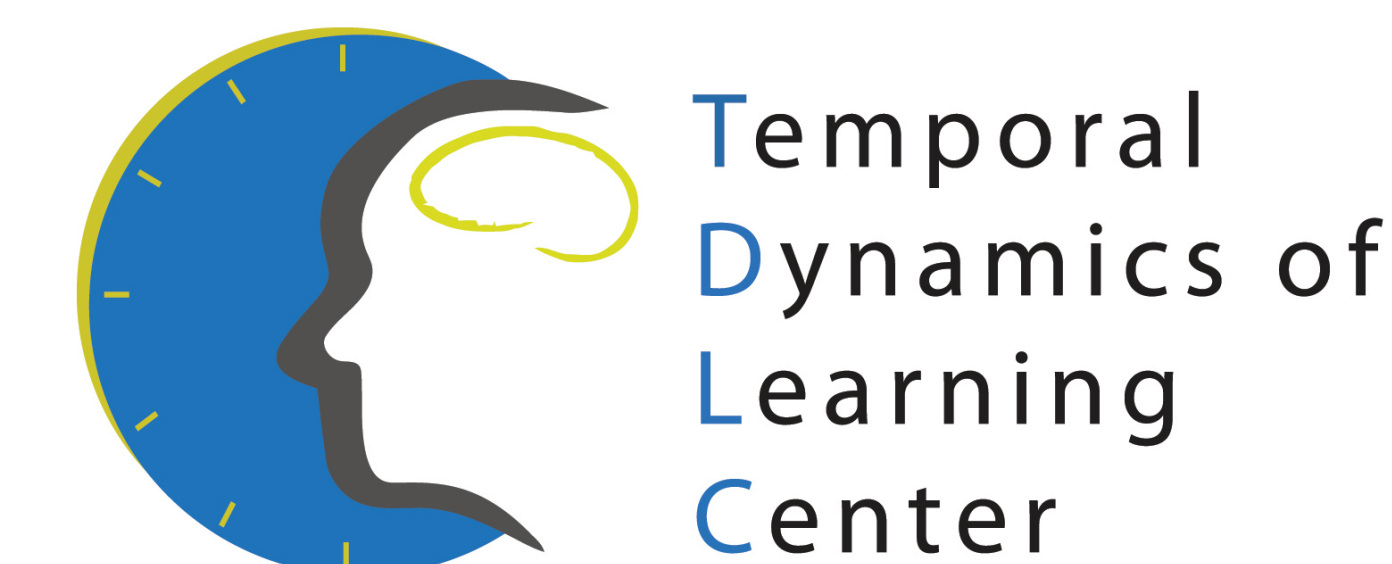# Predicting Subsequent Memory Performance For Auditory and Visual Encoding

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Introduction

Summary

- We attempted to predict whether a subject would later recall studied words presented either visually or aurally based on EEG activity recorded during study. Encoding period EEG was decomposed into 6 oscillatory bands (4–64 Hz). Memory success was defined by recalling words in a free recall period.

Oscillations during encoding

- Theta (4–8 Hz) and gamma (28–100+ Hz) are found while encoding new information (Klimesch, Doppelmayr, Russegger, & Pachinger, 1996; Sederberg et al., 2006).

Questions and Hypotheses

- Because particular frequency bands have been associated with successful encoding of memories, it might be possible to predict subsequent memory performance based on encoding period band power.
  - Successful encoding might have different oscillatory signatures for different stimulus modalities (auditory and visual).
  - Oscillatory band activity during early and late portions of the encoding period might differentiate based on subsequent memory.
- If these are true:
  - We should be able to train multivariate pattern classifiers to distinguish successful from unsuccessful encoding.

