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Using electroencephalography to explore neurocognitive correlates of clinical reasoning: A pilot study.

Presenters: Serkan Toy & Kris Rau

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Virginia Tech Carilion School of Medicine

Research Team

Serkan Toy [1], Somayeh Shafiei [2], Sahin Ozsoy [3], James Abernathy [4], Eda Bozdemir [5], Kristofer Rau [1], and Deborah Schwengel [4]

1 Basic Science Education, Virginia Tech Carilion School of Medicine, Roanoke, VA

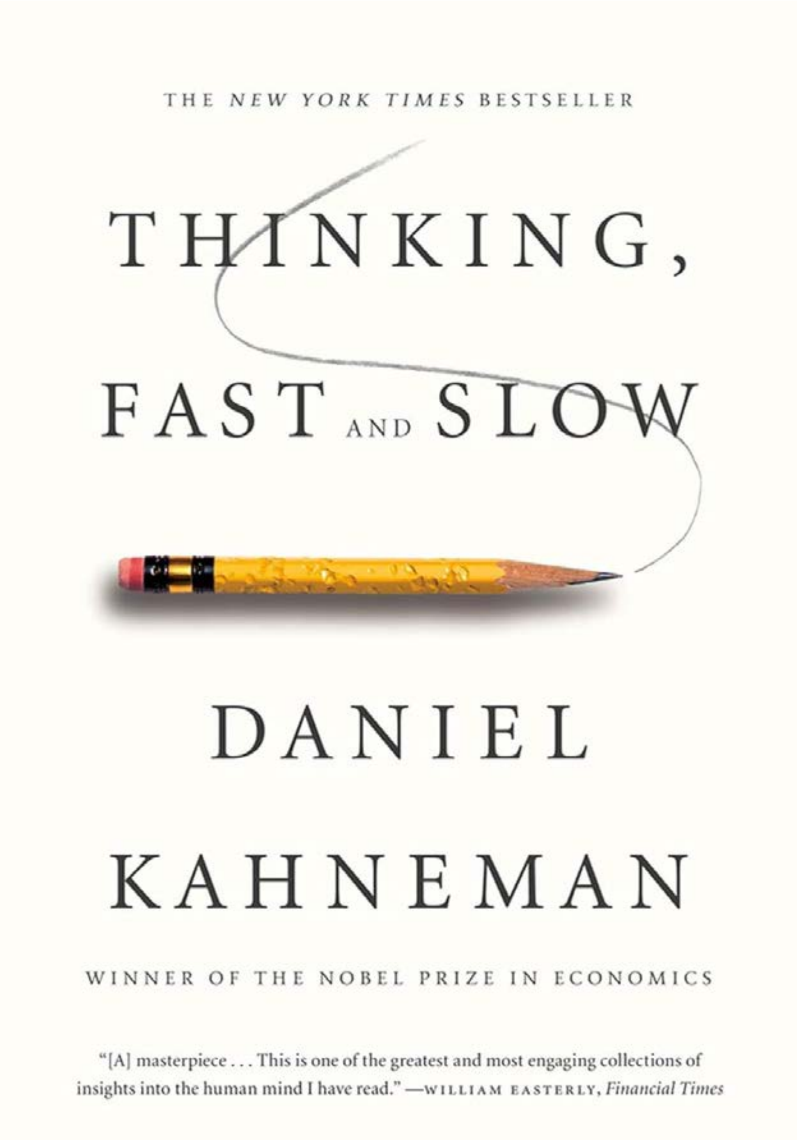
2 Roswell Park Comprehensive Cancer Center, Buffalo, NY

3 BioSoftPro, LLC, Kensington, MD 20895, USA

4 Anesthesiology and Critical Care Medicine, The Johns Hopkins University, Baltimore, MD

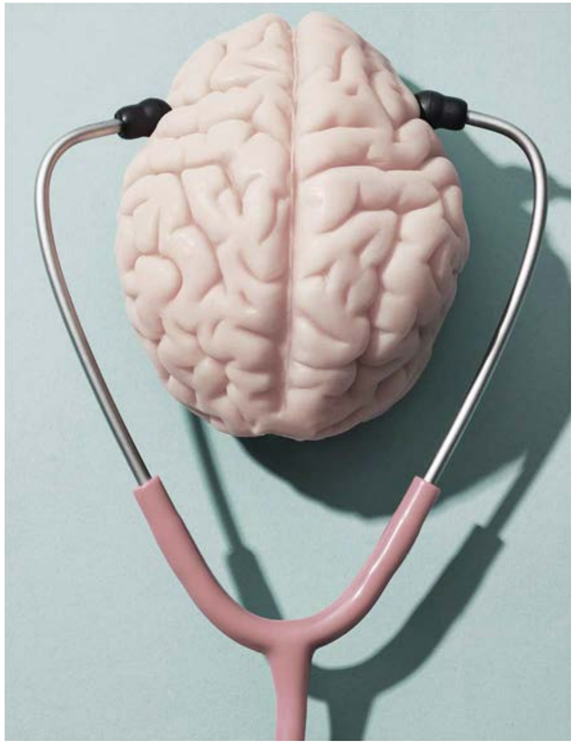
5 Yale School of Medicine, Pathology, New Haven, CT

Theory:
Clinical Decision-Making



Kahneman, 2011

Kahneman 2003
Maps of bounded rationality:
A perspective on intuitive judgement and choice.

