Practical Applications of Wearable EEG

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Outline

- Challenges in Real-World EEG
- Sample applications of wearable EEG

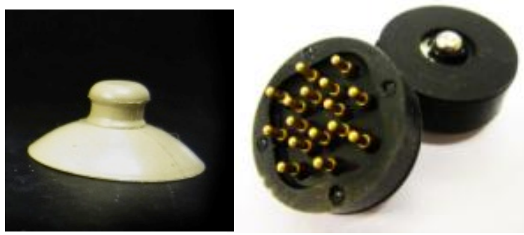
Challenges in Real-World Neuroimaging

- ☐ We lack new sensors and technologies to measure high-quality *neural, physiological, behavioral, and contextual* data in real-world environments.
- ☐ We need advanced signal-processing and machine-learning algorithms to jointly analyze multi-modal data.

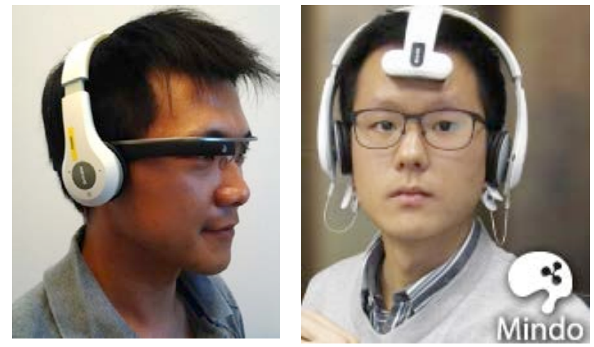
Setting up an EEG Experiment is Laborious and Time-consuming

Non-prep EEG Sensors and Systems

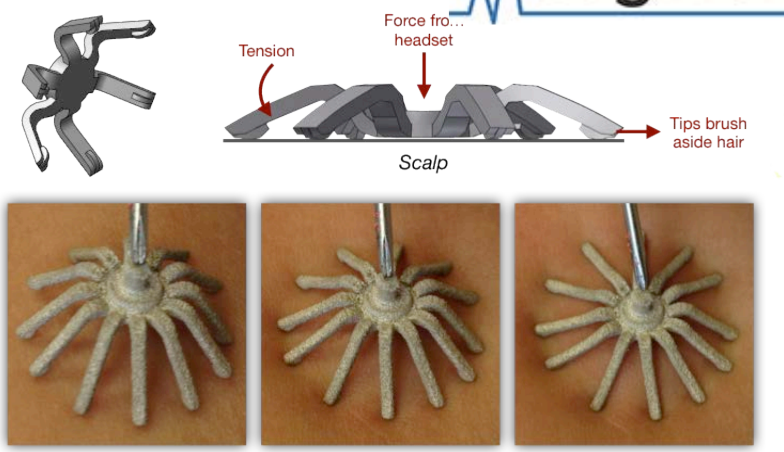
Dry and non-prep EEG sensors



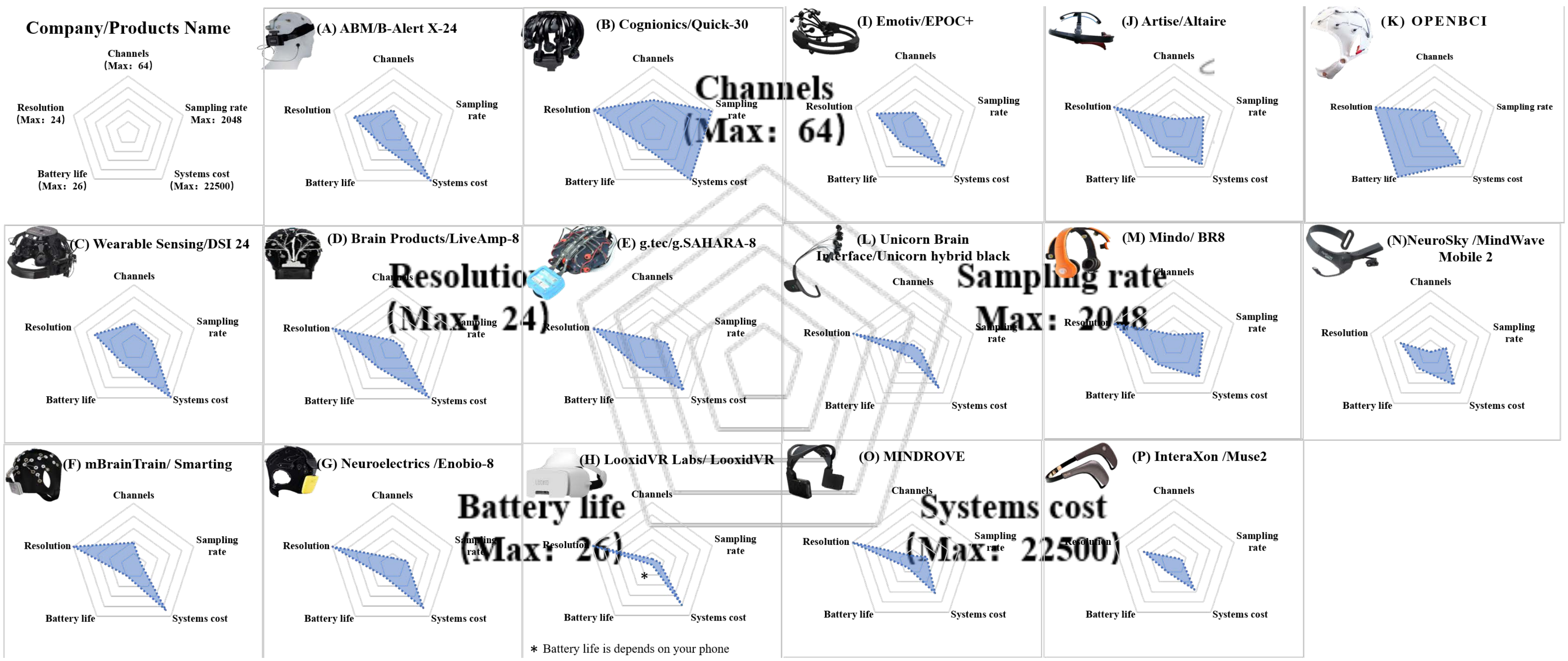
Wearable EEG Headgears



Cognionics High-density (64-chan) EEG Cap



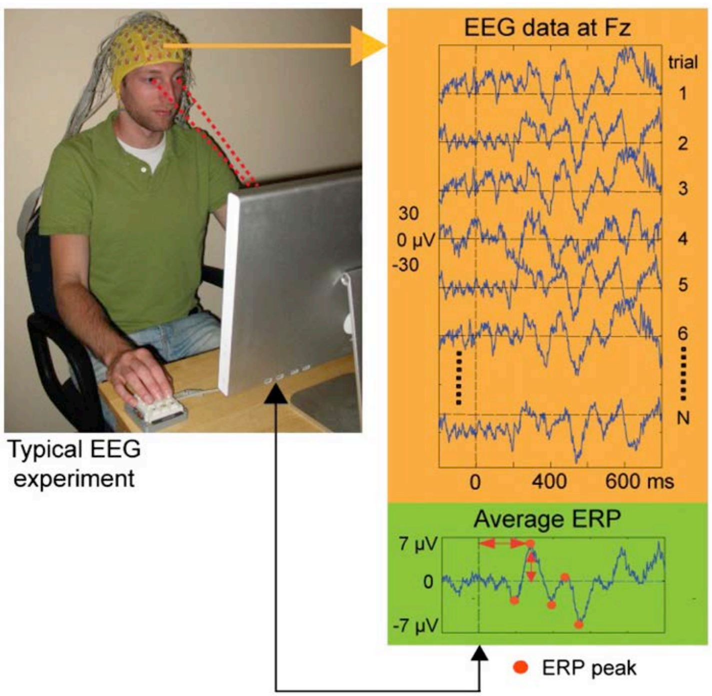
Wireless EEG Systems on the Market

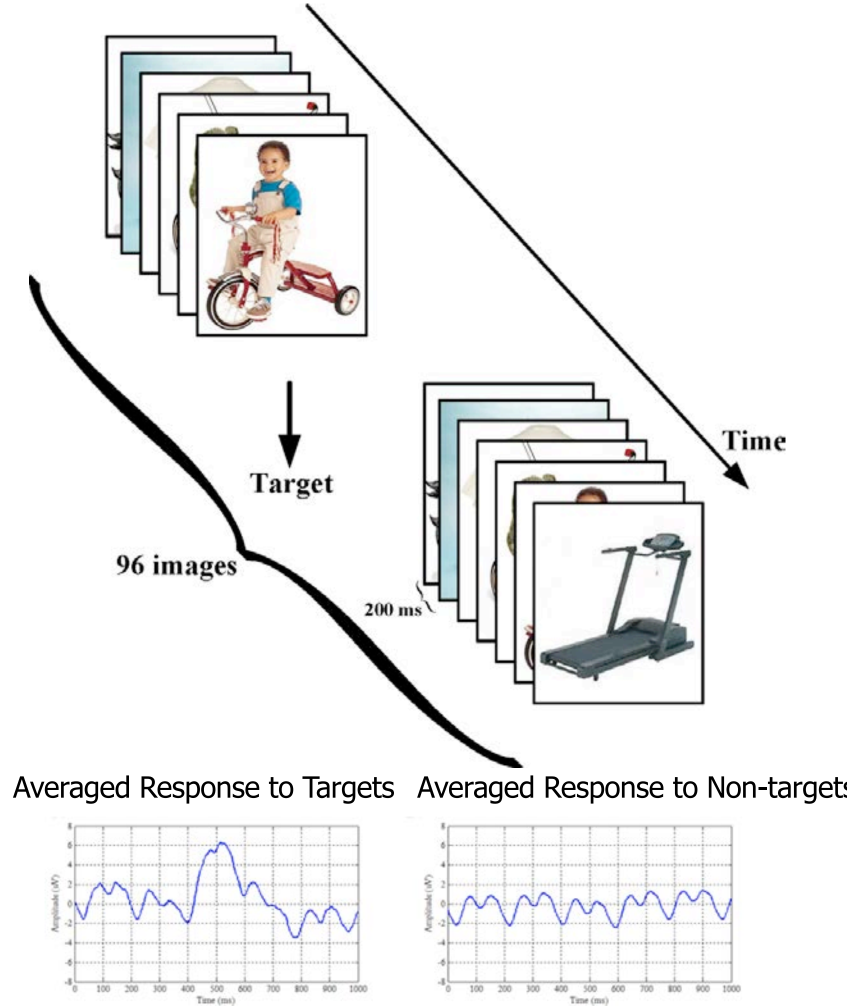


He *et al.*, under review.