Experiment

- 20 blocks of 16 intermixed auditory and visual stimuli.
- 1000 ms stimulus presentation, preceded by a modality cue.
- Distractor period: count backwards by 3s.
- Free recall of encoded stimuli. Recall was used to define successful encoding.
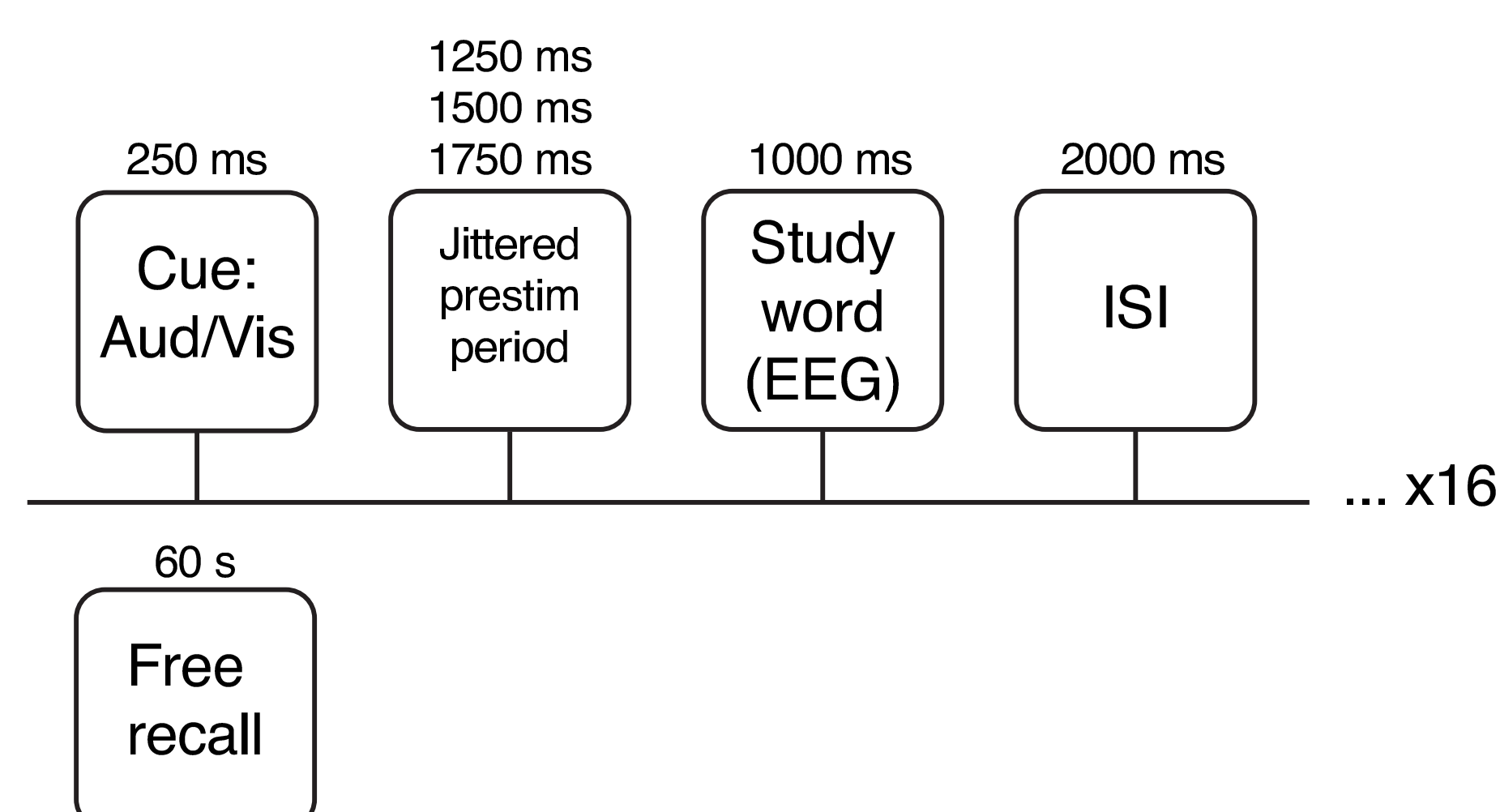
Classifier Details

- Balanced trial counts within modalities
- Z-transformed time–frequency data
- L1 regularized logistic regression
  - $\alpha = 1$
  - λ (regularization parameter) $= 0.1$
- 10-fold cross-validation

Behavioral Results

- 10 right-handed adults
- Two trials from the start and end of encoding blocks were excluded to eliminate primacy and recency.
- **Trial counts** before balancing conditions within modality:

Subject	S03	S05	S06	S07	S08	S09	S12	S13	S14	S15	Average
Auditory: Recalled trials	35	52	32	32	25	59	42	37	28	34	37.6
Auditory: Forgotten trials	58	58	85	32	30	41	72	75	53	34	57.5
Visual: Recalled trials	38	23	37	20	20	61	23	37	18	19	29.6
Visual: Forgotten trials	54	89	72	63	44	38	92	73	61	85	67.1