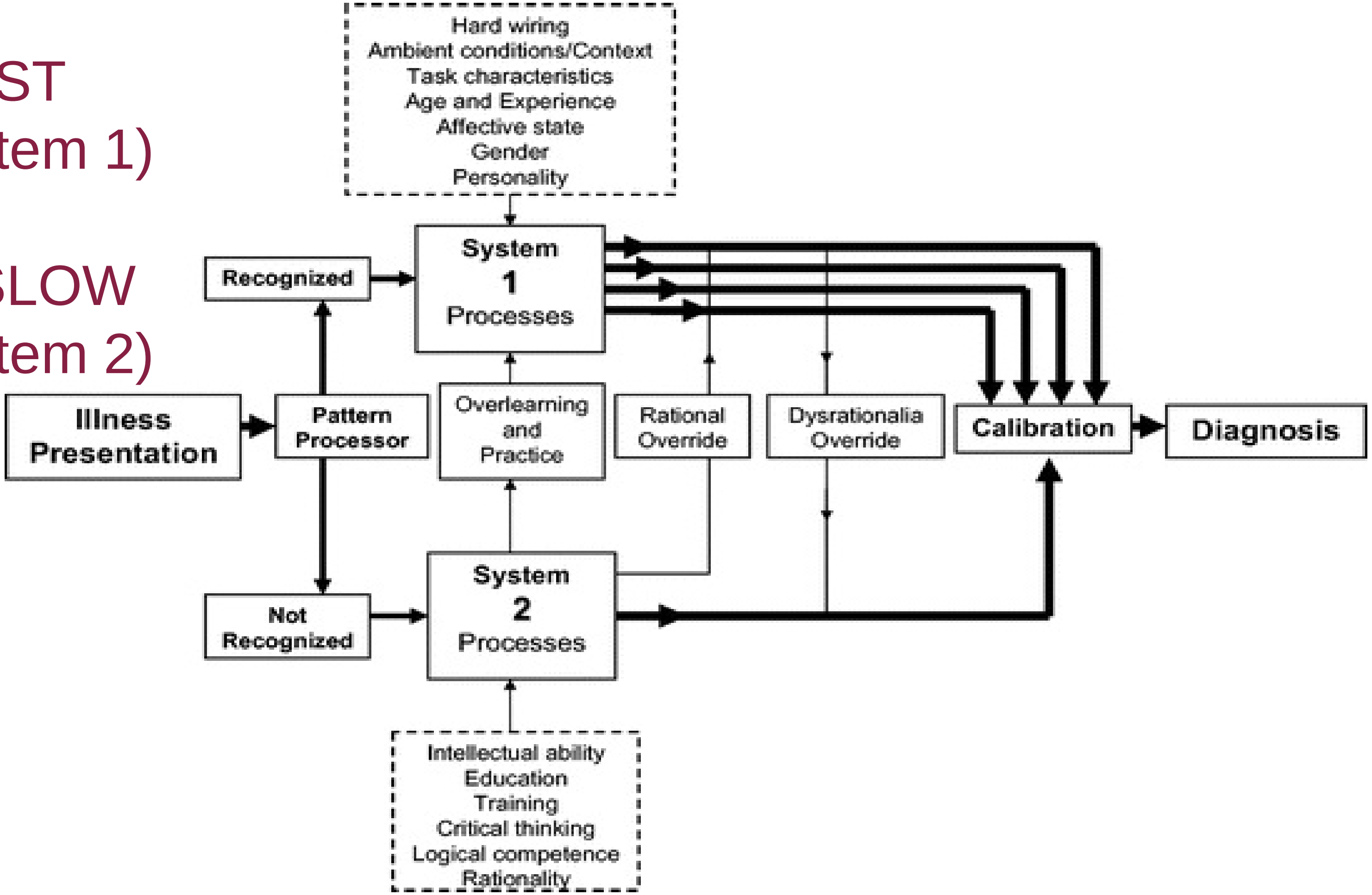


Dual Processing Theory

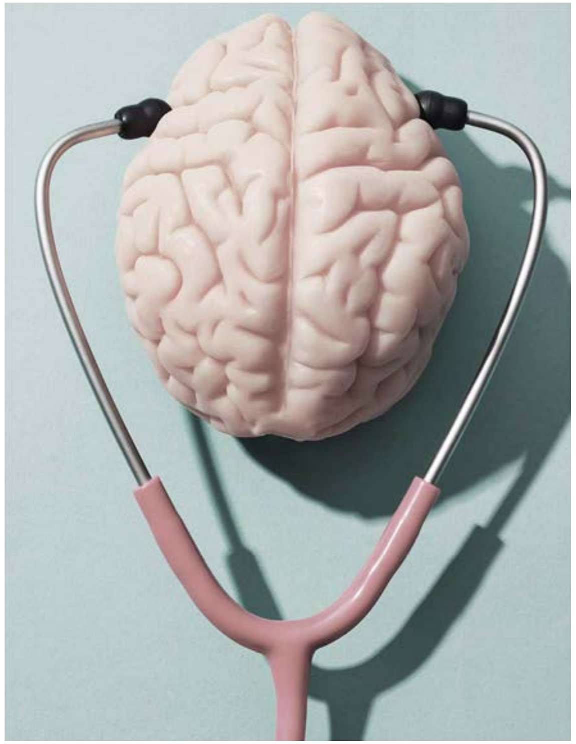
Reasoning and decision-making

- Intuitive – FAST
 – Type 1 (System 1)

- Analytical – SLOW
 – Type 2 (System 2)



Croskerry, 2009 Academic Medicine84(8):1022-1028, 2009.



Neural Efficiency Theory

Function of intellect/cognitive skills & Learning

Neubauer and Fink (2009)

- Higher intellect → Less brain activation

- Experts/more knowledgeable → Less brain activation

- Working memory: short-term storage and central executive processing
- Neuroimaging studies: The prefrontal cortex (PFC) is a major hub for storage and executive processes.

Grabner, et al., 2004
Smith & Jonides, 1999

Neuroimaging Findings - Clinical Reasoning

A recent review found 15 articles published between 2011 and 2020 (Toy et al., 2022)

- Feasibility or proof of concept studies
- Predominantly used fMRI
- Dual processing framework (PFC engagement)

Durning et al. (2012): incorrect answers were associated with significantly higher PFC activation than correct answers for licensing exam-type questions

Hruska et al. (2016): reading clinical cases activated multiple brain regions and novices relied more on working memory than experts.

Rotgans et al. (2019) concluded that only unfamiliar cases invoked a significant level of blood oxygenation in the PFC as the medical students diagnosed chest X-rays

Our working “hypothesis”

Clinical reasoning is a dynamic, complex, multifaceted process involving many factors

Cognitive load (short-term memory)
Prior experience with the task
Long-term memory
Cognitive control

Hence, multiple brain areas will show functional interaction during reasoning besides PFC engagement.

Anatomy:
Clinical Decision-Making

The Brain

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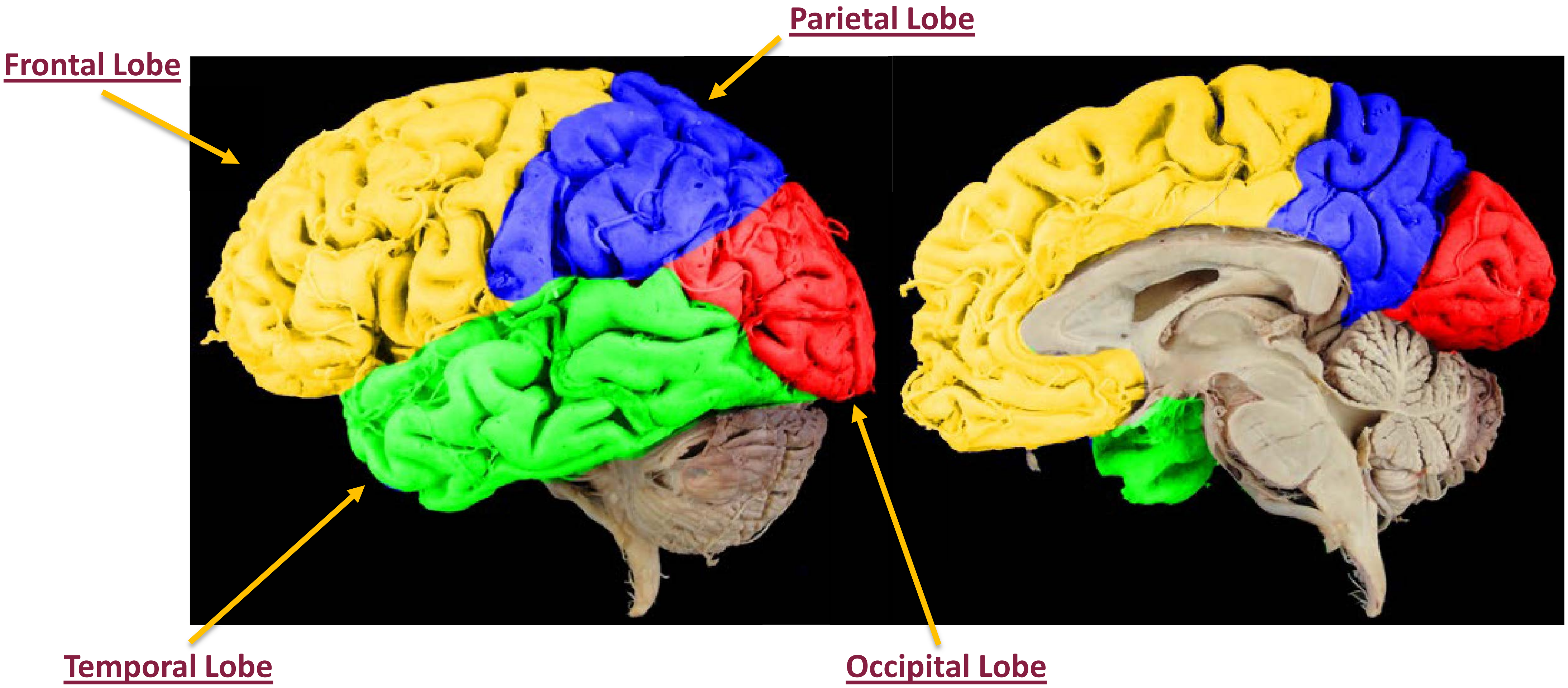
Lobes of the Brain