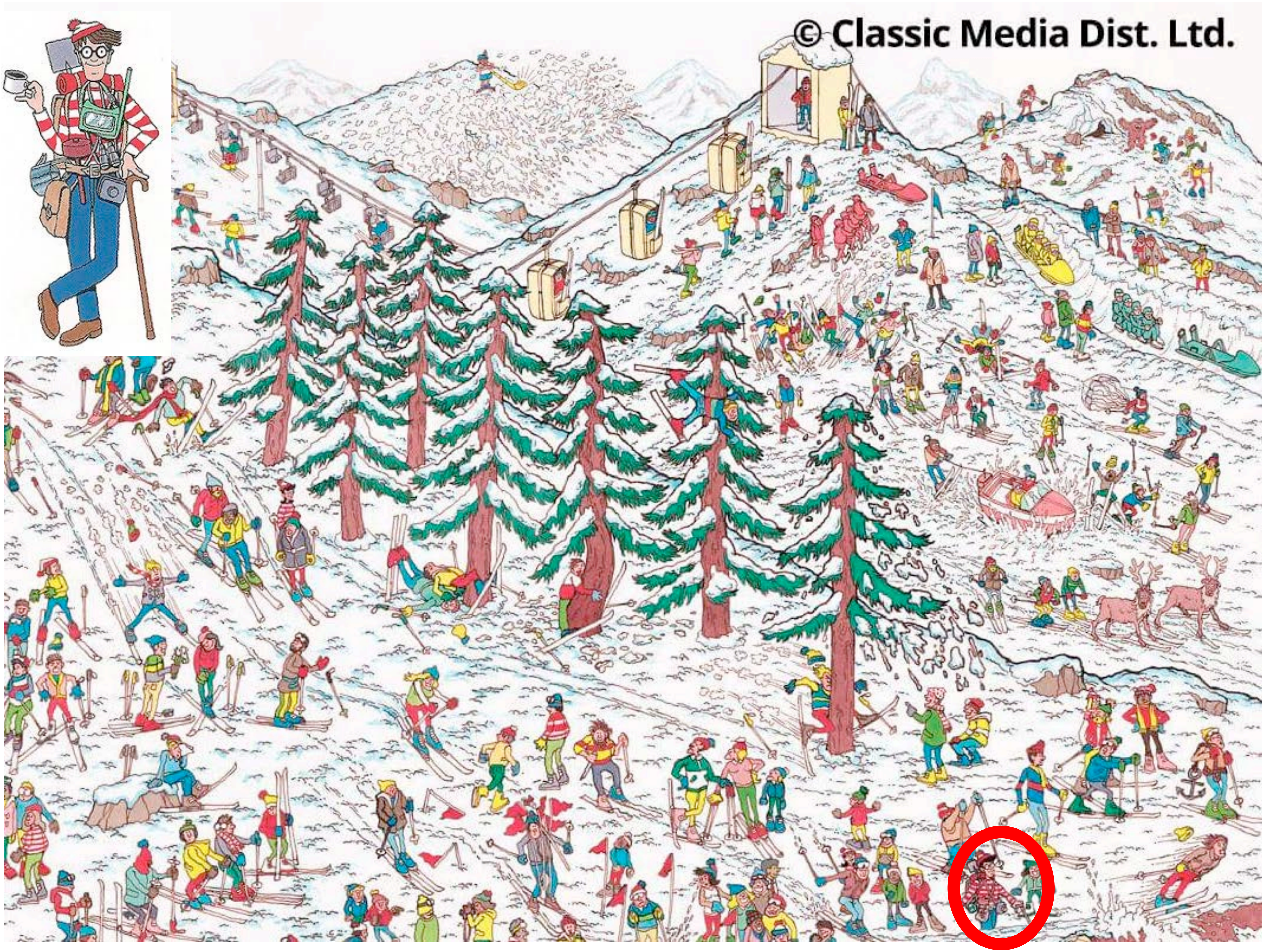
ERP in a Well-controlled Laboratory

Laboratory Research





Zhimin Lin, *et al*., *PLoS ONE*, 2017.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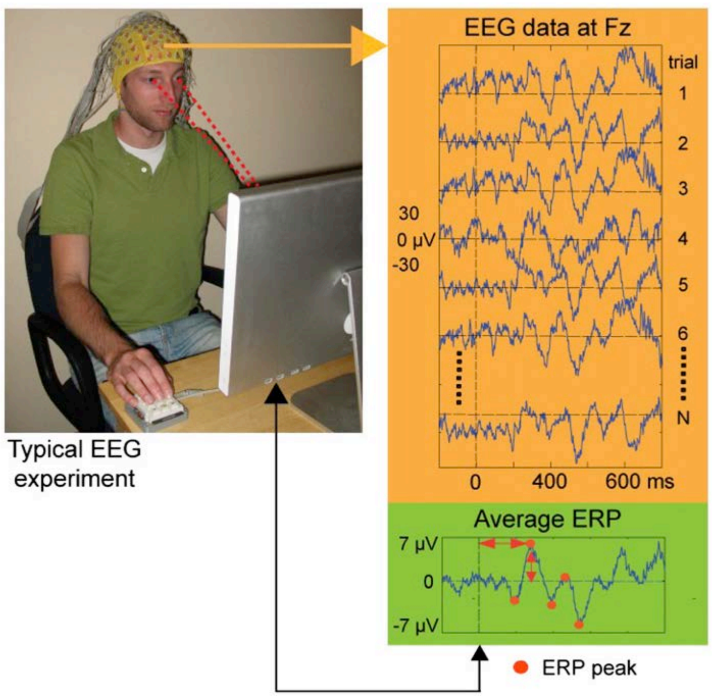
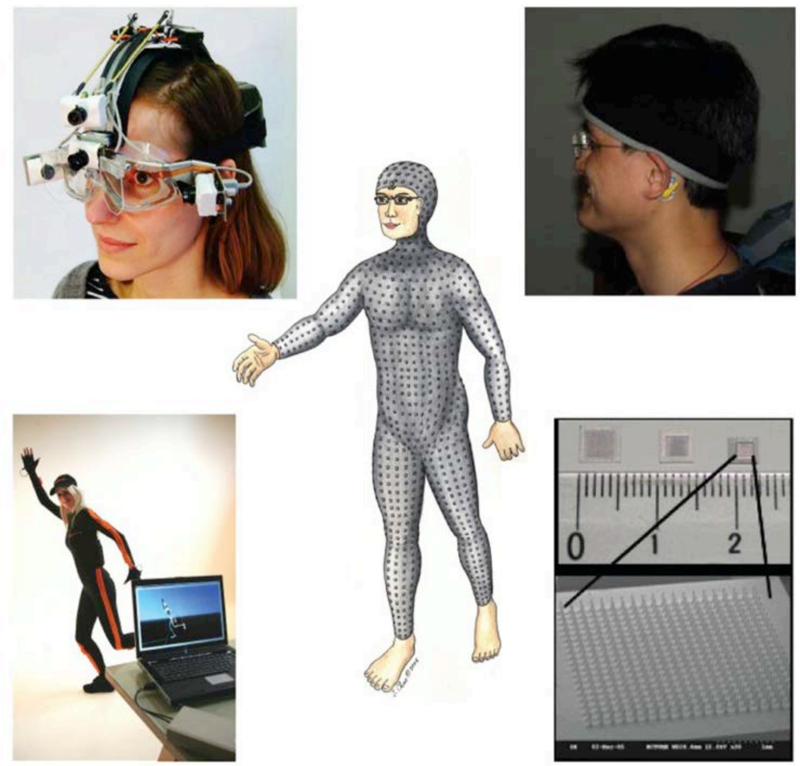
Mobile Brain/Body Imaging (MoBI)

Laboratory Research



Real-world Neuroimaging



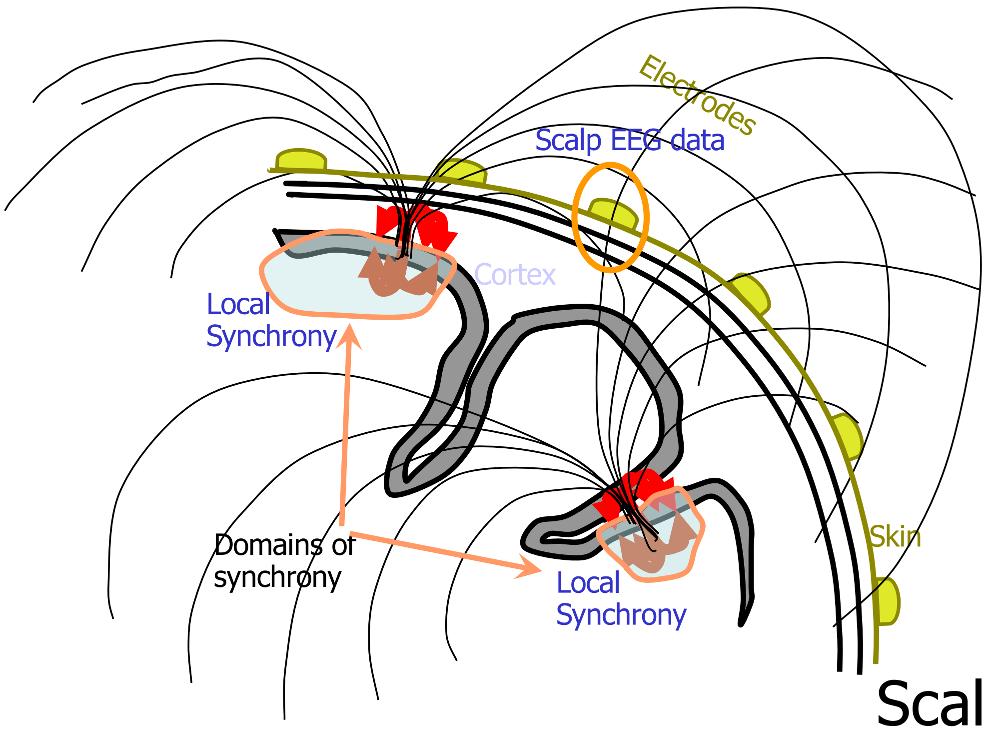
Makeig, et al., *Int'l Journal of Physiology*, 2009

Challenges in Real-World Neuroimaging

☑ New sensors and technologies to measure high-quality *neural, physiological, behavioral, and contextual* data in real-world environments.

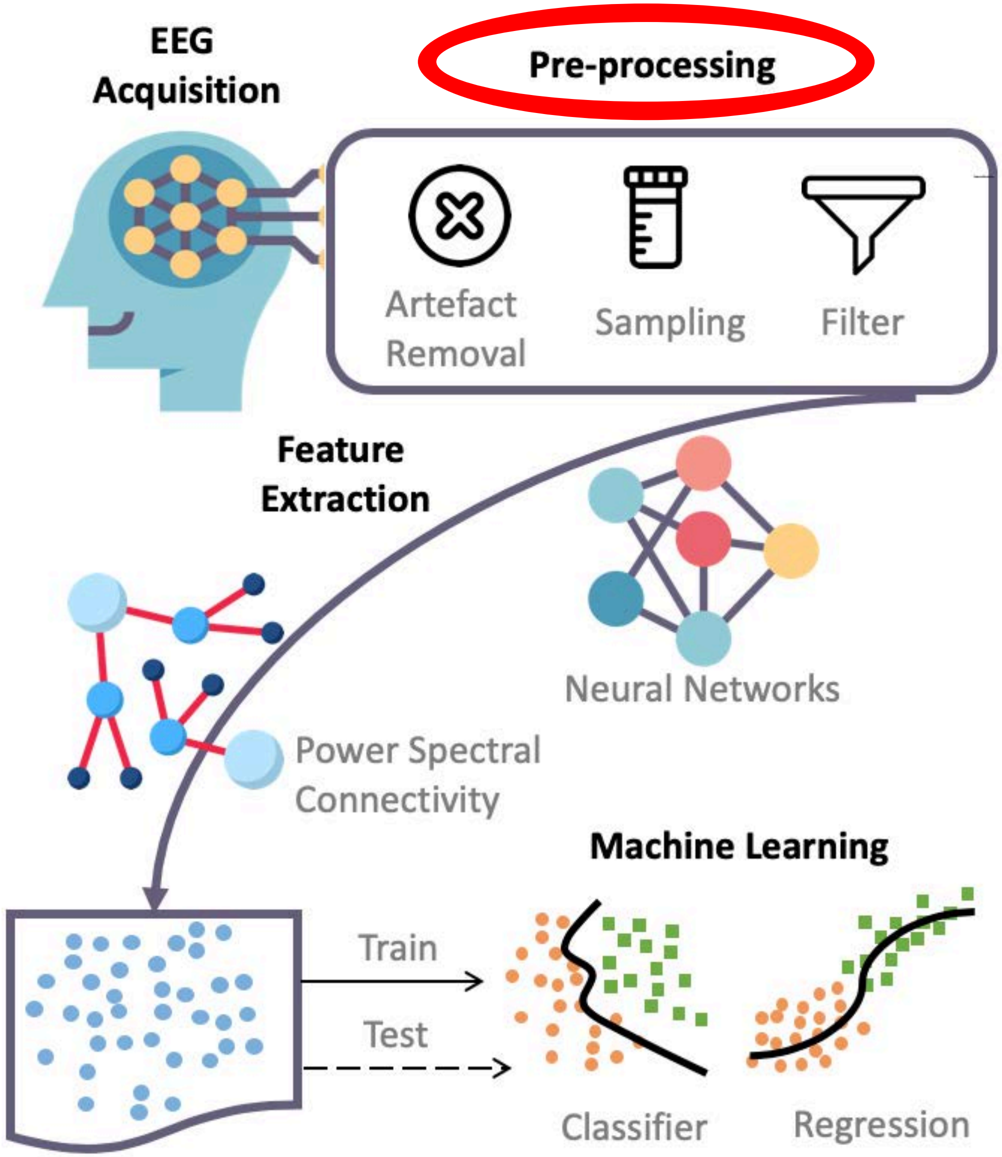
☐ Advanced signal-processing and machine-learning algorithms to jointly analyze multi-modal data.

Difficulties in Observing Distributed EEG dynamics



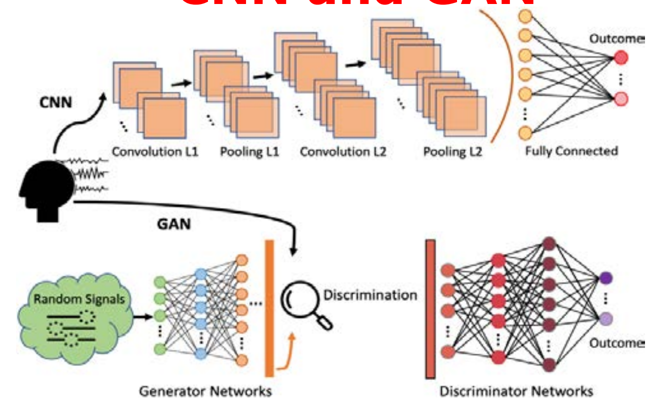
Scalp EEG signals appear to be noisy because they are a mixture of signals generated in many brain areas.