- **Accuracy** before balancing conditions within modality:

Subject	S03	S05	S06	S07	S08	S09	S12	S13	S14	S15	Average
Auditory: accuracy	37.6	47.3	27.4	50.0	45.5	59.0	36.8	33.0	34.6	32.4	40.4
Visual: accuracy	41.3	20.5	33.9	24.1	31.3	61.6	20.0	33.6	22.8	18.3	30.7

  - Auditory > Visual [$t(9) = 2.49, p < .05$]

Classification Results

- **Auditory: Early time window**

Subject	S03	S05	S06	S07	S08	S09	S12	S13	S14	S15	Average
4–8 Hz	40.0	51.9	60.9	48.4	56.0	35.4	45.2	40.5	37.5	47.1	46.3
8–14 Hz	68.6	49.0	53.1	45.3	58.0	63.4	47.6	48.6	55.4	52.9	54.2
14–21 Hz	60.0	54.8	53.1	32.8	48.0	56.1	56.0	54.1	57.1	41.2	51.3
21–28 Hz	51.4	72.1	68.8	51.6	58.0	51.2	35.7	50.0	53.6	55.9	54.8
28–42 Hz	55.7	59.6	56.2	59.4	48.0	47.6	47.6	58.1	41.1	70.6	54.4
28–64 Hz	61.4	52.9	59.4	28.1	40.0	58.5	44.0	54.1	41.1	47.1	48.7

- **Auditory: Late time window**

Subject	S03	S05	S06	S07	S08	S09	S12	S13	S14	S15	Average
4–8 Hz	32.9	42.3	53.1	57.8	42.0	48.8	44.0	41.9	37.5	47.1	44.7
8–14 Hz	47.1	56.7	62.5	59.4	40.0	46.3	64.3	50.0	35.7	39.7	50.2
14–21 Hz	50.0	61.5	51.6	64.1	68.0	42.7	53.6	52.7	44.6	55.9	54.5
21–28 Hz	45.7	52.9	34.4	39.1	40.0	54.9	57.1	47.3	67.9	39.7	47.9
28–42 Hz	50.0	42.3	50.0	35.9	28.0	53.7	50.0	52.7	41.1	51.5	45.5
28–64 Hz	52.9	46.2	48.4	35.9	52.0	43.9	48.8	56.8	37.5	63.2	48.6

- **Visual: Early time window**

Subject	S03	S05	S06	S07	S08	S09	S12	S13	S14	S15	Average
4–8 Hz	43.4	58.7	44.6	57.5	40.0	52.6	47.8	40.5	41.7	39.5	46.6
8–14 Hz	60.5	60.9	32.4	52.5	60.0	48.7	47.8	43.2	55.6	36.8	49.8
14–21 Hz	46.1	47.8	58.1	45.0	50.0	53.9	60.9	44.6	50.0	31.6	48.8
21–28 Hz	52.6	71.7	47.3	52.5	42.5	48.7	43.5	45.9	36.1	42.1	48.3
28–42 Hz	46.1	45.7	54.1	65.0	37.5	52.6	37.0	44.6	44.4	42.1	46.9
28–64 Hz	55.3	56.5	50.0	40.0	82.5	44.7	73.9	37.8	55.6	63.2	55.9

- **Visual: Late time window**

Subject	S03	S05	S06	S07	S08	S09	S12	S13	S14	S15	Average
4–8 Hz	47.4	41.3	41.9	50.0	35.0	50.0	39.1	44.6	38.9	57.9	44.6
8–14 Hz	52.6	30.4	52.7	35.0	55.0	51.3	32.6	56.8	66.7	39.5	47.3
14–21 Hz	55.3	60.9	41.9	37.5	55.0	42.1	65.2	62.2	55.6	39.5	51.5
21–28 Hz	47.4	58.7	44.6	57.5	42.5	61.8	76.1	50.0	72.2	50.0	56.1
28–42 Hz	52.6	52.2	51.4	40.0	37.5	36.8	50.0	56.8	69.4	50.0	49.7
28–64 Hz	57.9	52.2	59.5	45.0	60.0	40.8	69.6	50.0	33.3	60.5	52.9

- Significance:

