Neural Evidence of Serial Dependence in Ocular Tracking

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Introduction

Serial dependence (SD): perception biased toward recent stimuli, promoting perceptual stability (Fischer & Whitney, 2014).

This effect was also observed in early eye movement responses during smooth pursuit (Hong et al, 2024), suggesting that SD occurs at early sensory-driven stages of visual processing.

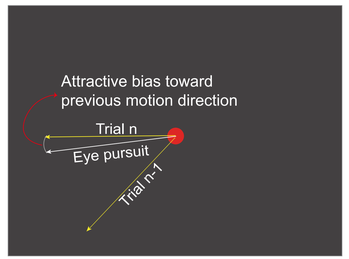
Two key open questions:

1.Temporal substrate: recent behavioral findings implicate oscillations activity in maintaining perceptual history (Cicchini, 2024), but direct neural evidence remains missing.

2.Spatial locus: while some studies attribute SD to higher-level decisional processes (frontal), others propose a sensory origin in early visual cortex (occipital).

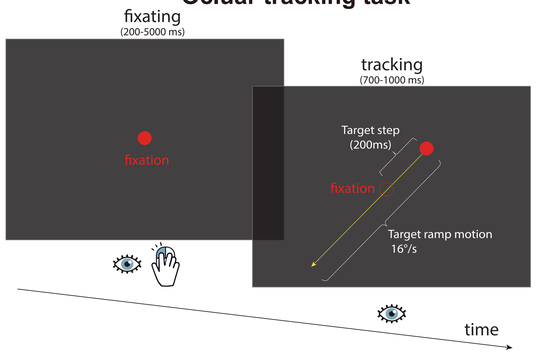
Goal: Combine EEG + eye-tracking to reveal neural implementation of SD.

Attraction bias illustration



General Methods

Ocular tracking task



(Rashbass, 1961; Chen et al., 2021; Chen et al., 2022)

Participants:
Sixteen undergraduate and graduate students (aged 18-25 years, F/M = 8/8).

Task:
keep head still and track the step-ramp motion of a red spot (0.64°) with its speed (16°/s) and moving direction (0°-360°,-steps: 12°) randomly varied from trial to trial.

Condition:
Each participant completed 1,440 trials (30 directions × 48 repetitions) divided into 16 blocks, across two separate sessions.
Trials were pseudorandomized to ensure an unpredictable sequence of motion directions.

Data Acquision :
Eye movements were recorded using an EyeLink 1000 eye tracker (1000 Hz).
EEG signals were recorded simultaneously with a 64-channel Brain Products system (10–20 layout,1000 Hz).The impedance was maintained below 20 kΩ.

Behavioral Analyses and Results

Pursuit response:

Pursuit onset was identified using a hinge model. The pursuit direction was defined as the mean eye velocity direction within the 0–160 ms interval following pursuit onset (Lisberger & Westbrook, 1985), during which eye movements are driven by target motion input.

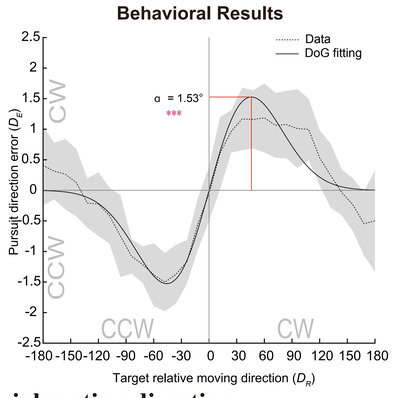
Serial dependence:

Pursuit direction error (D_E) : the difference between pursuit direction and the target moving direction

The relative target moving direction of the previous trial (D_R): the difference between the target moving direction in the previous trial and the current trial

Serial dependence quantified by DoG fit to pursuit direction error (D_E) as the funtion of the relative target moving direction (D_R)