Biomedical Data Processing

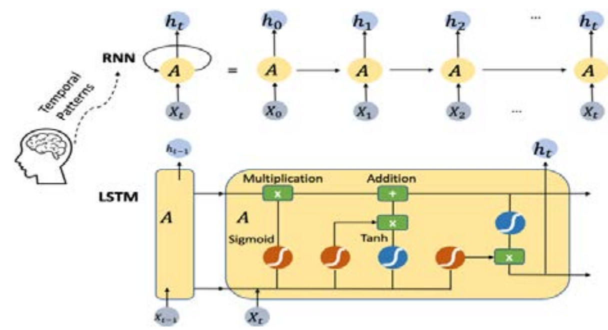


Gu *et al. IEEE/ACM Trans. on Computational Biology and Bioinformatics*, 2020.

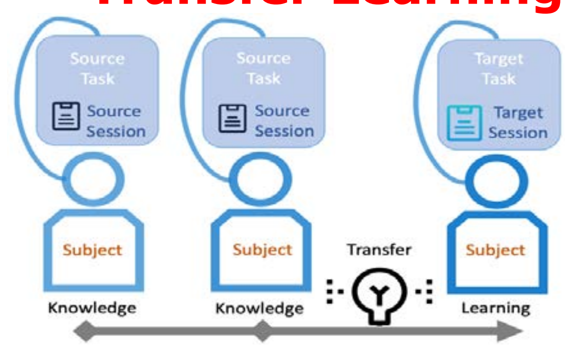
CNN and GAN



RNN and LSTM



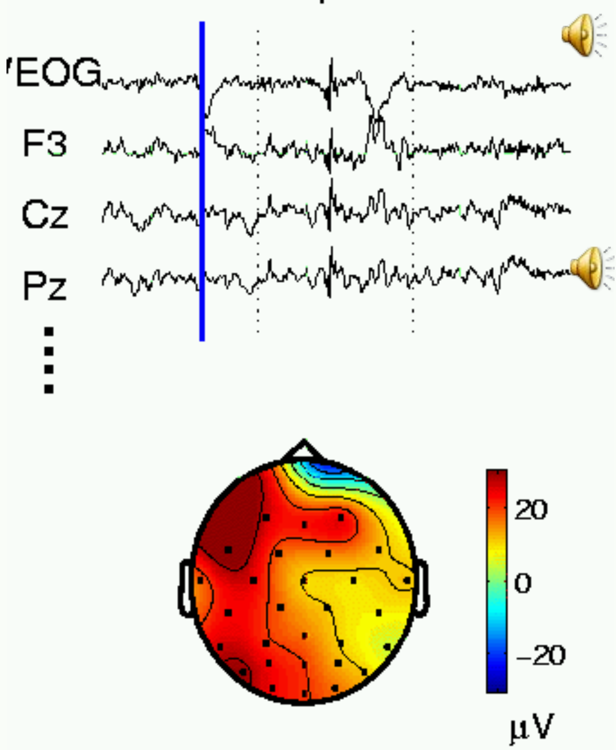
Transfer Learning



Independent Component Analysis

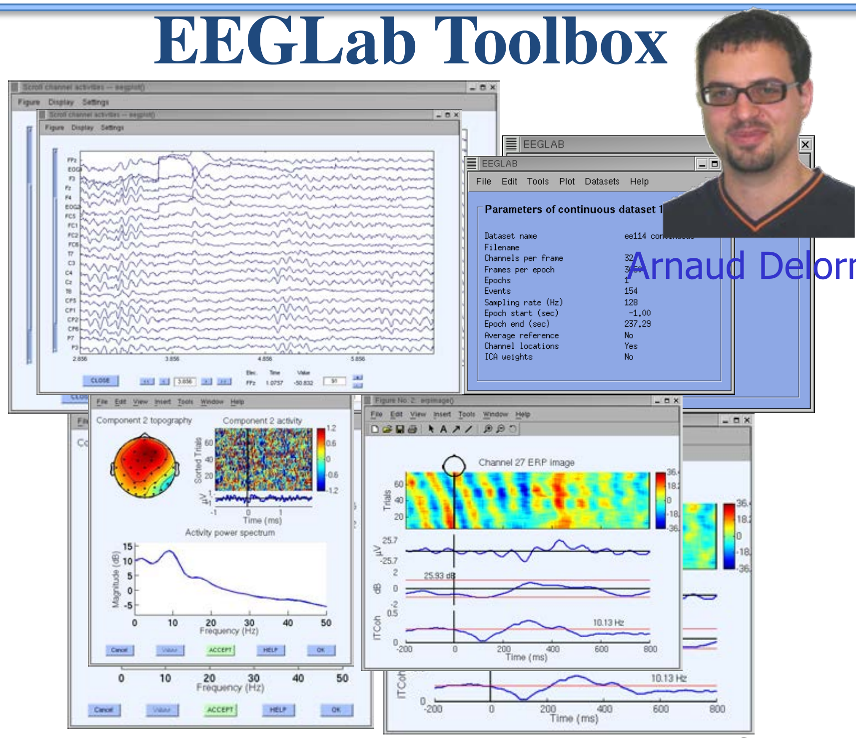
Courtesy of SoftMax, Inc

EEG Scalp Channels



Off-line Analysis and Visualization of EEG Source Dynamics

EEGLab Toolbox



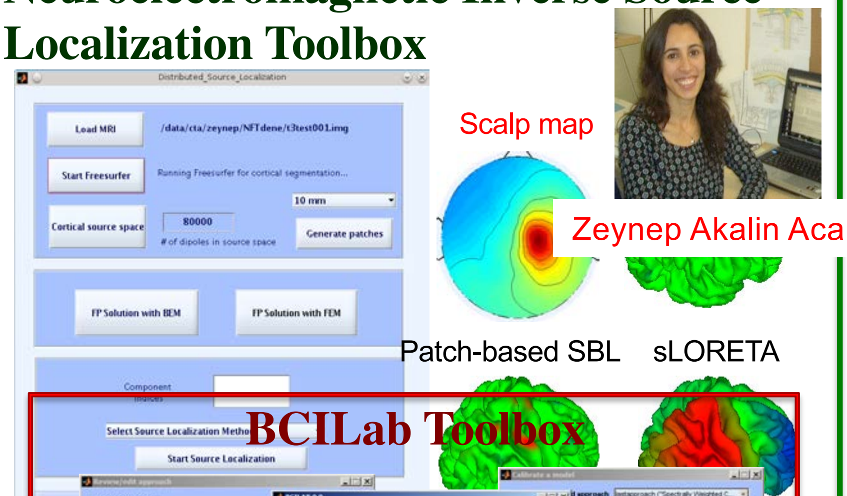
Arnaud Delorme

EEGLAB – An Open Source Environment for Electrophysiological Research

Over 250,000+ downloads over the past 15 years!

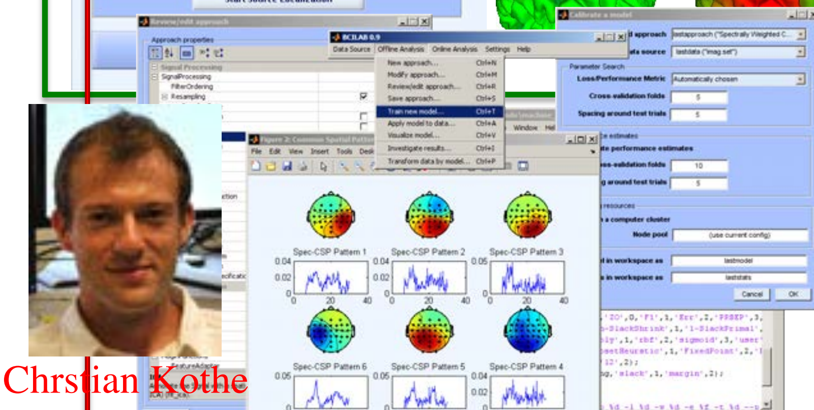
Over 11,000 citations

Neuroelectromagnetic Inverse Source Localization Toolbox



Zeynep Akalin Acar

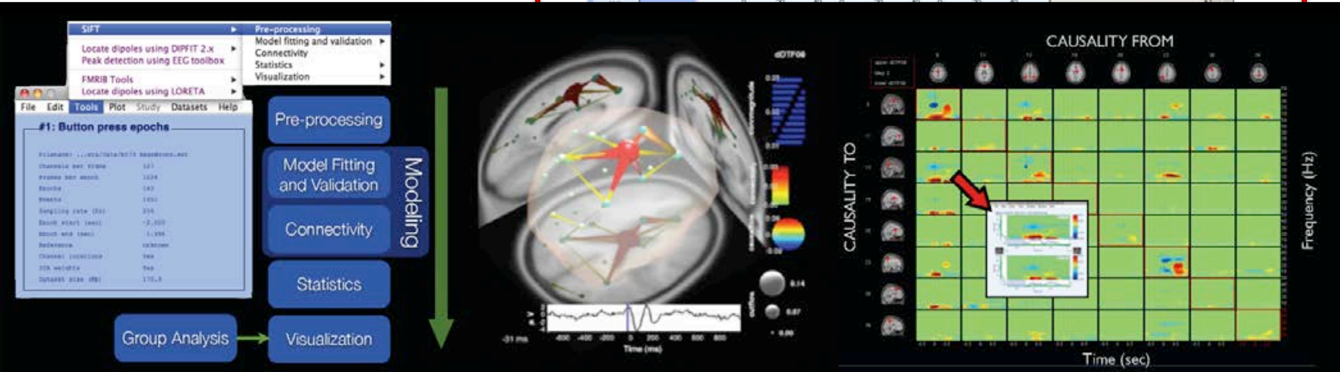
BCILab Toolbox



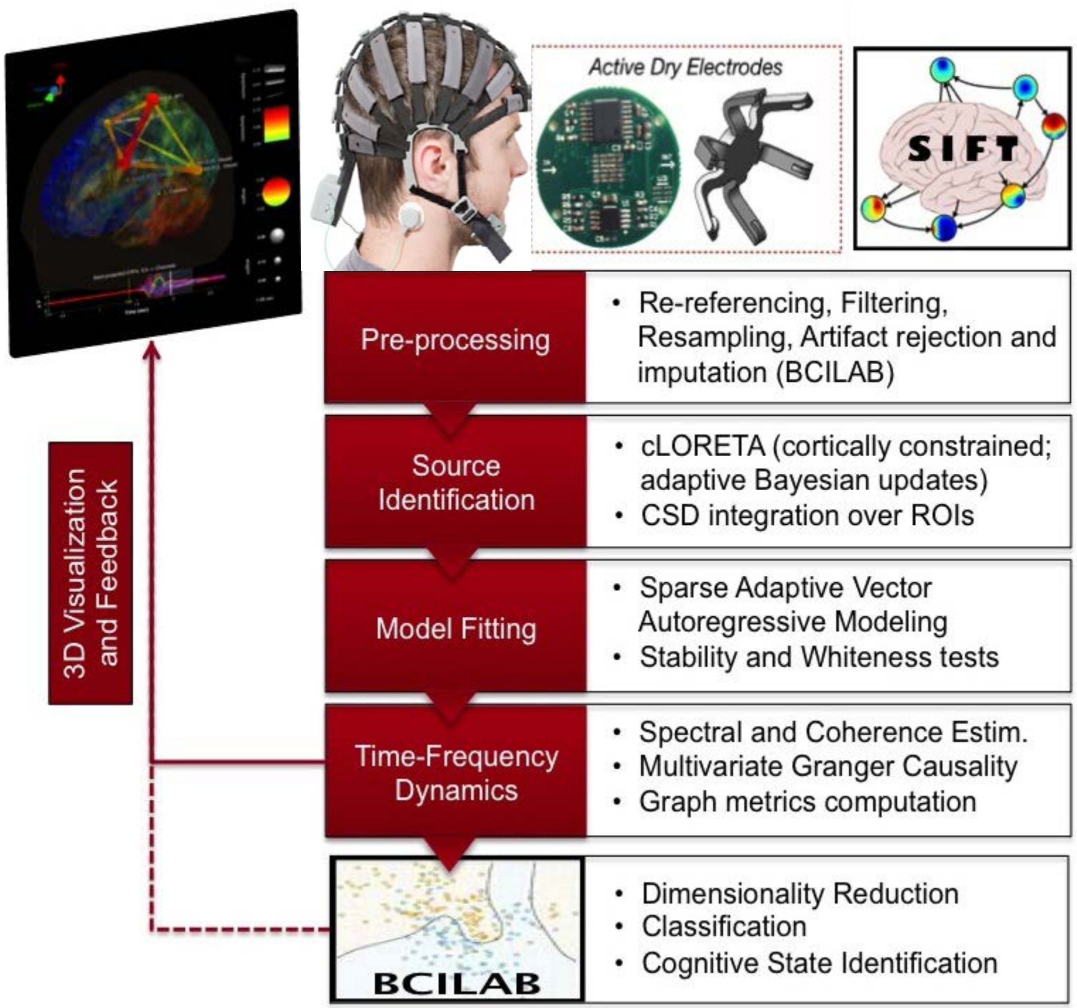
Chrstian Kothe

Source Information Flow Toolbox (SIFT)