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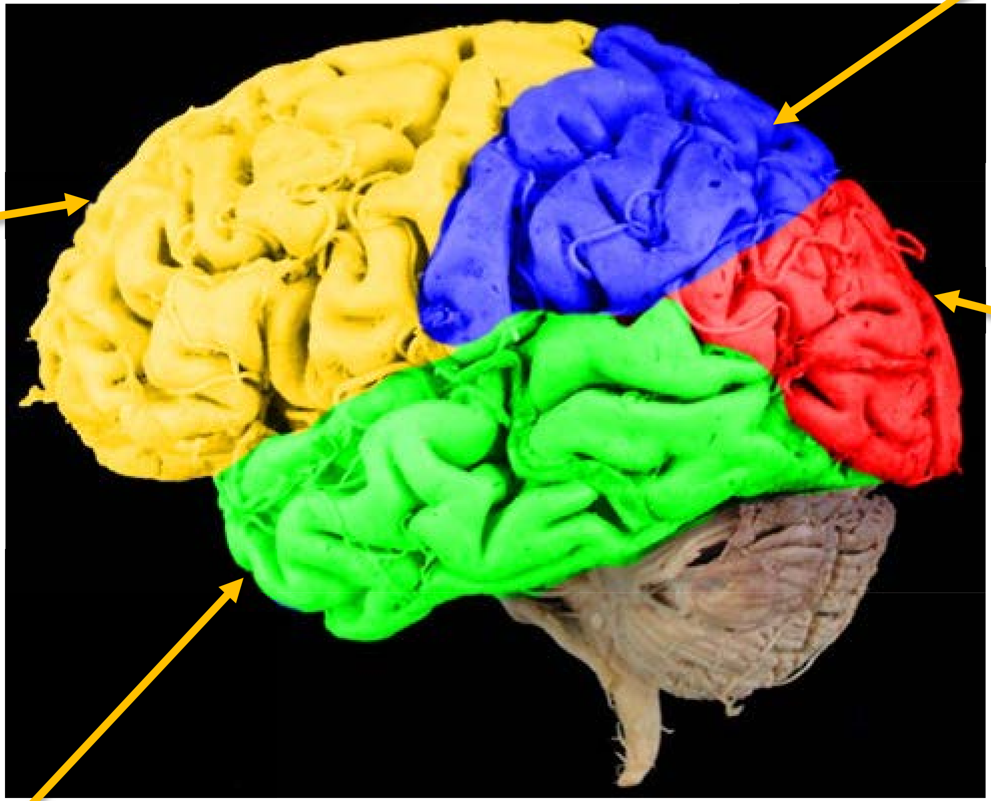
Functions of the Brain

Frontal Lobe

Movement
Short-term (working) memory
Attention and concentration
Planning
Reasoning and decision making
Judgement
Intelligence
Emotional expression
Creativity
Inhibition / moderating social behavior
Personality expression
Control of speech and language



Parietal Lobe

Sensation
Speech and language comprehension

Occipital Lobe

Visual perception and processing

Temporal Lobe

Long-term memory
Visual memory / object recognition
Speech and language comprehension
Hearing
Emotion association