Light gray	$p < .1$
Dark gray	$p < .05$

Scalp EEG

- 128-channel 500-Hz EGI scalp EEG system; 200 MΩ high-impedance amplifier; EEG preprocessed; average reference.
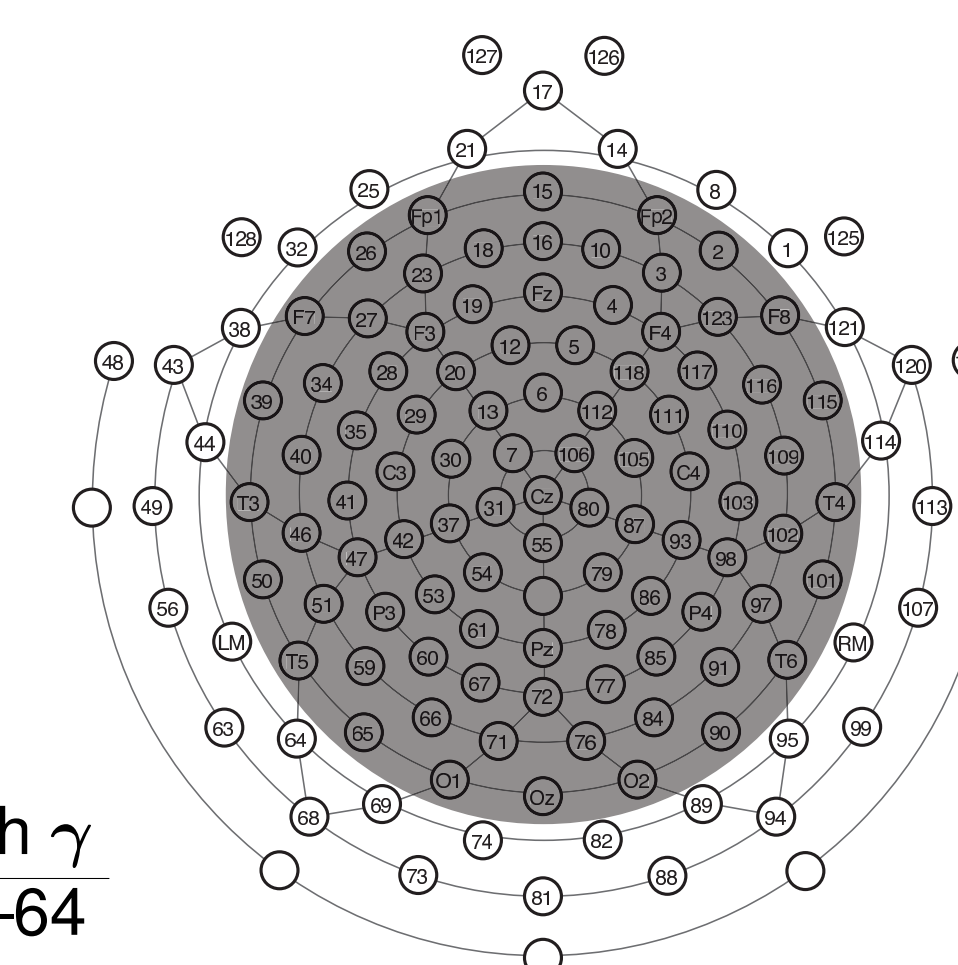- EEG preprocessing:
  - ICA-based eye blink artifact correction
  - Artifact rejection
  - Average rereference; baseline correction (-300–0 ms pre-stimulus)
- 91 central channels sub-selected
- 6 frequency bands:

Band	θ	α	Low β	High β	Low γ	High γ
Hertz	4–8	8–14	14–21	21–28	28–42	42–64

- EEG divided into **early** (0–500 ms) and **late** (500–1000 ms) windows

Summary of Results

Behavioral

- More items were forgotten than recalled.
- More accurate for auditory than visual stimuli.

Classification

- Qualitatively, auditory stimuli differentiate in lower oscillatory bands while visual stimuli differentiate in higher oscillatory bands.
- Across subjects, no bands are different from chance.
- During exploration of classifier options, some subjects were fit better by particular classifiers (e.g., elastic net, L1, L2, SVM).

Next Steps

- Better exploration of classifiers and their parameters.
- Include primacy and recency items for analysis of oscillatory dynamics as influenced by serial position (Sederberg et al., 2006).

References

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Sederberg, P. B., Gauthier, L. V., Terushkin, V., Miller, J. F., Barnathan, J. A., & Kahana, M. J. (2006). Oscillatory correlates of the primacy effect in episodic memory. *Neuroimage, 32*(3), 1422–1431.

Acknowledgments