Tim Mullen

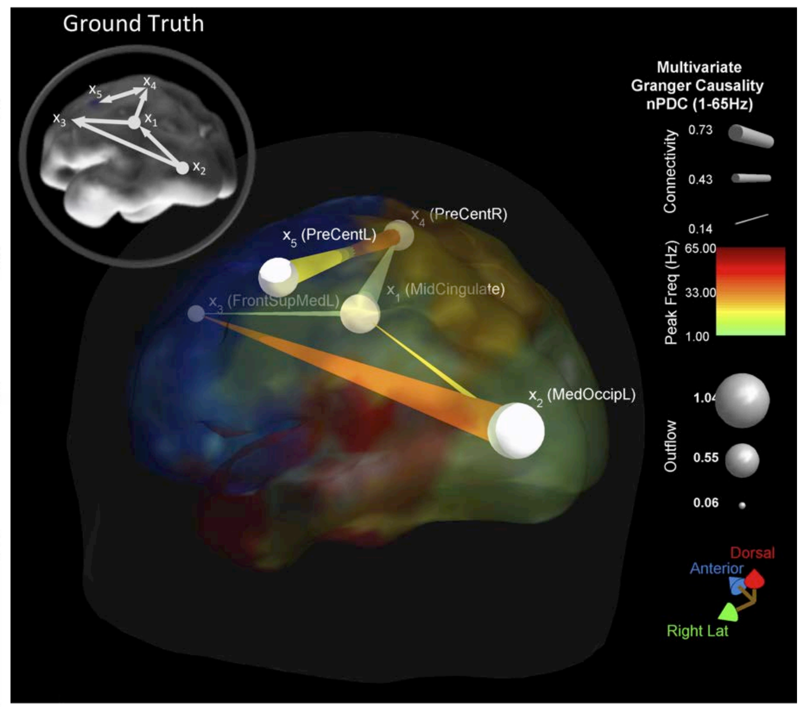


Real-time Data Processing Pipeline




Tim Mullen


Christian Kothe



Mullen et al., Best Technical Poster of *International BCI Meeting*, Asilomar, CA, 2013.
Mullen et al., *IEEE TBME,* 2015.
UCSD Chancellor's Dissertation Award, 2015.

Outline

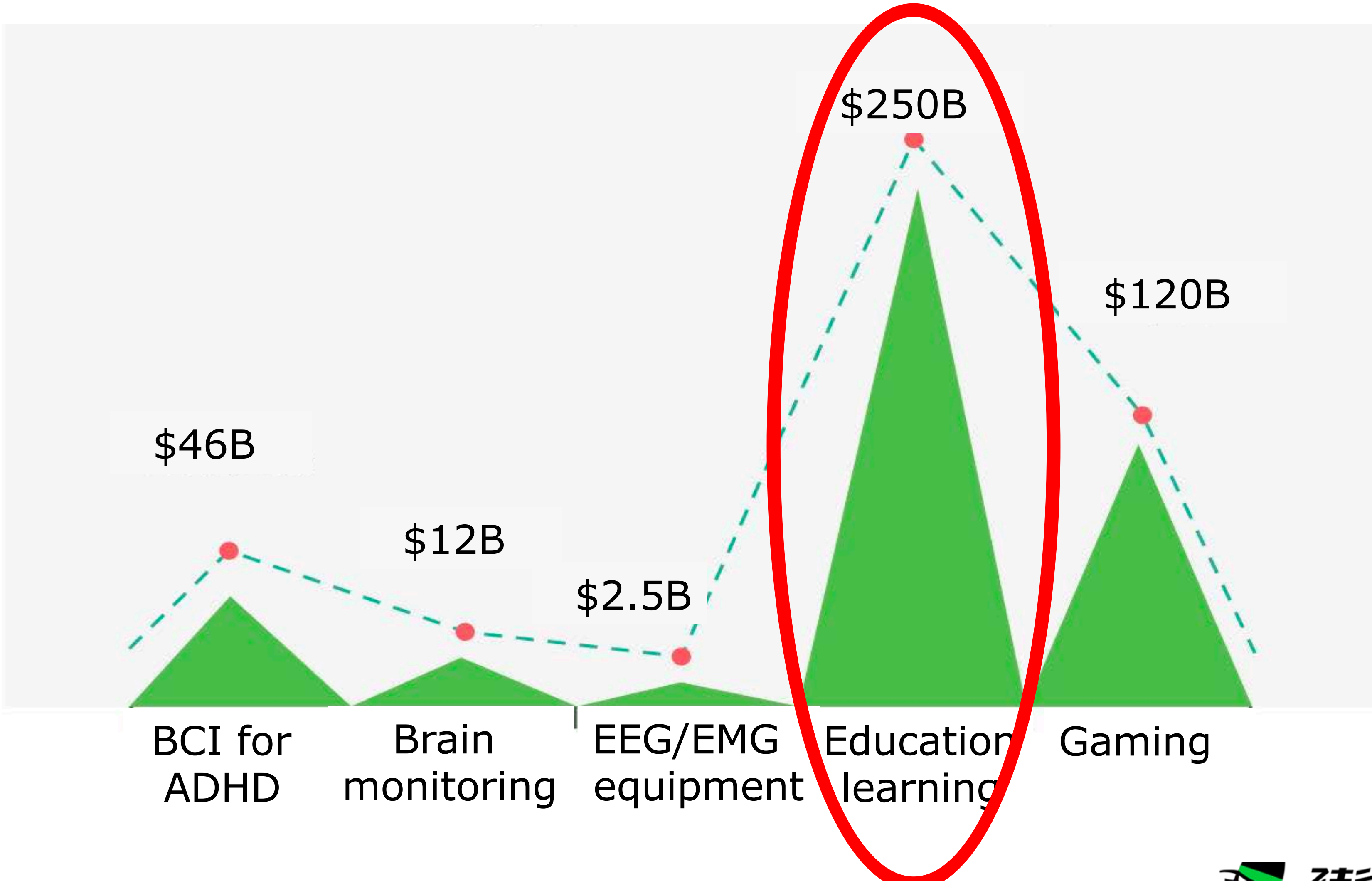
- Challenges in Real-World EEG
- Sample applications of wearable EEG

Global BCI Market Research Report

- Silicon Valley Live (service number: guigumitanv), scientists at the Brain Science Center of Harvard University, and industry experts jointly published an analysis of the brain-computer interface industry in China and the United States in 2017. The article described the technical aspects of BCI, summarized the past, present and future of BCI, and discussed trends in the commercialization of BCIs.
- “硅谷 Live（服务号：guigumitanv）联合哈佛大学脑科学中心科学家及行业专家学者，共同打造中美首份脑机接口行业分析长文，深度解构脑机接口领域技术路线，描绘脑机接口商业化趋势及学科地图，预见前所未见。

Source：硅谷密探 探秘全球科技精华

Estimated BCI Markets



A Sample Multi-modal Neuroimaging Study in Science Learning

Hsiao-Ching She, Chih-Ping Liang, Li-Yu Huang, Wen-Chi Chou, Sheng-Chang Chen, Ming-Hua Chuang, Jiun-Yu Wu, Jie-Li Tsai, and Tzyy-Ping Jung

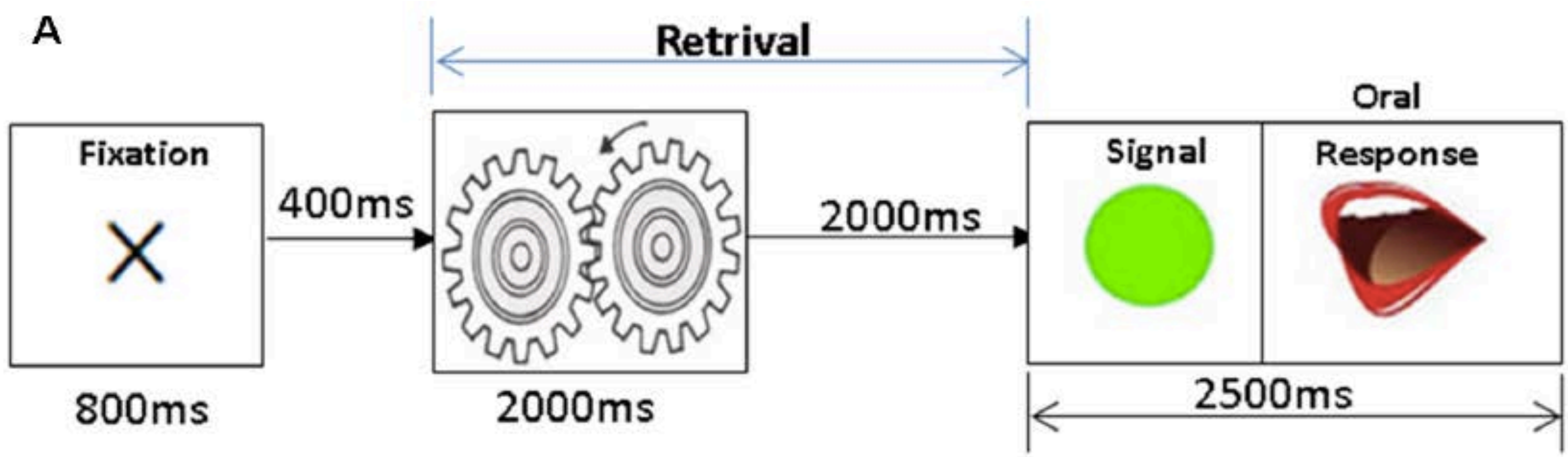
National Chiao Tung University and UC San Diego

- Chen, She, et al. (2014). Eye movements predict students' computer-based assessment performance of physics concepts in different modalities. *Computers & Education*, 74 (61-72).
- Tsai, She, et al., (2019). Eye fixation-related fronto-parietal neural network correlates of memory retrieval *International Journal of Psychophysiology,* 138 (57-70).
- Liang, She, et al. (2020). "Human Brain Dynamics Reflect the Correctness and Presentation Modality of Physics Concept Memory Retrieval." *Frontiers in Human Neuroscience* 14. 331.

Science Learning

Participants N = 63 (undergraduate students)

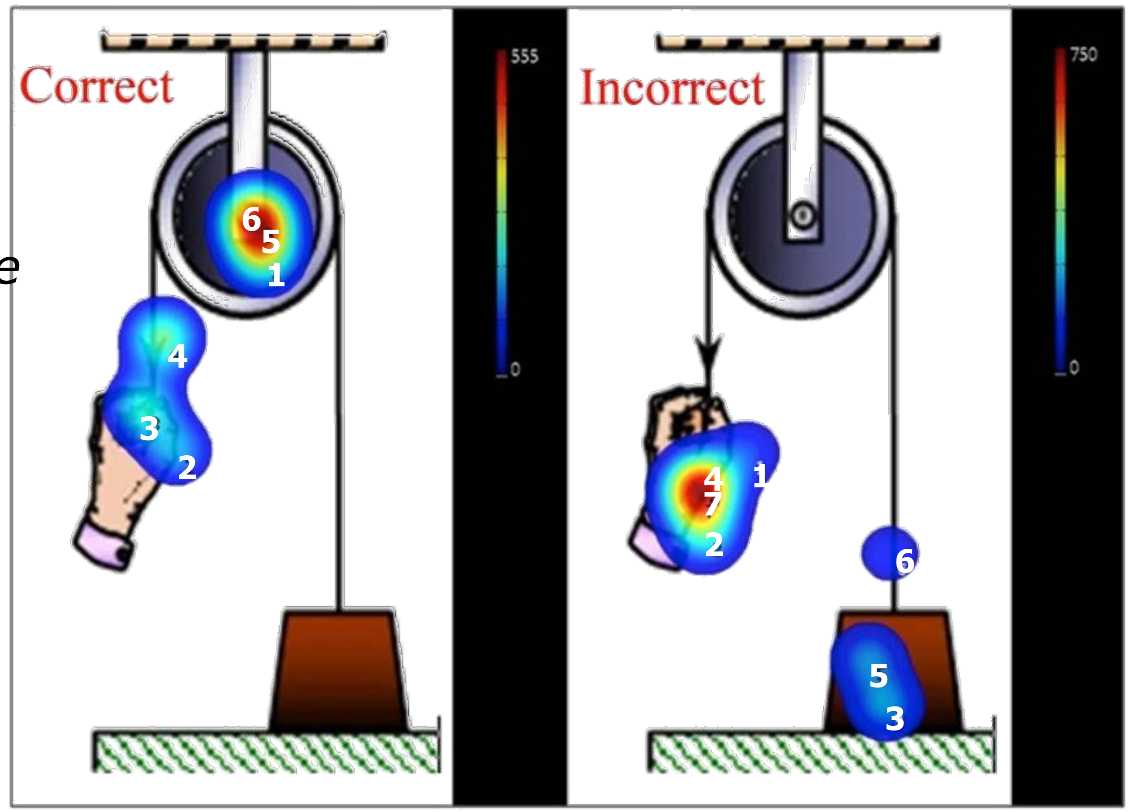
Experimental procedure



Chen, She, et al. *Computers & Education*, 74 (61-72), 2014.
Tsai, She*, et al*., *International Journal of Psychophysiology*, 2019.