White Matter

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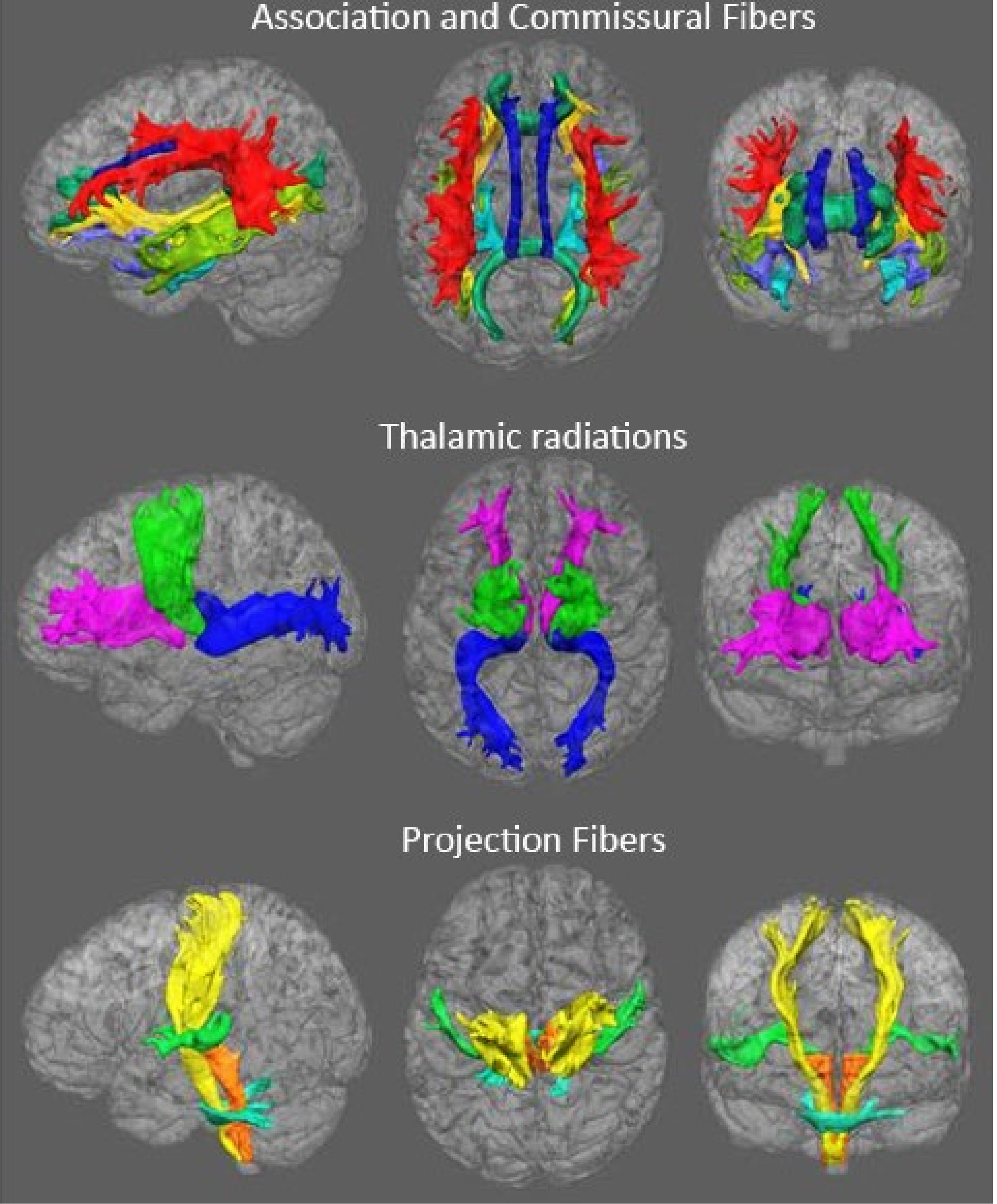
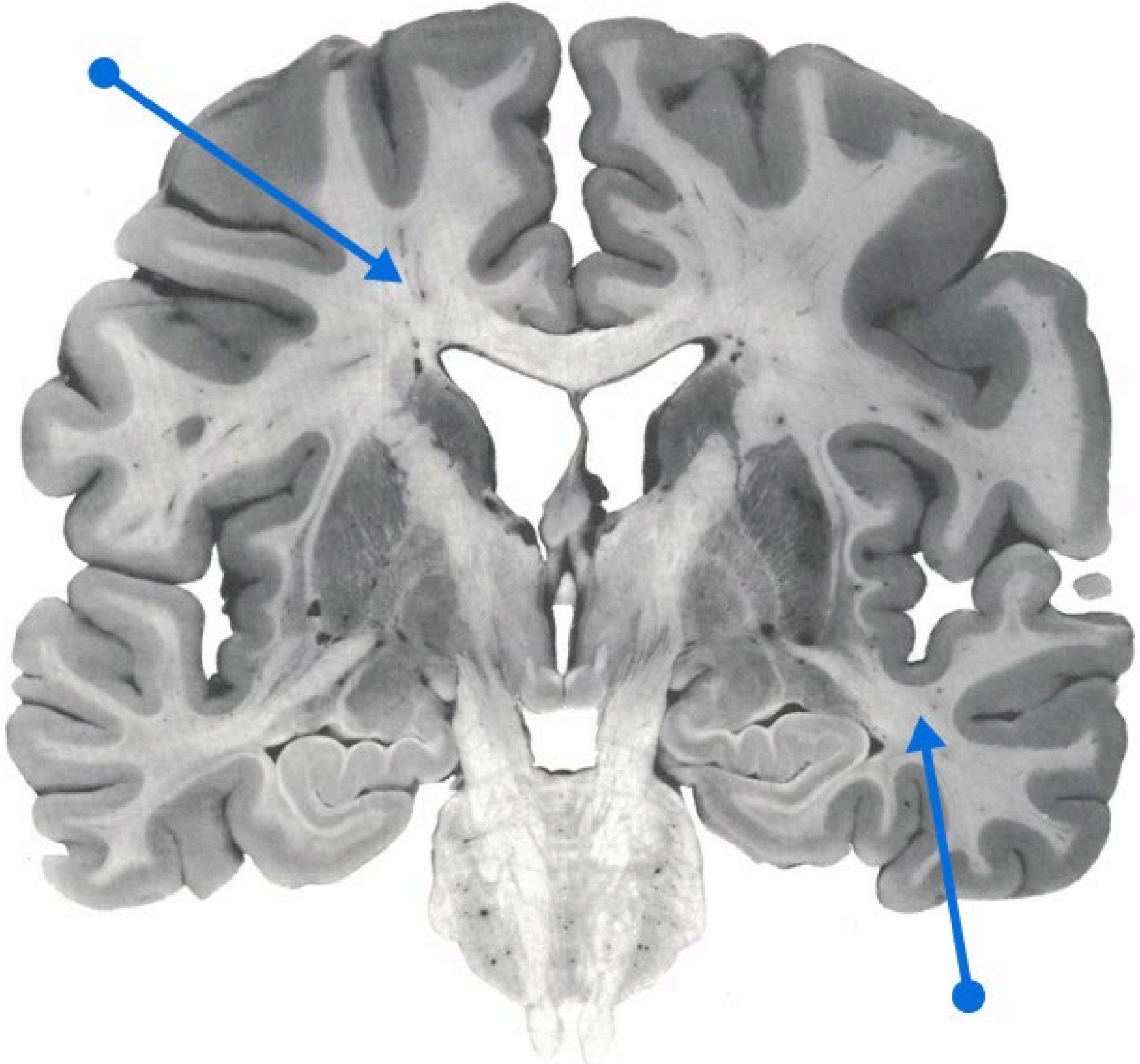
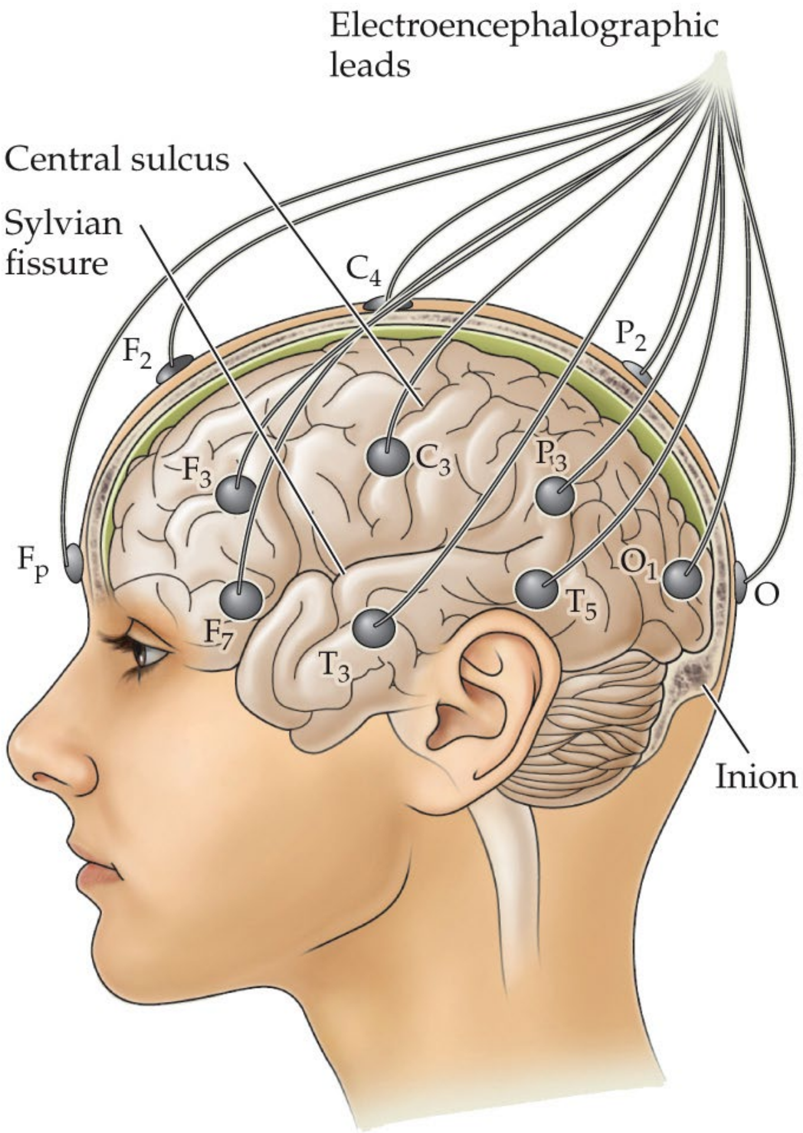