Behavioral Results



Eye pursuit responses were biased toward the previous-trial motion direction

Neural Analyses and Results

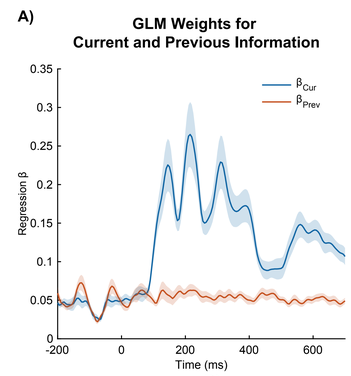
Neural oscillation analysis

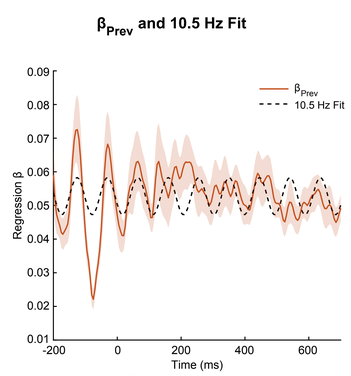
1.Regression analysis

For each electrode and time point, EEG voltage (y(t)) was modeled as a linear combination of the current (θ_{Curr}) and previous (θ_{Prev}) motion directions using sine–cosine coding (simplified notation shown here):

$$y(t)= \beta_{Curr}(t)\cdot\theta_{Curr} + \beta_{Prev}(t)\cdot\theta_{Prev} + \varepsilon$$

- β_{Curr} increased sharply after stimulus onset (150–300 ms)
- β_{Prev} was smaller in amplitude but exhibited rhythmic fluctuations

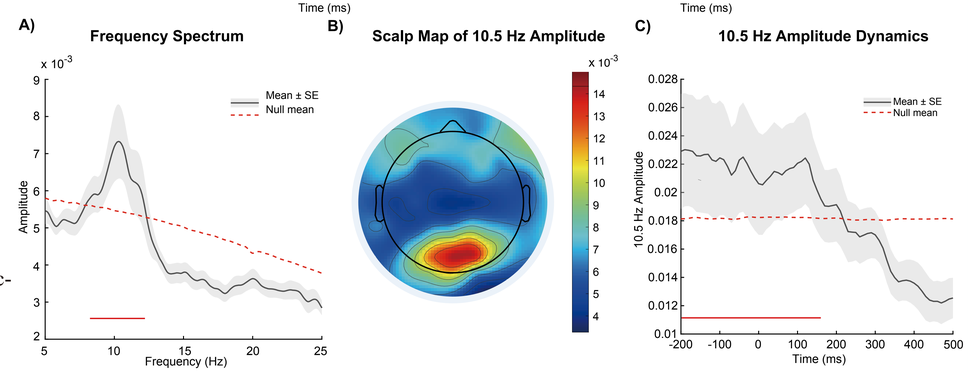




2.Spectral analysis

Frequency spectra (5–25 Hz) were computed from β_{Prev} time series, and a sliding-window regression tracked temporal evolution of rhythmic components (200ms window in 10ms step).

- Significant alpha-band (~10.5 Hz) peak in β_{Prev} power.
- The 10.5 Hz component emerged before stimulus onset (−200 to 140 ms), decreased after ~100 ms, and was strongest over occipital–parietal electrodes.

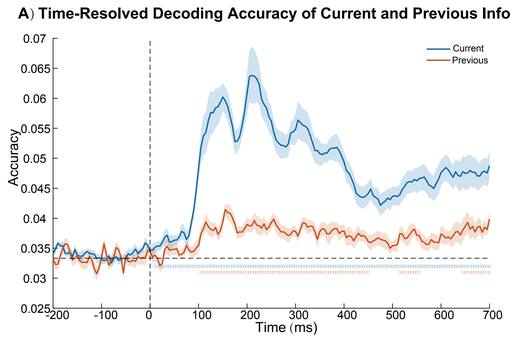


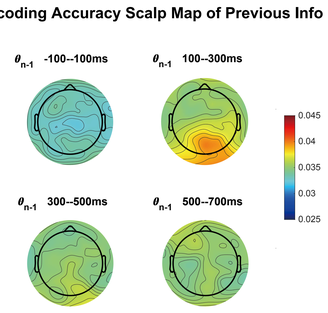
Preparatory alpha rhythmic activity in visual cortex maintaining previous-trial motion information

Time-resolved MVPA decoding

Time-resolved multivariate pattern analysis (LDA classifier) decoded motion direction from EEG across 63 electrodes with three-fold cross-validation.

- Current-trial direction: increased sharply after stimulus onset from ~100 ms.
- Previous-trial direction: decodable from ~100 ms, strongest over occipital–parietal electrodes (100–300 ms).
- At the same time, alpha rhythmic activity diminished as visual motion input accumulated, indicating that the previously maintained information was integrated with new sensory evidence.





Visual cortex represents and integrates past and current motion information during early visual processing

Conclusion

- Early pursuit responses showed an attractive serial dependence effect.
- Alpha-band rhythmic activity over visual cortex reflected preparatory maintenance and integration of past motion information to stabilize perception

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