A Multi-modal Approach to Study Science Learning

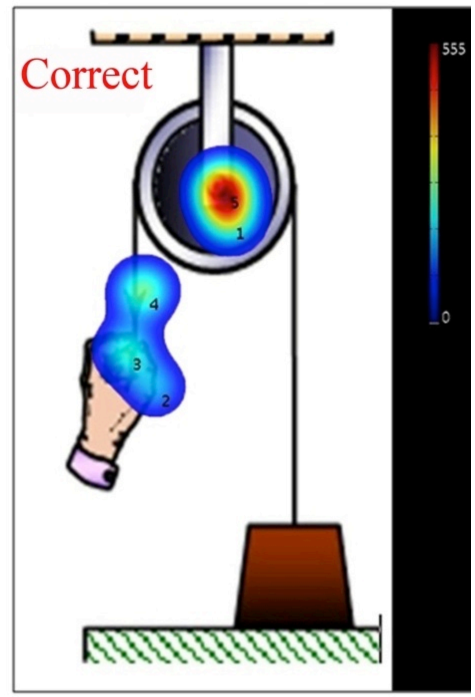
N = 63 (undergraduate students)



Chen, She, et al. *Computers & Education*, 74 (61-72), 2014.

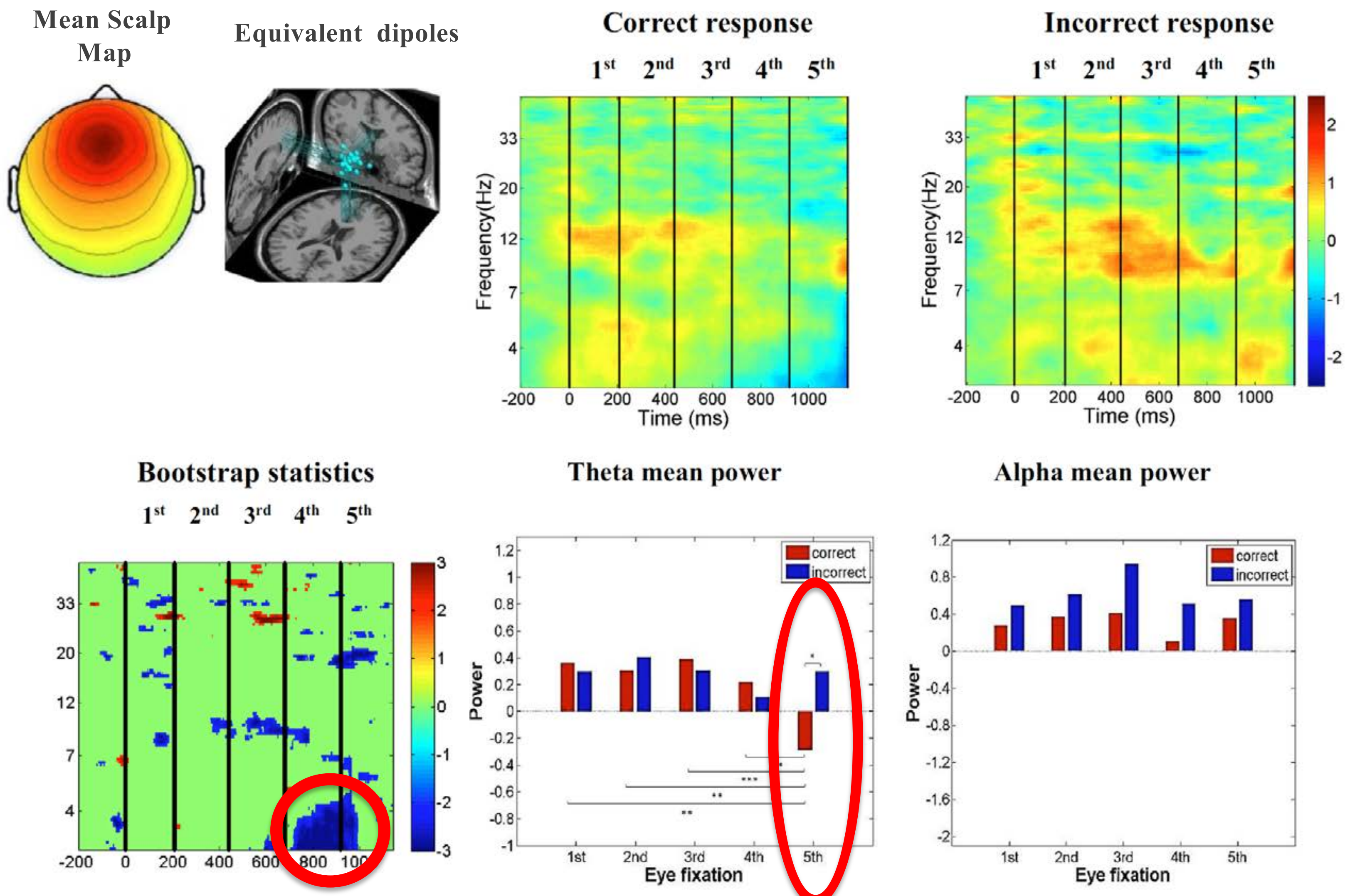
Fixation Durations Predicts Students' Performance

Covariate	B^{a}	SE	p	95% CI Low
Intercept	0.099	0.218	0.650	-0.3
First 1 fixation point	-0.023	0.053	0.668	-0.1
First 2 fixation point	0.036	0.050	0.474	-0.0
First 3 fixation point	0.021	0.044	0.631	-0.0
First 4 fixation point	0.027	0.045	0.539	-0.0
First 5 fixation point	0.116***	0.029	0.000	0.0



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-related Spectral Perturbations of the Frontal-midline Cluster



Tsai, She, *et al*., *International Journal of Psychophysiology*, 2019.

Multi-modal Neuroimaging: From Lab to Classroom

Li-Wei Ko, Oleksii Komarov, W. David Hairston, Tzyy-Ping Jung, Chin-Teng Lin

National Chiao Tung University,

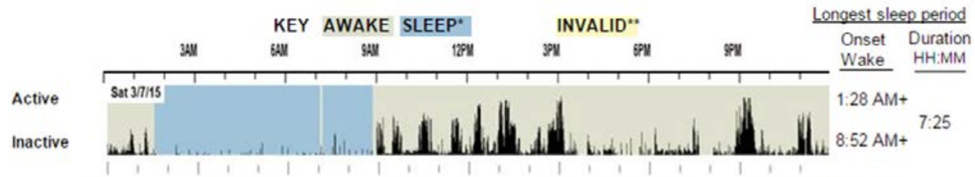
UC San Diego

US Army Research Lab

A Wearable Daily Sampling System (WDSS)

1. Objective measurements

The ReadiBand objectively measures sleep quality



Fatigue Group	Effectiveness Score	Reduced Reaction Time	Blood Alcohol Equivalence (BAC %)	Risk of Accident/ Serious Error
Normal	90-100%	5%	0.00%	Very Low
Reduced	80-90%	18%	0.00%	Low
	70-80%	34%	0.05%	Elevated
High Risk	60-70%	55%	> 0.08%	High
	0-60%	100%	> 0.11%	Very High

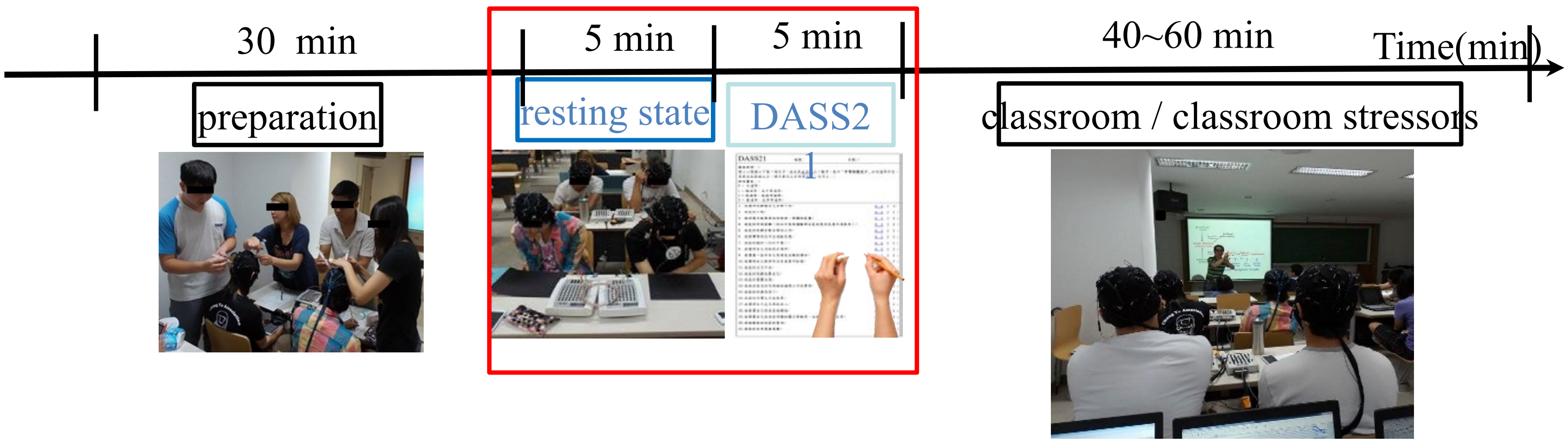
2. Subjective measurements

Subjective estimates of fatigue and stress are logged on a smartphone

- Karolinska Sleepiness Scale (KSS, scale 1-9)
- Fatigue Visual Analog Scale (FVAS, scale 0-100)
- Pittsburgh Sleep Diary (PSD)
- Stress Visual Analog Scale (SVAS, scale 0-100)
- Depression Anxiety Stress Scales (DASS-21)

A Longitudinal Study of the Effects of Stress on Neurophysiology and Task Performance