Using Electroencephalography (EEG) to Record Brain Waves



F - frontal
P - parietal
O - occipital
T – temporal
C - central

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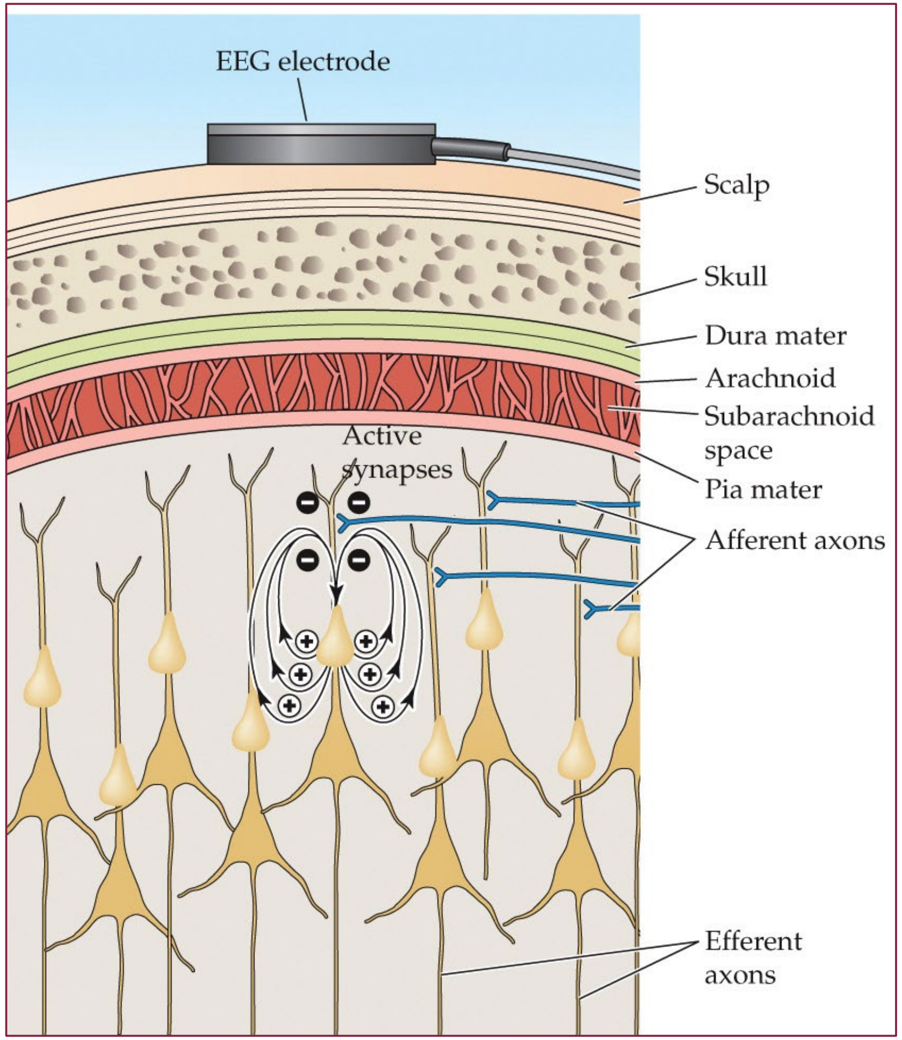
Using Electroencephalography (EEG) to Record Brain Waves

EEG - Summed activity of electrical potentials in dendrites of cortical neurons



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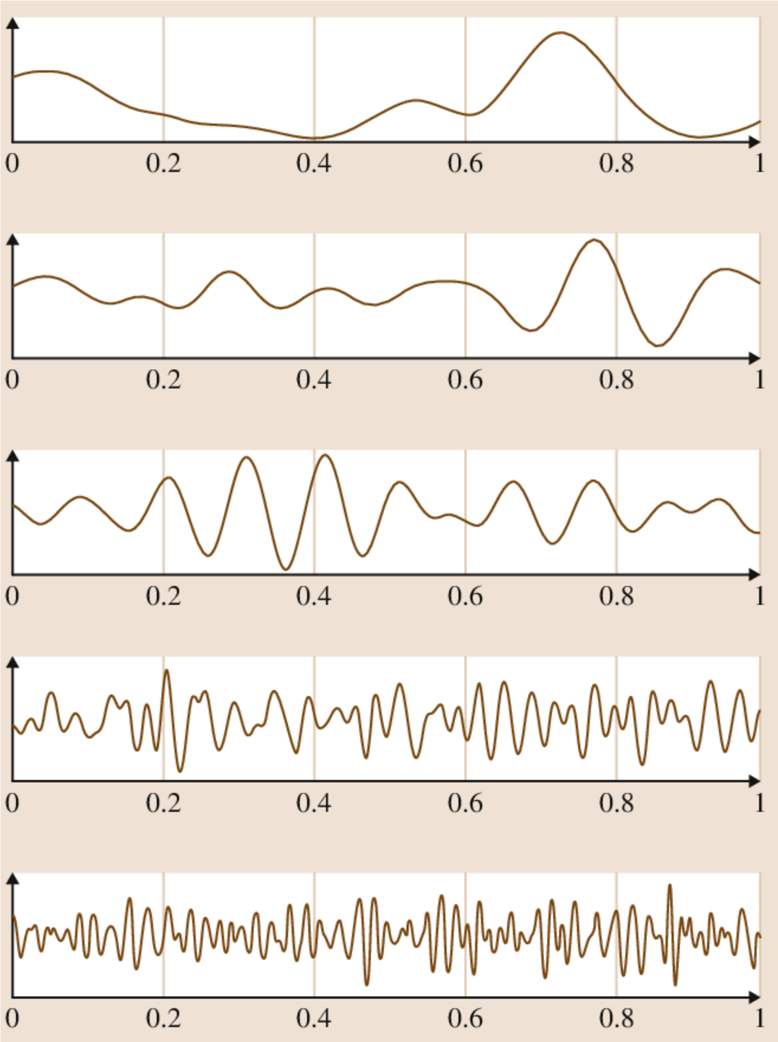
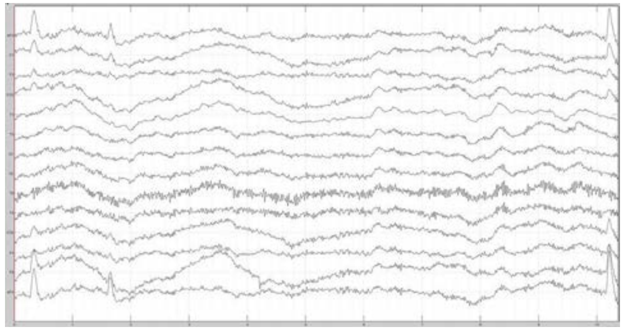


Neural Oscillations (Waveforms)	Functional Correlates
Delta (0.5-4 Hz)	Deep, restorative sleep
Theta (4-8 Hz)	Engagement in implicit learning (Loonis et al., 2017)
Alpha (8-12 Hz)	Processing of visual information in memory (Kozlovskiy et al., 2021) Visual learning (Michael et al., 2022) Mistake prediction (Mazaheri et al., 2009) Increased creativity (Martindale et al., 1978)
Beta (12-30 Hz)	Planning movement (Takahashi et al., 2011) Controlling movement (Zhang et al., 2008; Pogosyan et al., 2009) Engaged in thought and concentration (Baumeister et al., 2008)
Gamma (30-100 Hz)	Higher aspects of cognition and problem solving (Abhang et al., 2016) Engagement in conscious attention and perception (Buzsaki et al. 2006; Baldauf et al., 2014)

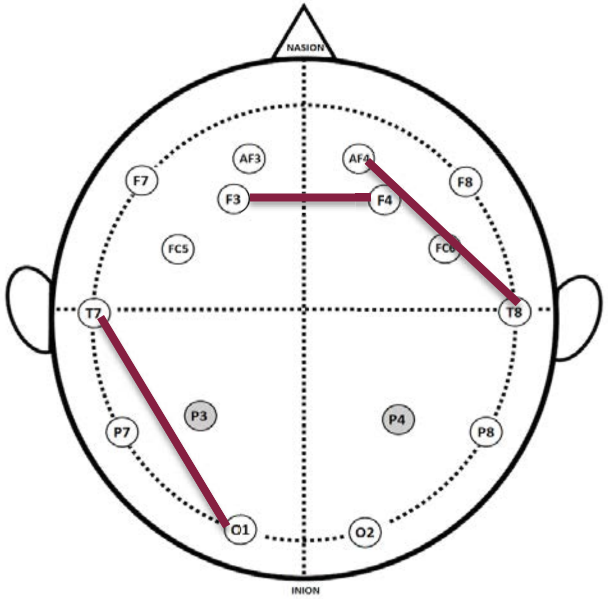
EEG Data analysis



Power spectral density (PSD)

Allows quantitative analysis of the activation patterns at each brain region (channel/electrode) for a given frequency band.

