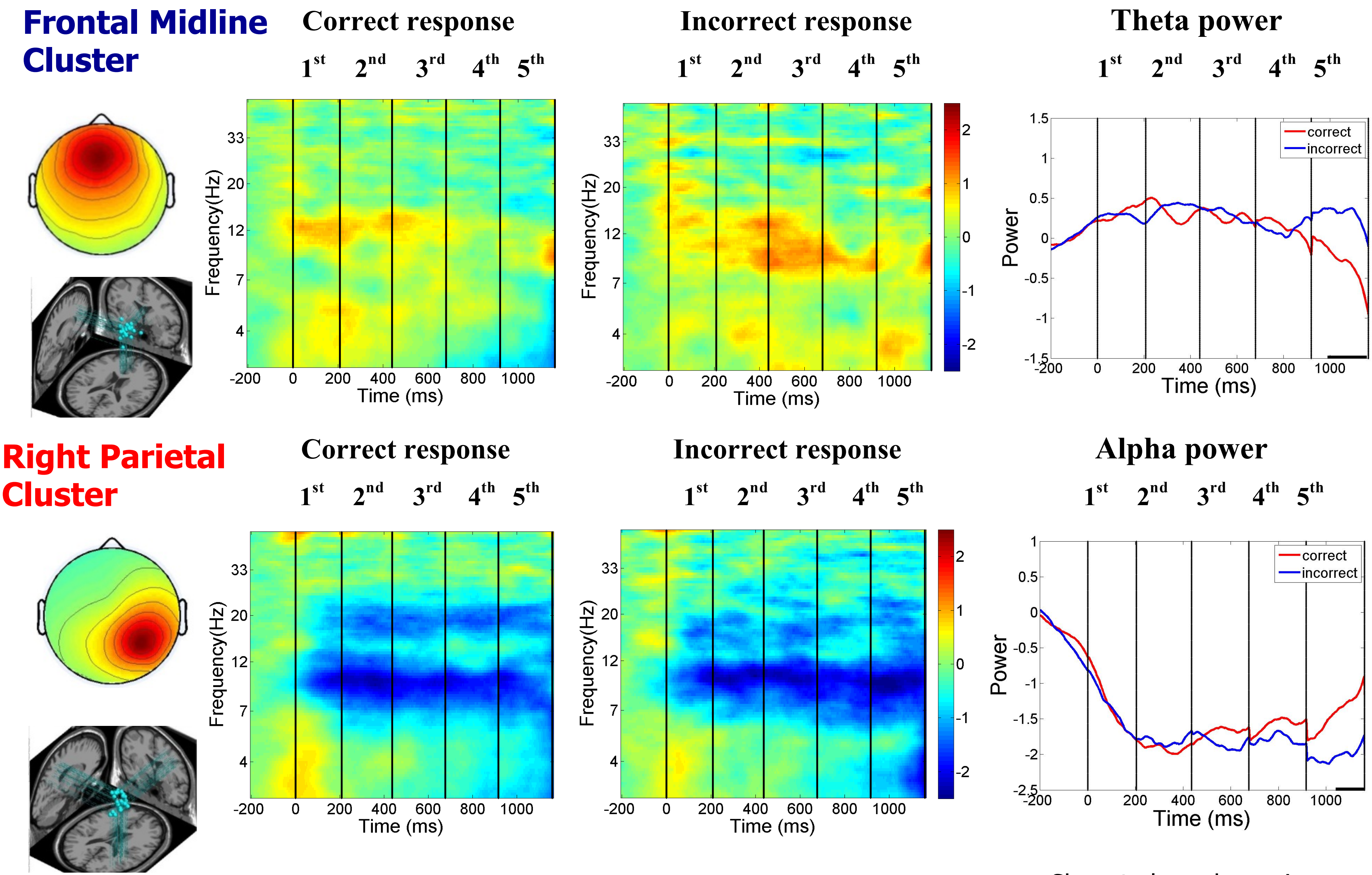
Table 3

The results of Generalized Estimating Equation (GEE) analysis of the fixation points' durations predicting students' likelihood of correct response in picture presentation modality.

Covariate	B [a]	SE	*p*	95% CI Low lim	95% CI Up lim
Intercept	0.099	0.218	0.650	-0.329	0.527
First 1 fixation point	-0.023	0.053	0.668	-0.127	0.081
First 2 fixation point	0.036	0.050	0.474	-0.062	0.134
First 3 fixation point	0.021	0.044	0.631	-0.065	0.108
First 4 fixation point	0.027	0.045	0.539	-0.060	0.115
First 5 fixation point	0.116***	0.029	0.000	0.060	0.173

The odds of students' providing accurate responses ($e^{0.116} = 1.123$) increased by *12.3%* for every 100 ms increase at the 5th fixation point.

Fixation-locked EEG Dynamics



She, et al., under review.

Summary

- Low-cost multi-modal systems for measuring and synchronizing neural, physiological, and behavioral data from unconstrained subjects in virtual and real-world environments.
- Signal-processing techniques to automatically remove pervasive artifacts of the MoBI data collected in virtual and real-world environments.
- Pilot data showed that eye movements and fixation-locked EEG spectral changes can predict the likelihood of responding with correct answers in science leaning.

Thank you for your attention!

Questions and Comments?

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