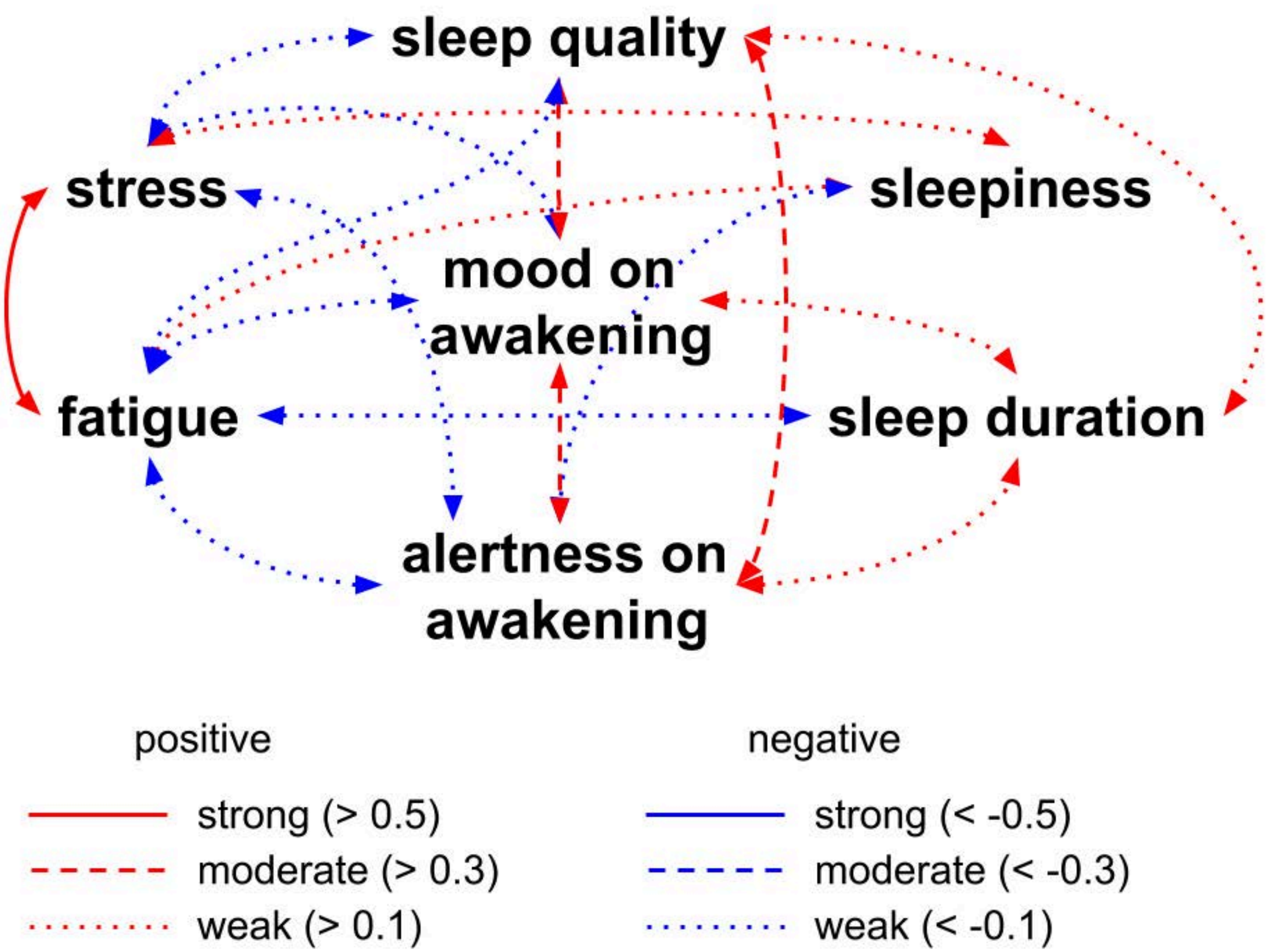
- This pilot study has collected 197 sessions of EEG/behavioral data from 26 (18+8) students over two 20-week semesters.
- Students' resting EEG data were collected under the eyes-open condition for 5 minutes, followed by a DASS21 test before classes.



- Classroom stressors: examination (midterm & final), quiz, teacher asked subjects questions, teacher monitored the subjects to answer the exam.

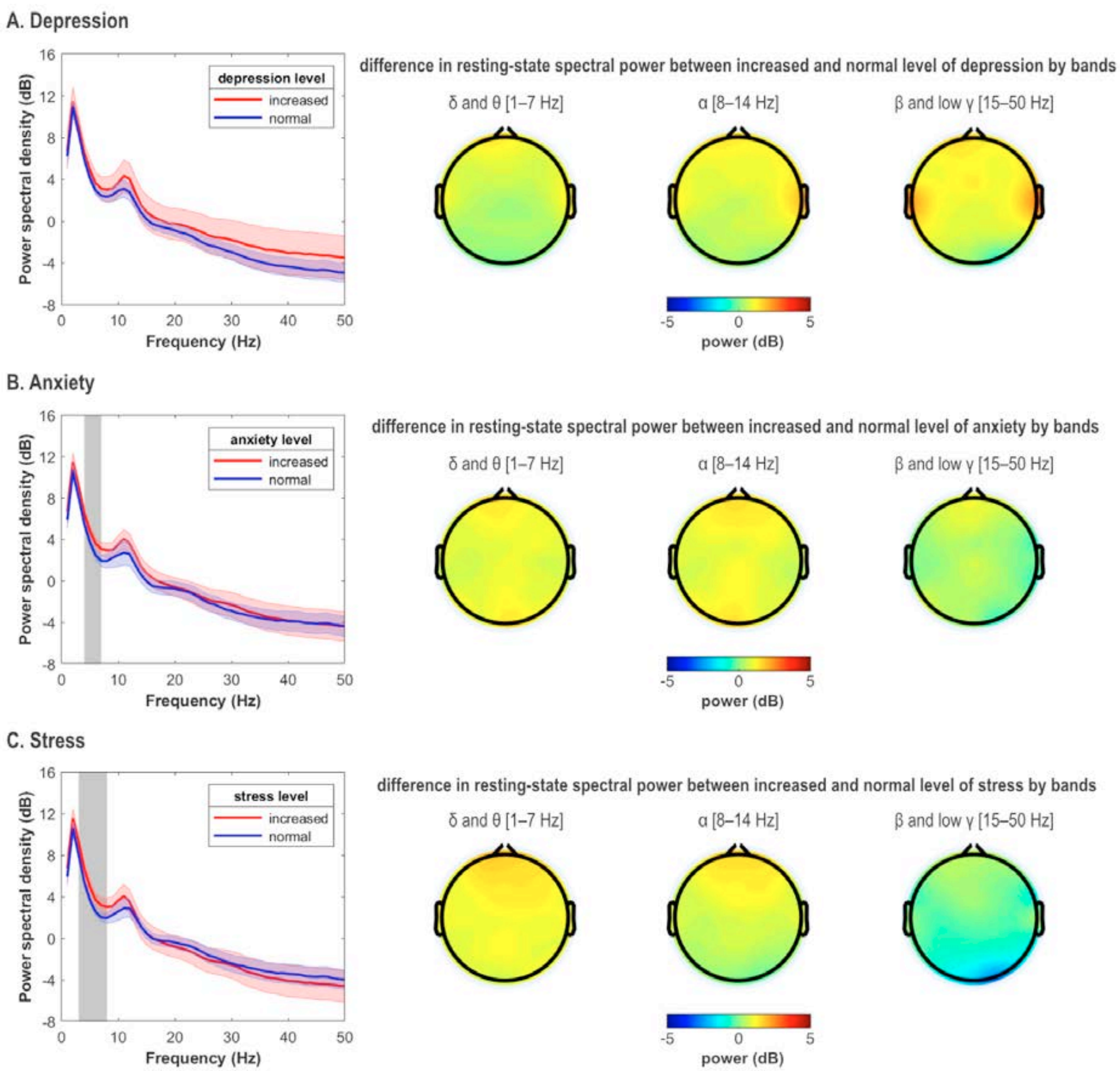
Ko *et. al.*, *Frontiers in Human Neuroscience*, 2017.

Correlations between Daily Sampling Measurements



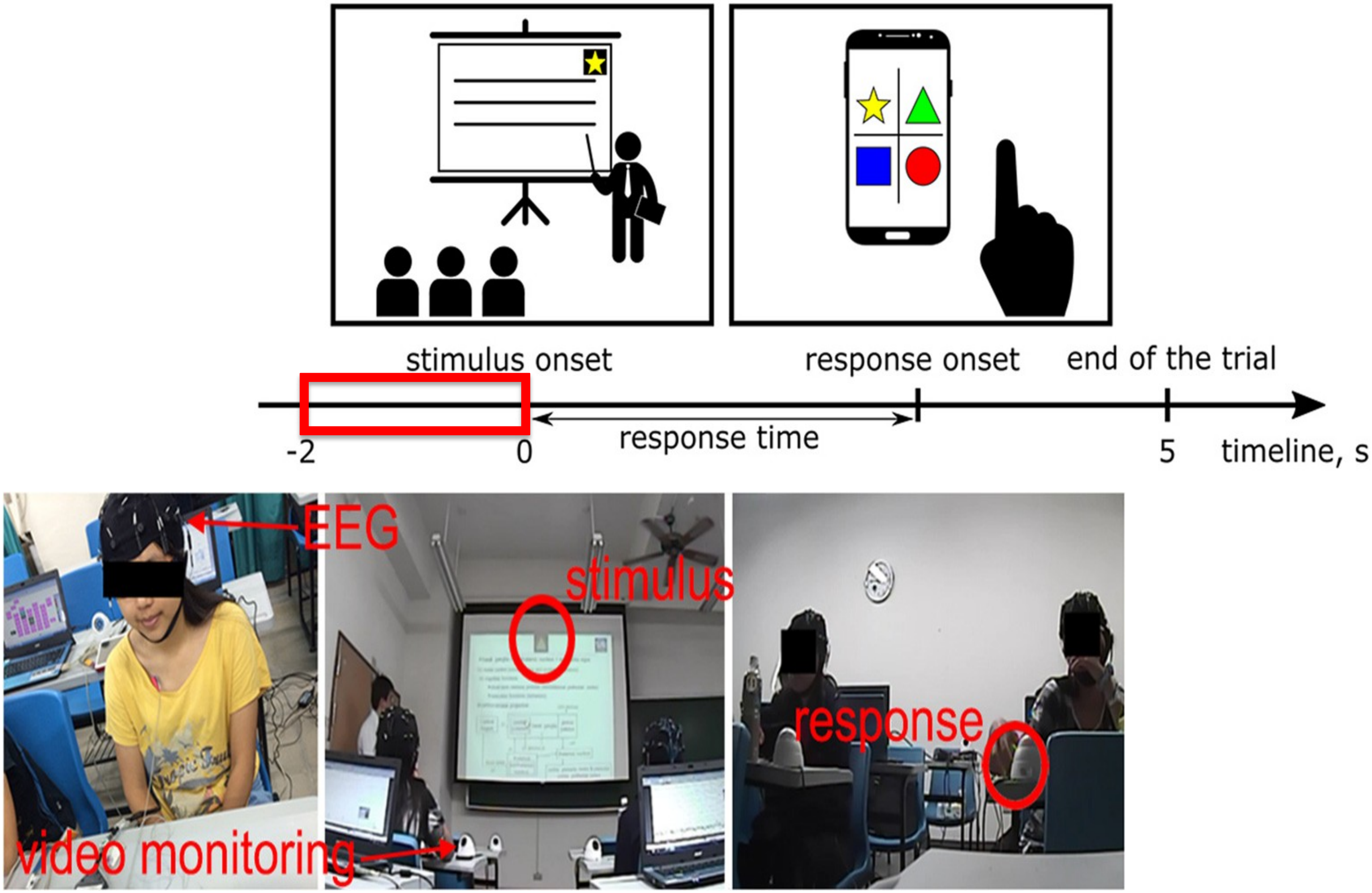
Komarov, Ko, Jung, *IEEE TNSRE*, 2020.

Resting-state EEG spectral characteristics under stress



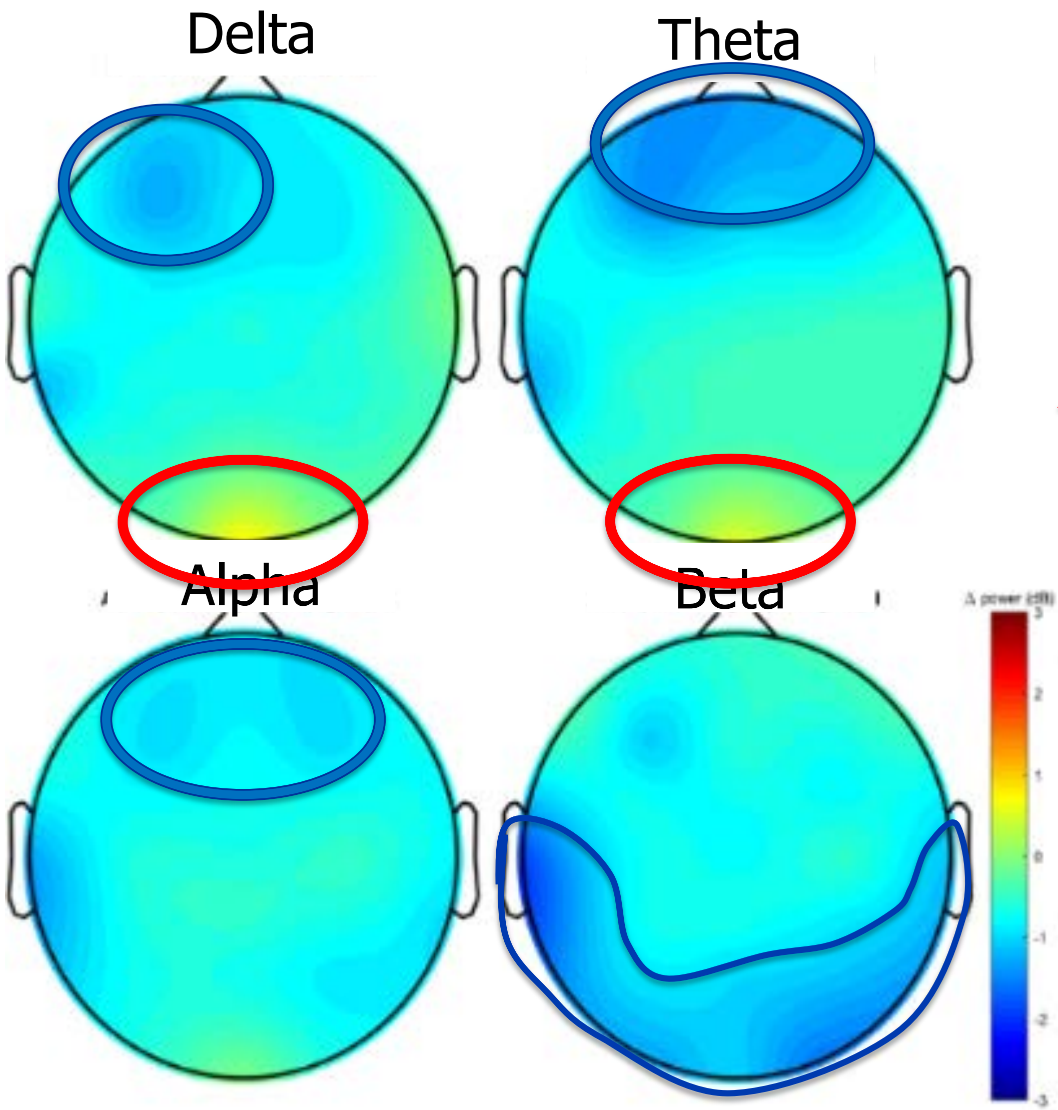
Komarov, Ko, Jung, *IEEE TNSRE*, 2020.