Coherence analysis



Provides estimates of functional interactions between activated brain areas in each frequency band.
Srinivasan et al. 2007.

METHODS

Task

Measures

Participants

Data analysis

PARTICIPANTS

- Graduating fellows PGY-5 (recently certified anesthesiologists)

- N=8
- Age: 32.8 (3.3)

- 1st-year anesthesiology residents PGY-2

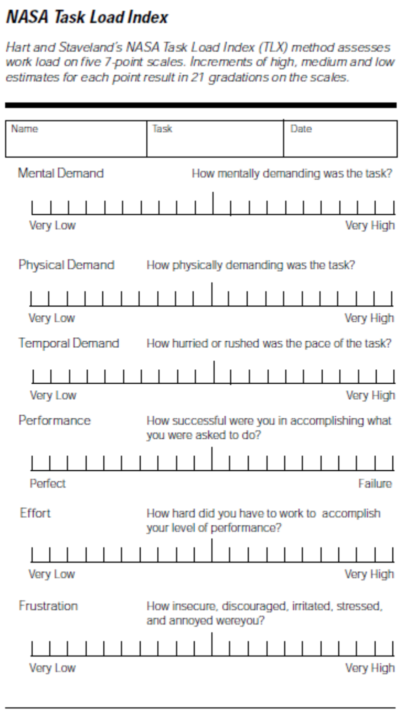
- N=8
- Age: 29.1 (3.1)

TASK

American Board of Anesthesiology (ABA) Style Standardized Oral Board Examination (SOE)

- 3 minutes to read and think about a clinical case stem
- An experienced ABA examiner asked scripted questions
- 12 minutes for questioning on the case, and an additional
- 3 minutes on a new brief vignette presented by the examiner

MEASURES



NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?
Very Low — Very High

Physical Demand — How physically demanding was the task?
Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?
Very Low — Very High

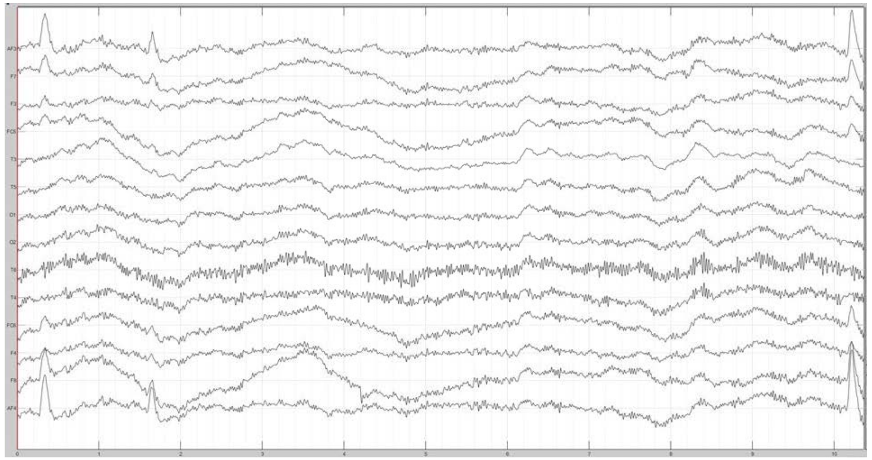
Performance — How successful were you in accomplishing what you were asked to do?
Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?
Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?
Very Low — Very High

Section A: Core Question – 12 minutes

Topic & questions			
Evaluation of respiratory status	**Y**	**M**	**N**
What further evaluation of respiratory status is indicated? Would you suggest further medical therapy? What & why? What is the impact of URI on anesthetic risk? Impact of wheezing on anesthetic risk?			
Choice of anesthetic	**Y**	**M**	**N**
What anesthetic technique would you use for this case? Explain. Would regional anesthesia be a reasonable choice? Why? Why not? What agents would you use for induction? Why? How does the recent URI affect your decision? How does her asthma affect your decision? She is afraid of being awake for the procedure. What is your response? Consideration of NPO status?			
Pain Control			
What are your plans for pain control? Multimodal? Would regional be a reasonable choice? Which? Why? Patient requests epidural. Would a spinal be appropriate? What about peripheral nerve block? Which? What local anesthetic agent would you use for a subarachnoid block? Explain your choice. Is epinephrine necessary? Explain What level of block is needed for this procedure? After completion of epidural dosing, she begins to complain of numbness in her fingers. DDx? Rx?			
Bronchospasm under general anesthesia			
Anesthesia is maintained with Sevoflurane and nitrous/oxygen by ETT. Fifteen minutes into the case, the ETCO2 increases. DDx? Marked wheezing and heart rate increases to 122 bpm. What is your evaluation and management? While attempting to manage, her end-tidal CO2 falls to 22 mm Hg. DDx? Rx? Albuterol? Epinephrine? Deepen anesthetic? Should you cancel the case?			
Intraoperative Steroid Dosing			
Should this patient be given stress doses of steroids? Why? What evidence? How much will you give? What dosing regimen? Should this patient be given steroids for other purposes? For what? Why?			



Self-report Cognitive Load

NASA-TLX

Observed Performance

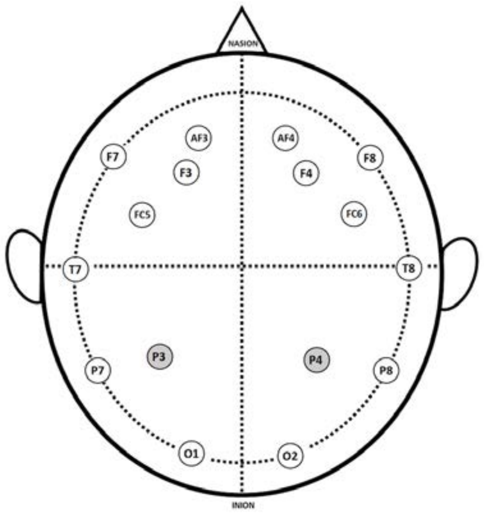
Analytical checklist

EEG features

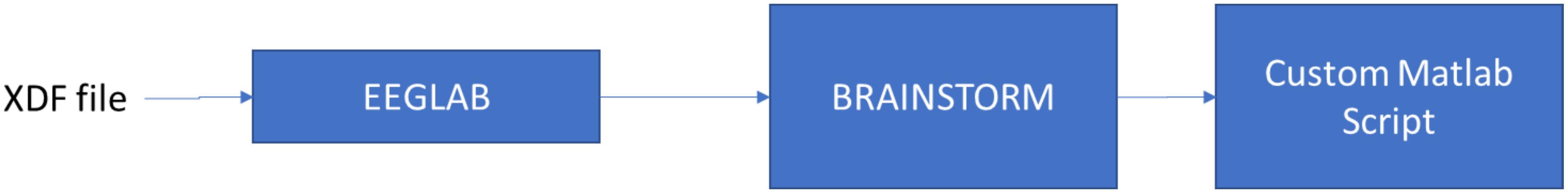
- Power spectral density
- Coherence

EEG Data Acquisition, Processing, Analysis

14-channel wireless headset
Data capture XDF file
EEGLAB
BRAINSTORM
Custom Matlab Script



