Translating neurophysiological recordings into dynamic estimates of conceptual knowledge and learning

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tl;dr

- We used computational approaches to create **knowledge estimates** based on **EEG data** of participants who were watching a set of lecture videos
- We asked if we can use these approaches to accurately reconstruct the **conceptual knowledge** and **progress of learning** with a **moment-by-moment resolution**
- We found that brain waves in the **gamma band** may be **indicative of knowledge acquisition**
- Further analysis may reveal a robust method of **knowledge prediction**

Background

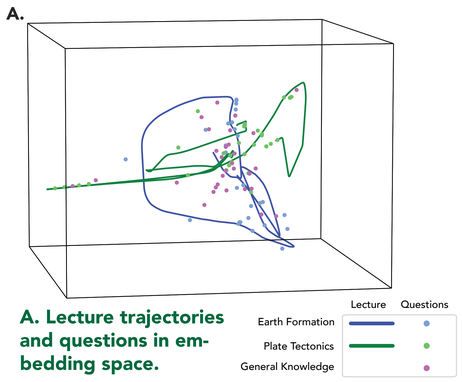
- Fitzpatrick, et al. (2023) developed a computational framework to **estimate the conceptual trajectory** of a lecture video over time
- Prior studies have used **inter-subject correlations** (ISC) and **inter-subject functional correlations** (ISFC) between neurophysiological signals recorded from different individuals to **identify stimulus-driven dynamics** (Hasson et al., 2004; Simony et al., 2016)

Approach

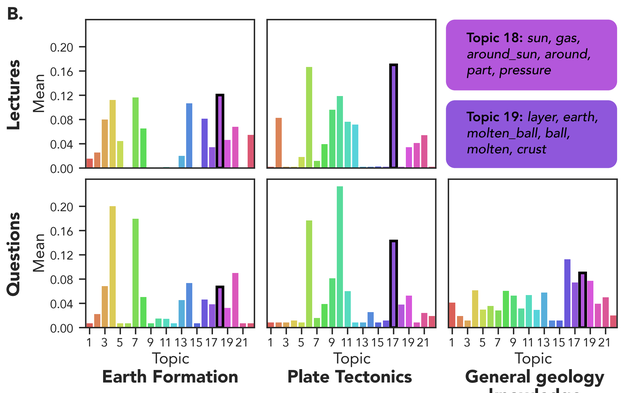
- We selected the Khan Academy lectures "Earth formation" and "Plate tectonics," and created three sets of 30 questions each that test **conceptual understanding**
- We used a topic model (Blei, et al. 2003) to estimate the **conceptual trajectory** of each lecture
- We collected **64-channel EEG data** (n = 42) while participants were watching the two lecture videos and answered three rounds of 30 questions
- For each recording, we computed **five neural features** per channel corresponding to the five common brain wave frequency bands
- We leveraged **timepoint-by-timepoint ISFC values** as a measure of each participant's level of **knowledge acquisition** at each moment in the lecture video
- We treated the topic vector of the transcript in each sliding window as the **"question"** and the ISFC value at the corresponding timepoint as the **"answer"**
- This allowed us to create **ISFC-derived knowledge predictions**

Results

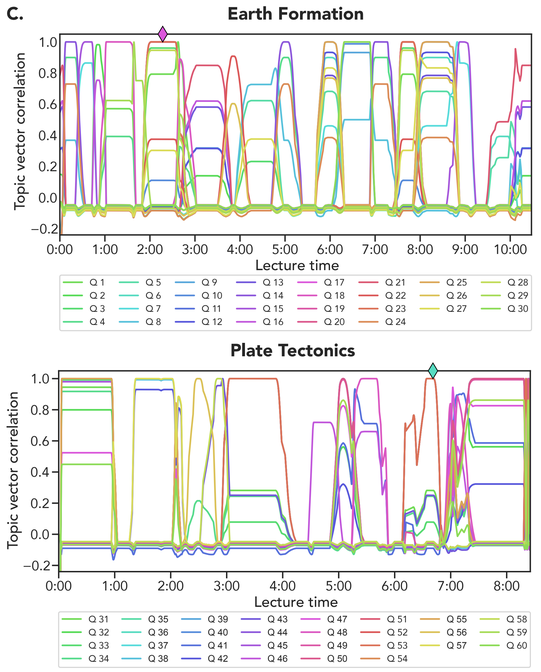
I. Text Embedding



A. Lecture trajectories and questions in embedding space.

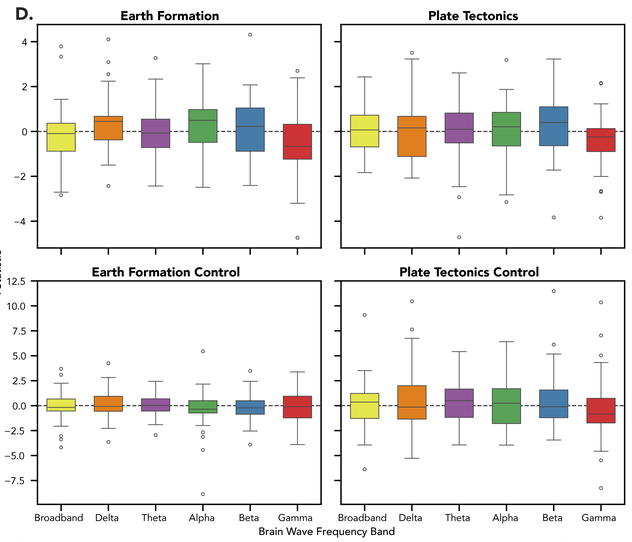


B. Average topic weight by lecture and question set.

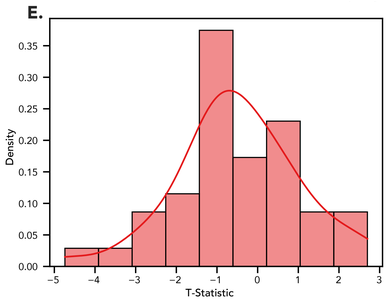


C. Correlation between lecture trajectory and question embeddings. This gives us an estimate of how relevant any moment in a lecture is for a given question.

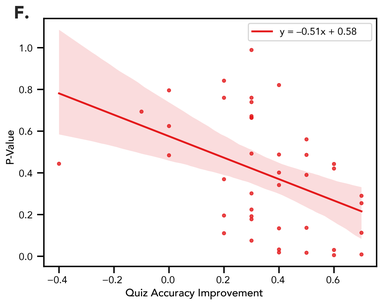
II. ISFC Analysis



D. Distribution of t-statistics by brain wave frequency band. Each t-statistic measures the difference of means between ISFC values of correctly and incorrectly answered quiz questions.



E. Distribution of t-statistics in the gamma band.



F. OLS regression between quiz accuracy improvement and p-values.

Discussion

- We asked if we can treat participants' ISFC values aligned with the conceptual trajectory of a lecture as a **moment-by-moment knowledge and learning estimate**
- We found that **ISFC values of gamma band activity** may contain a signal informative of knowledge acquisition
- We discovered that the **confidence of our estimates** is directly tied to the learning progress made while watching a lecture
- We will investigate if the ISFC signal of specific **brain regions** is indicative of knowledge and learning

References & Acknowledgements

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