Classroom Activity



Mental Fatigue in the Classroom

Spectral Differences (Inattentive - alert)



An increase in the normalized RT in the visual attention task is associated with

↑ delta and theta powers in the occipital region.

↓ beta power in the temporal and occipital regions.

↓ delta, theta and alpha powers in the frontal region.

Ko *et. al.*, *Frontiers in Human Neuroscience*, 2017.

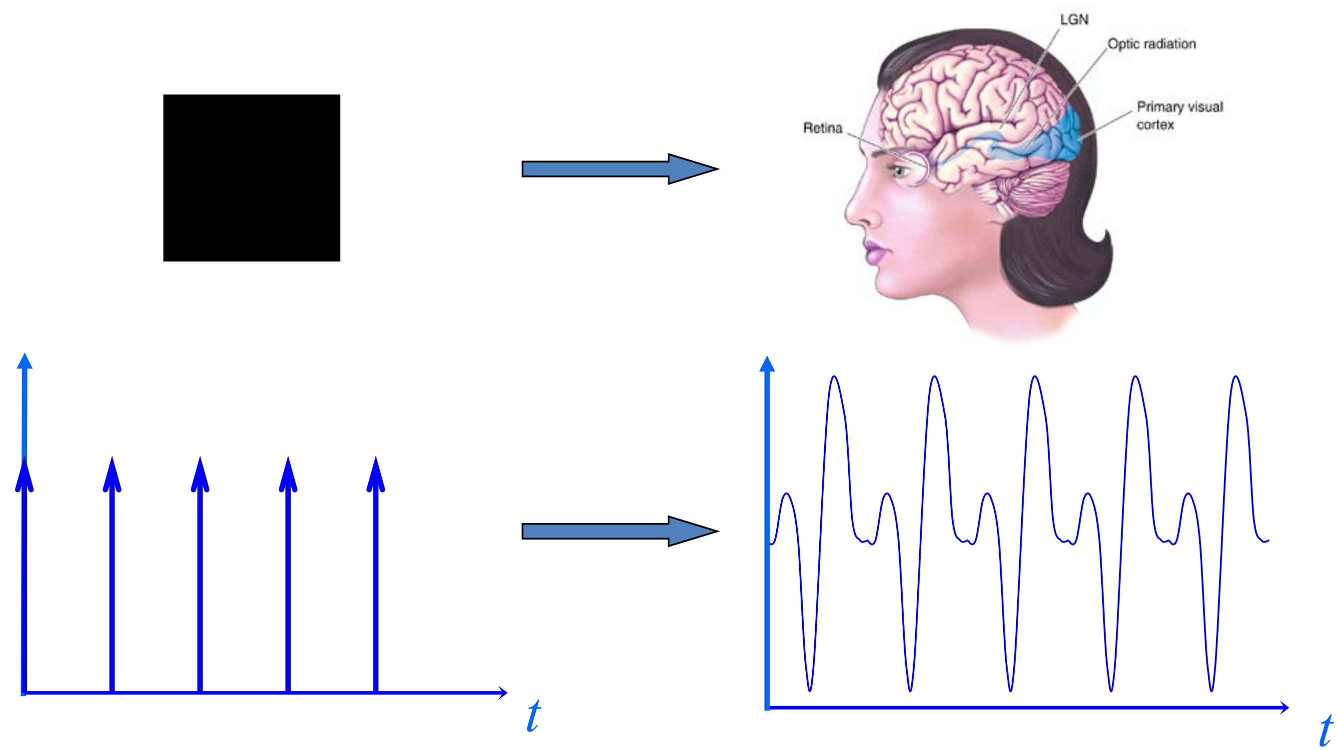
Translating a BCI from Bench to Clinic

Masaki Nakanishi, Yu-Te Wang, Tzyy-Ping Jung, John K Zao, Yu-Yi Chien, Alberto Diniz-Filho, Fabio B Daga, Yuan-Pin Lin, Yijun Wang, Felipe A Medeiros

UC San Diego, Duke University, and nGoggle

Steady-state visual evoked potentials (SSVEP)

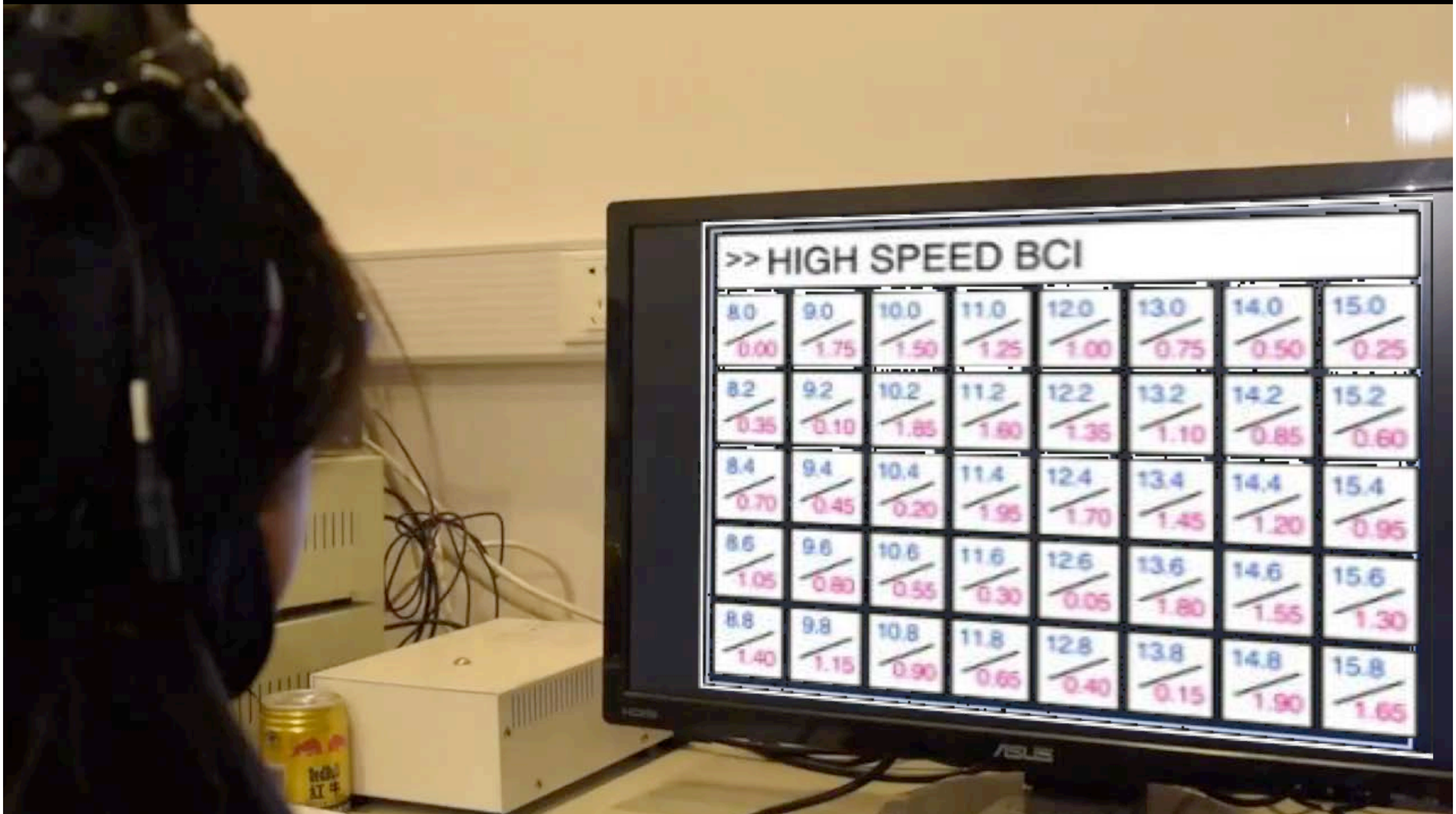
SSVEP are signals that are natural responses to visual stimulation at specific frequencies.



Stimulus >6Hz

SSVEP

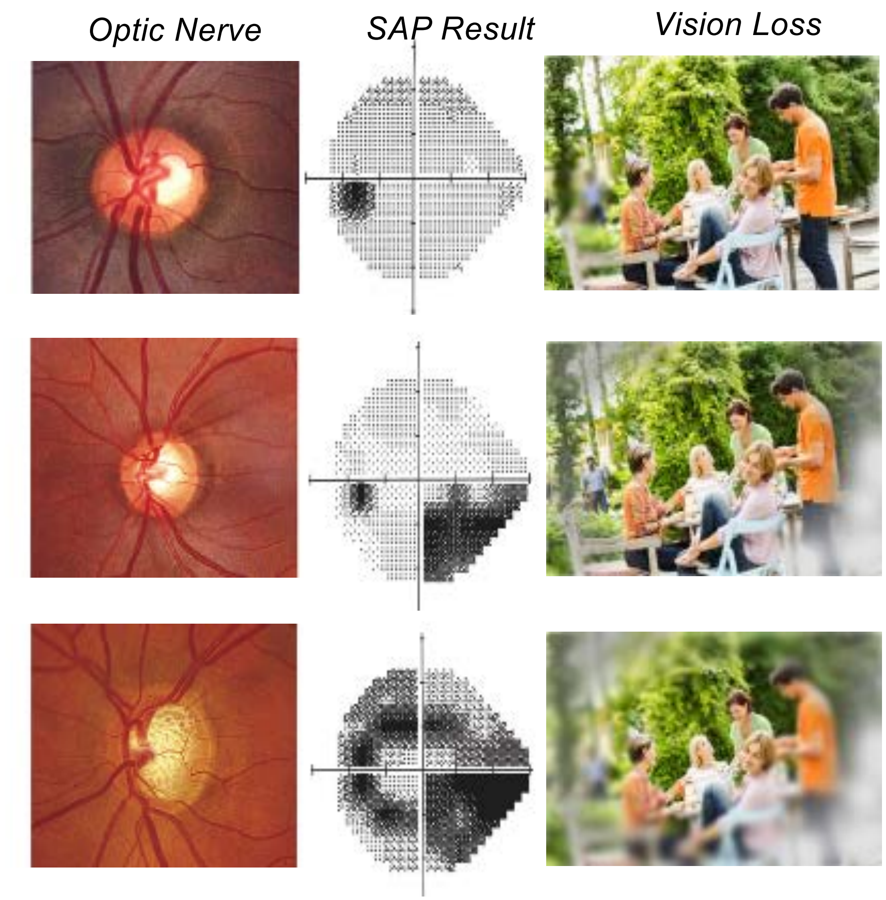
A High-Speed BCI Speller



High ITR ~ 325.33 ± 38.17 bits/min (75 letters/min)
Nakanishi *et al., IEEE TNSRE*, 2018.