Emotiv Epoc+ Headset

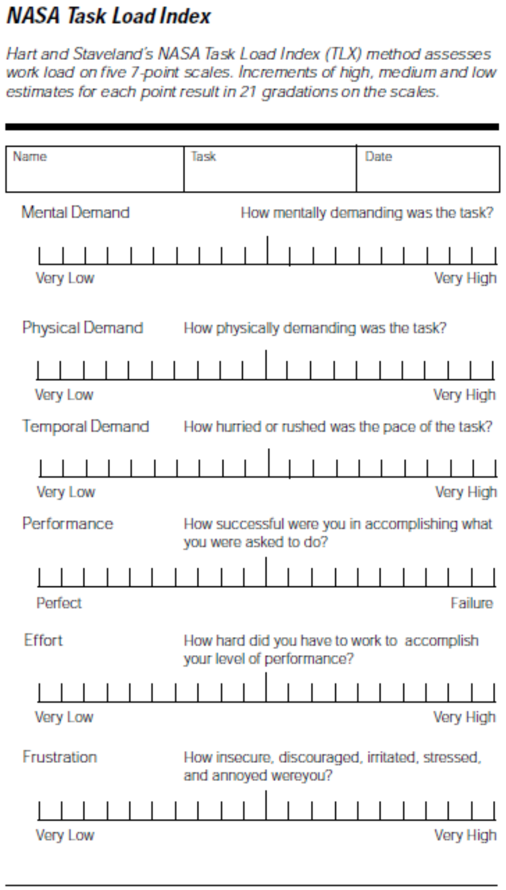


- Convert to *.set file
- Merge when required

- Channel Location Correction
- DC Offset Correction
- Artifact Detection

- Epoch Generation
- Feature Calculation
- Table Generation
- Statistical Analysis

RESULTS



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Perfect — Failure

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Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?
Very Low — Very High

No difference between the

- **Novice (residents)**:
- mean = 0.66, SD = 0.09) and

- **Fellows (experienced trainees):**
- mean = 0.63, SD = 0.17

(p = 0.840).

Self-report Cognitive Load

RESULTS

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Intraoperative Steroid Dosing			
Should this patient be given stress doses of steroids? Why? What evidence? How much will you give? What dosing regimen? Should this patient be given steroids for other purposes? For what? Why?			

Observed performance

Fellows outperformed novice residents

- **Novice (residents)**:
- mean = 54%, SD = 13%

- **Fellow (experienced trainees)**:
- mean = 93%, SD = 5%

($p < 0.001$).

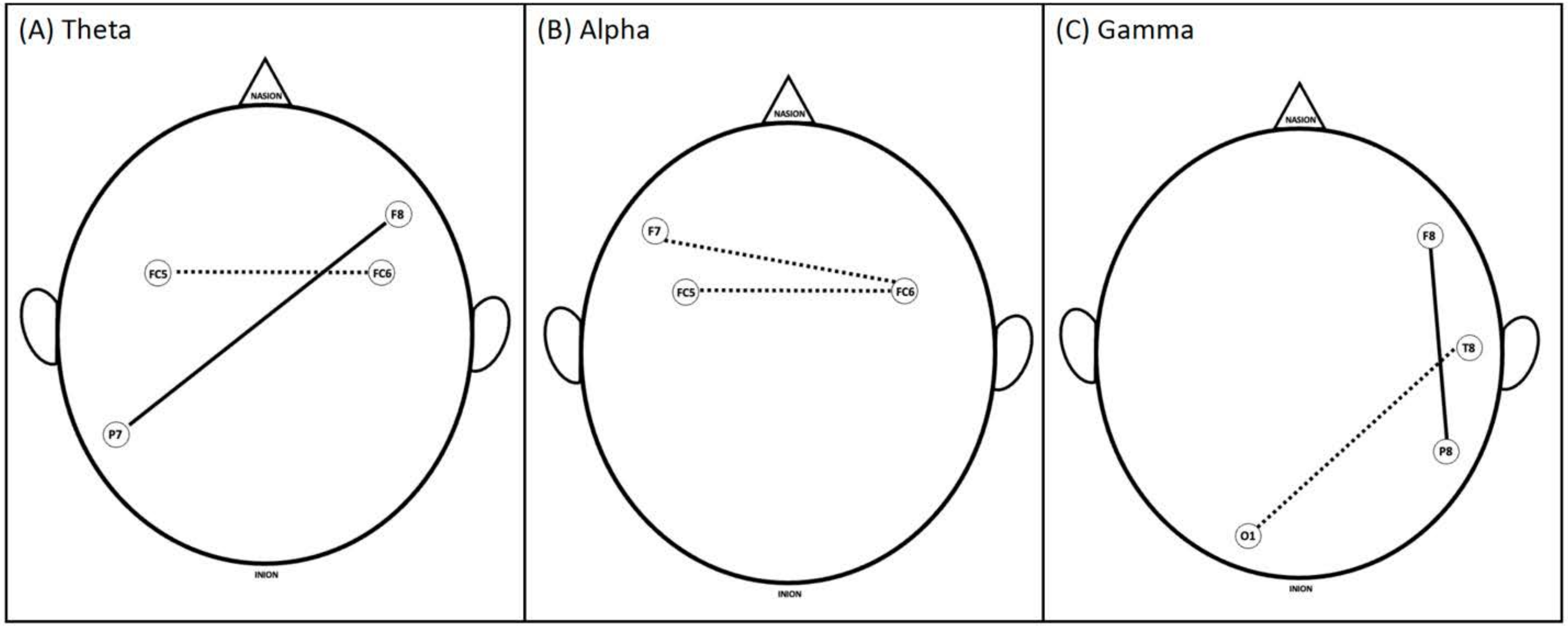
A two-way random effects model for absolute agreement showed high agreement in the raters' scores, 0 .886. 95% CI was 0.683 to 0.960. ($F_{15,15} = 9.330$, $P < .001$).

RESULTS: EEG Data

Power Spectral Density: No significant differences between the groups.

Coherence: Several coherence features showed significant differences mostly related to the channels:

- within the frontal,
- between frontal and parietal, and
- between frontal and temporal areas.



Reading the clinical vignette

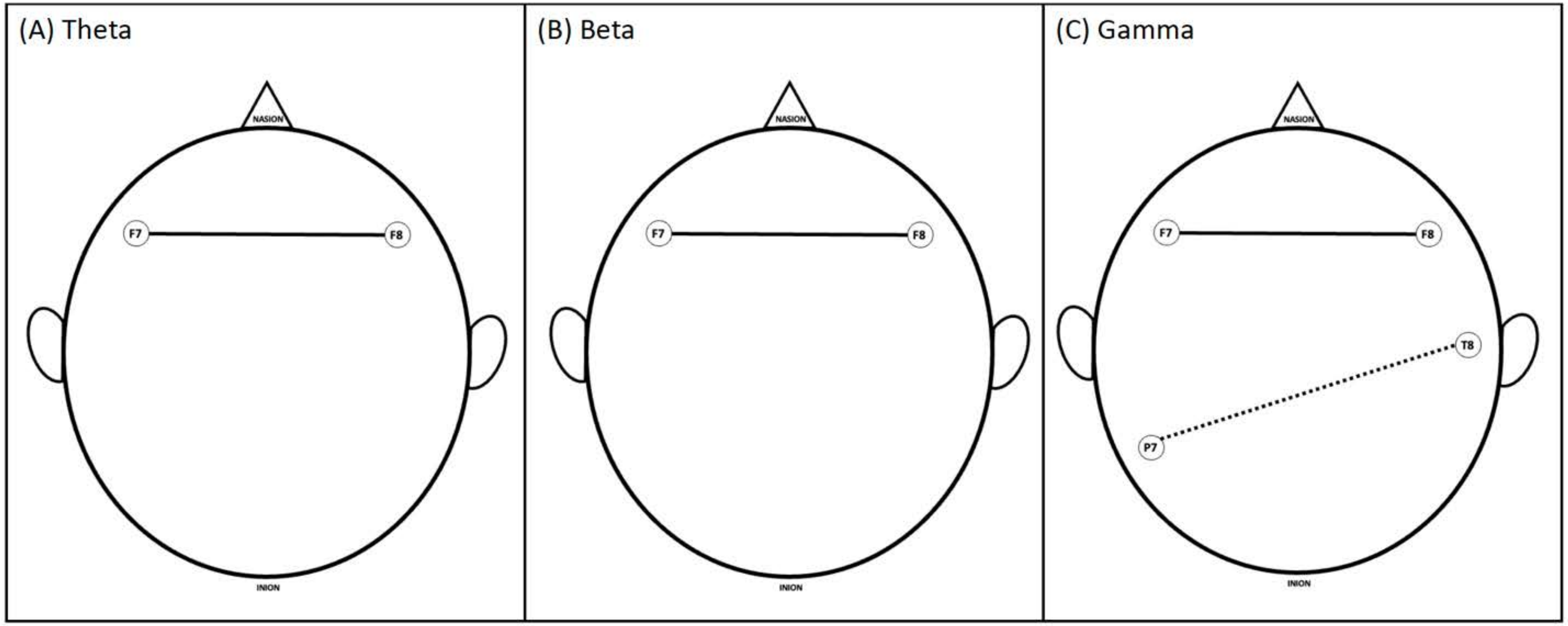
Figure 1. Coherence between brain areas of experienced and novice groups during the initial reading phase for (A) Theta, (B) Alpha, and (C) Gamma frequency bands. Solid lines: the experienced group had significantly higher coherence; dashed lines: novices had significantly higher coherence.