Glaucoma

- Glaucoma, once thought of as a single disease, is a broad term for a group of certain pattern damage to the optic nerve.
- Glaucoma is a leading cause of irreversible blindness.
- Vision loss can occur with normal or even below-normal intraocular pressure
- In 2020, about 80 million people have glaucoma worldwide.
- At least 50% of people with glaucoma do not know they are affected.



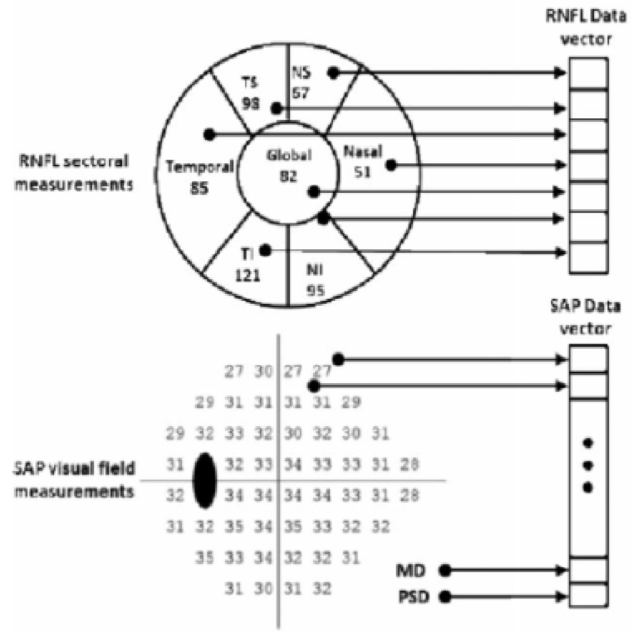
	GLAUCOMA PATIENTS	AGING POPULATION
US	3M	69M
JAPAN	3M	42M
CHINA	21M	217M
TOTAL	27M	358M
	34% OF TOTAL GLAUCOMA POPULATION	40% OF TOTAL AGING POPULATION

Source: United Nations

Assessing Visual-Field Deficits

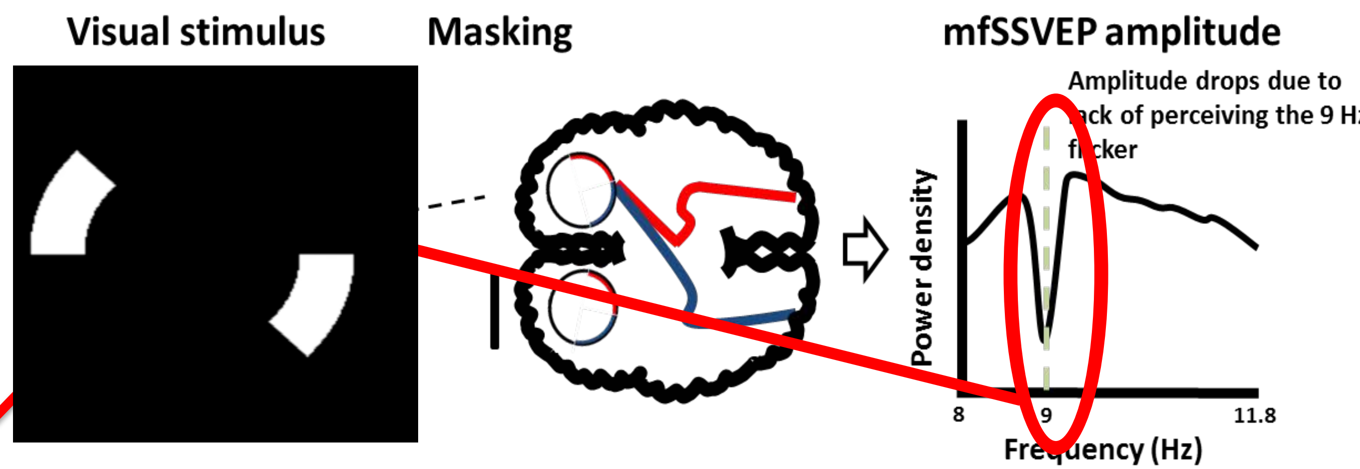
Standard Automated Perimetry (SAP) for Glaucoma Diagnosis

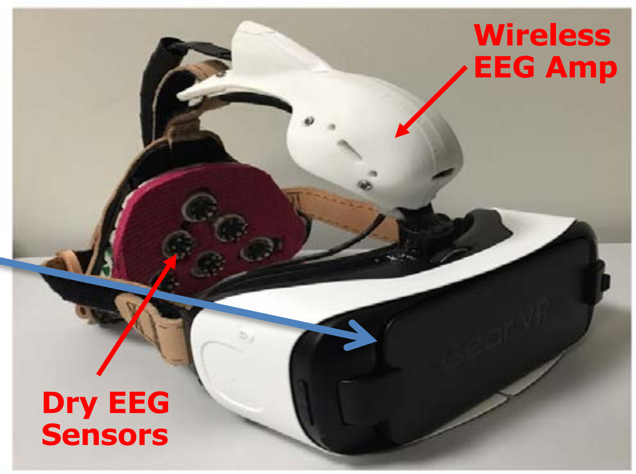
Siamak Yousefi *et al.*,
IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING



Assessing Visual-Field Deficits

Main idea:

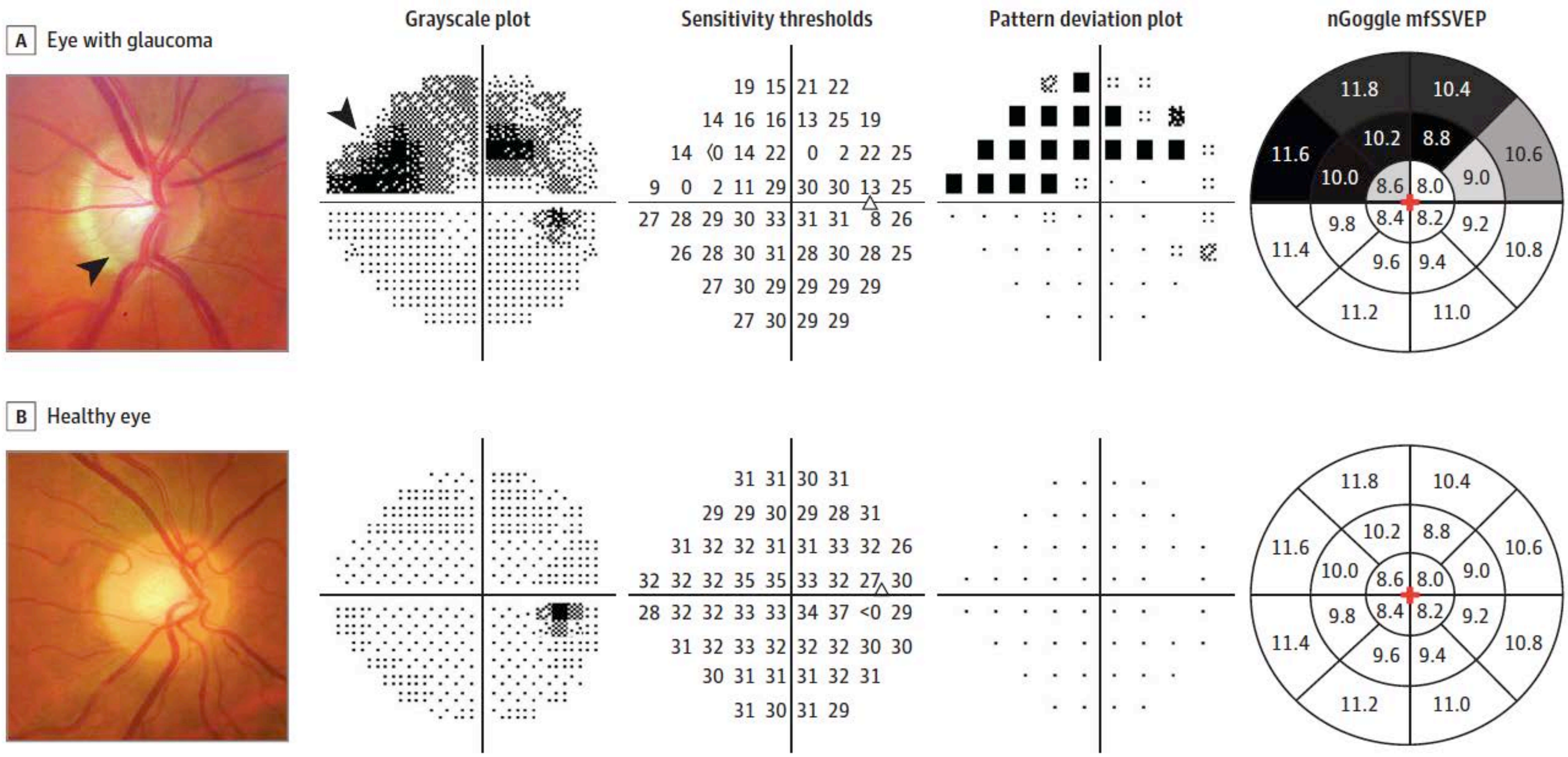




Courtesy photo from
NGoggle Inc

The smartphone renders mfSSVEP stimuli and measures EEG/EOG data from the on-board bio-amplifiers.

Results from mfSSVEP and Standard Perimetry of Glaucomatous and Health Eyes.



From Nakanishi et al., *JAMA Ophthalmology*, 2017.

A Comparison between SAP and BCI Perimetry

Standard Automated Perimetry (SAP)

BCI-based Visual-field Assessment

	Standard Perimetry	BCI Perimetry
Equipment Cost	$30,000 – $50,000	$500
Operation Cost	$100 / test	$30 / month
Test Procedures	Cumbersome: 30mins, Technicians	Simple: 10mins, DIY
Test Sites	Hospitals / Clinics, Appointments	Home, Free schedules
Test Frequency	Avg. once / 3–6 months	Avg. once / day
Test Reliability	Subjective & few data points	Objective & many data points

Well-controlled EEG Lab → a VR+EEG HMD

Setup for a typical EEG experiment

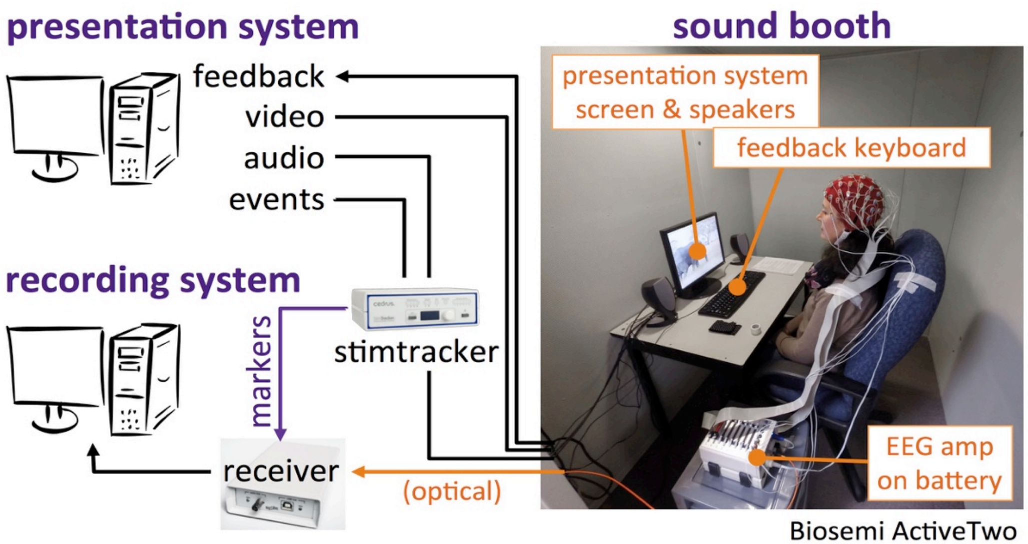


Figure from Stober *et al., ISMIR*, 2015.

A portable EEG Lab

Figure from Nakanishi *et al., JAMA Ophthalmology*, 2017.

Advantages:

- Integrate and synchronize visual/auditory stimulations and bio-signal collection.
- Miniaturized System-on-Modular for data collection, real-time signal processing and machine-learning classification
- Easy to set a standard operating procedure (SOP) and automation
- Cost-efficiency, portability, and scalability

Summary

- Challenges in Real-World EEG
    - New sensors and technologies to measure high-quality *neural, physiological, behavioral, and contextual* data in real-world environments.
    - Advanced signal-processing and machine-learning algorithms to jointly analyze multi-modal data.
- Sample applications of wearable EEG
    - Multi-modal approach to study science of learning
    - Multi-modal Neuroimaging from Lab to Classroom
    - Translate a Brain-Computer Interface from bench to clinic

Acknowledgements

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