- Theta coherence: Right frontal and left parietal, central executive circuits

  Sauseng et al.,2005; Mizuhara &Yamaguchi, 2007

- Novices showed higher working memory engagement, cognitive load - ***Hruska et al., 2016; Rotgans et al., 2019***

- Gamma coherence: *fellows* → higher-order cognitive processes -- novices → sensory processing

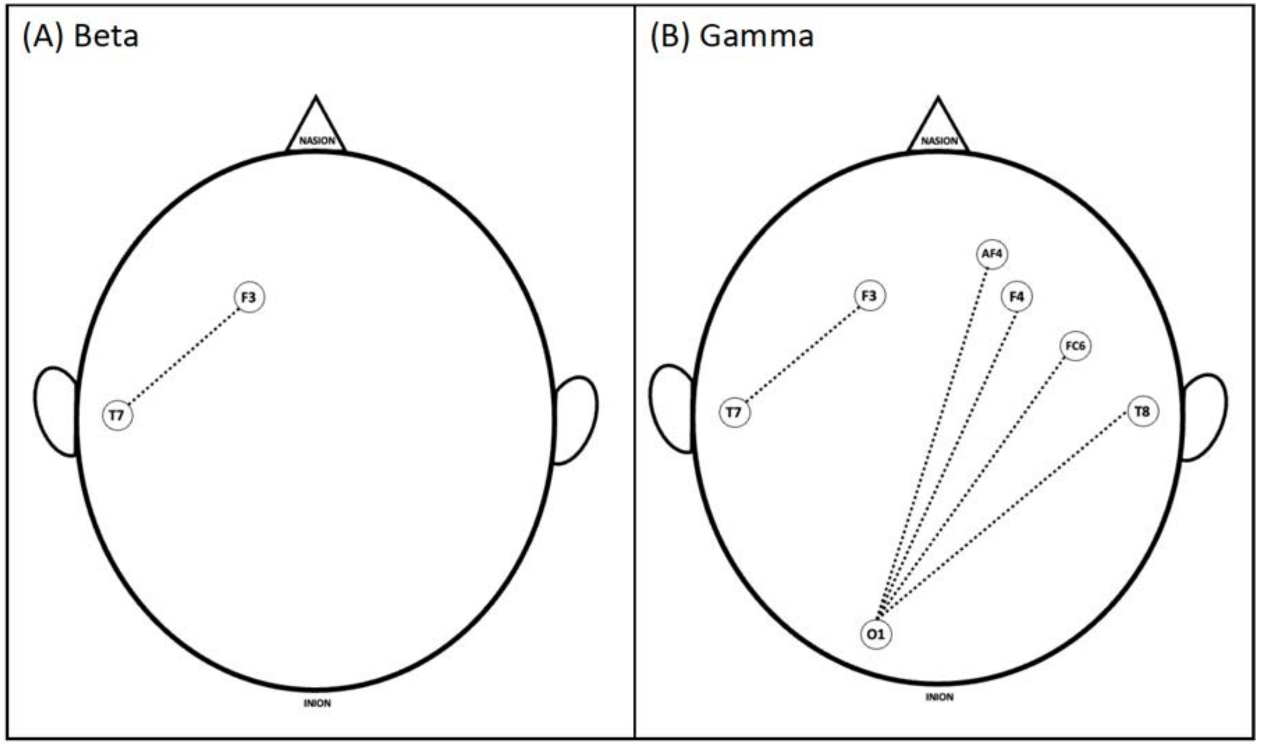


Questioning on the clinical vignette

Figure 2. Coherence between brain areas of experienced and novice groups during the applied exam for the first case for (A) Theta, (B) Beta, and (C) Gamma frequency bands. Solid lines: the experienced group had significantly higher coherence; dashed lines: novices had significantly higher coherence.

- **Frontal Theta, Beta, and Gamma coherence**: Experts engaged in integrating relevant medical knowledge for answering case-specific questions while making clinical decisions (cognitive control).

Rajan et al., 2019



Questioning on the spontaneous case - Case 2

Figure 3. Coherence between brain areas of experienced and novice groups during the applied exam for the second case (labeled as Answer 2, question and answer format) for (A) Beta and (B) Gamma frequency bands. Dashed lines: novices had significantly higher coherence.

- Novices: high cognitive effort in searching for relevant clinical information and integrating visual memory

Table 1. Results of a linear model with Lasso method for predicting performance

Variable	Coefficient	Std. error	P-value
(Intercept)	77.919	9.733	**< 0.001**
Reading, Gamma coherence between F7-FC5	-18.418	10.17	0.130
Reading, Gamma coherence between P8-F8	10.723	12.374	0.426
Reading, Gamma coherence between T8-AF4	4.453	13.226	0.750
Answer 1, Beta coherence between, F7-F8	30.216	13.823	0.081
Answer 1, Gamma coherence between P7-T8	-17.316	18.468	0.391
Answer 2, Alpha coherence between P7-P8	-6.21	13.38	0.662
Answer 2, Gamma coherence between F7-F3	-9.002	14.823	0.570
Answer 2, Gamma coherence between F3-T7	-4.092	11.078	0.727
Answer 2, Gamma coherence between O1-F8	-25.169	14.786	0.149
Beta power (PSD), Channel F7	-4.811	18.055	0.800

R^2= 0.94

Table 2. Results of a linear model with Lasso method for predicting cognitive load (NASA-TLX)

Variable	Coefficient	Std. Error	P-value
(Intercept)	0.59433	0.03666	< 0.001
Answer 1, Theta coherence between F4-F8	0.16768	0.06632	0.026
Answer 2, Theta coherence between F7-AF4	-0.25325	0.05181	< 0.001
Answer 2, Alpha power (PSD), Channel F3	0.12333	0.07644	0.133

R^2= 0.81

CONCLUSIONS

- EEG could potentially complement traditional measures
- The results highlighted the complexity of brain dynamics as physicians make decisions under pressure
- Identified functional connectivity patterns could guide future hypothesis-driven studies
- More research with larger samples is needed to understand how these EEG patterns might translate into actionable training or assessment strategies

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QUESTIONS