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For poster followup, contact yel2005@med.cornell.edu

Cognitive Influences on Ocular Drifts during Visual Discrimination

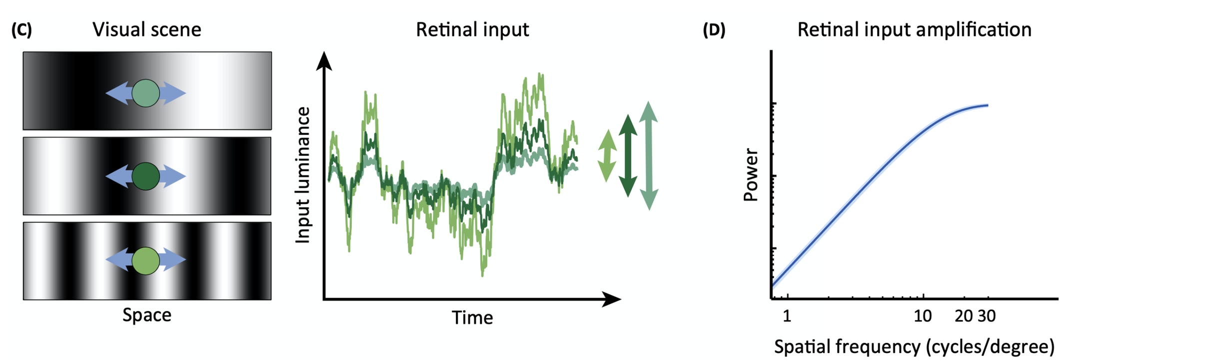
Yen-Chu Lin[1], Janis Intoy[2,3], Ashley M. Clark[2,3], Michele Rucci[2,3], and Jonathan D. Victor[1]

[1]Feil Family Brain and Mind Research Institute and Department of Neurology, Weill Cornell Medical College
[2]Center for Visual Science, University of Rochester, Rochester, NY 14627
[3]Department of Brain & Cognitive Sciences, University of Rochester, Rochester, NY 14627

INTRODUCTION AND MOTIVATION

Most visual information is acquired during fixation. Although ocular drifts are now known to be a crucial part of visual processing, the underlying mechanisms of the neuronal control of this fine oculomotor behavior is still not well understood. With the inspiration that large eye movements are known to be driven both by sensory information and cognitive factors, we investigate the role of cognitive factors - the influence of prior knowledge - on ocular drifts.

Ocular drifts modulate temporal coding of visual space

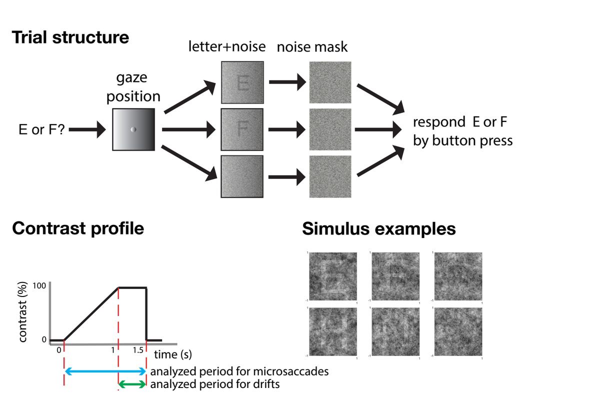


Rucci and Victor *(2015) Trends in Neuroscience*

Ocular drift modulates input signals in a way that depends on the spatial frequency of the stimulus. The same amount of drift yelds larger temporal fluctuations at higher spatial frequencies. Higher spatial frequences also lead to broader temporal distributions. *(Casile et al. 2019. Elife)*

METHODS

To probe cognitive influence, subjects performed a 2AFC letter discrimination task in which the letters to be discriminated were known in advance.. We tested the subjects with two separate blocks of letter pairs, E vs. F and H vs. N.



Trial structure, the contrast profile, and stimulus examples (below) For stimulus examples, top row shows E, F, and letter-absent; bottom row shows H, N, and letter-absent.

Subjects

6 healthy subjects participated in the study (4 females and 2 males with 20/20 vision after correction)

Stimulus

Stimulus subtended approximately 1.5° , presented in positive contrast and superimposed on a 2°square patch of 1/f noise (f from 1 to 16 cpd), with a root-mean-squared contrast of 0.195

Comparing drift statistics across conditions

We quantified the statistics of fixational eye movements by the covariance matrix of their velocities. To compare two covariance matrices, we used the following distance:

$$d_0(\mathrm{T}_1,\mathrm{T}_2)=\left\|\log \mathrm{T}_1^{-1}\mathrm{T}_2\right\|_F=\sqrt{\log^2(\lambda_1)+\log^2(\lambda_2)}$$

where λ_1 and λ_2 are the eigenvalues of $\mathrm{T}_1^{-1}\mathrm{T}_2$.

This measure takes into account the size, shape, orientation, and considers orientation more strongly when the shape becomes more eccentric. In addition, this measure is unchanged if both covariance matrices are multiplied by the same scale factor or rotated by the same amount.

HUMAN PSYCHOPHYSICS RESULTS

Directional bias in ocular drifts

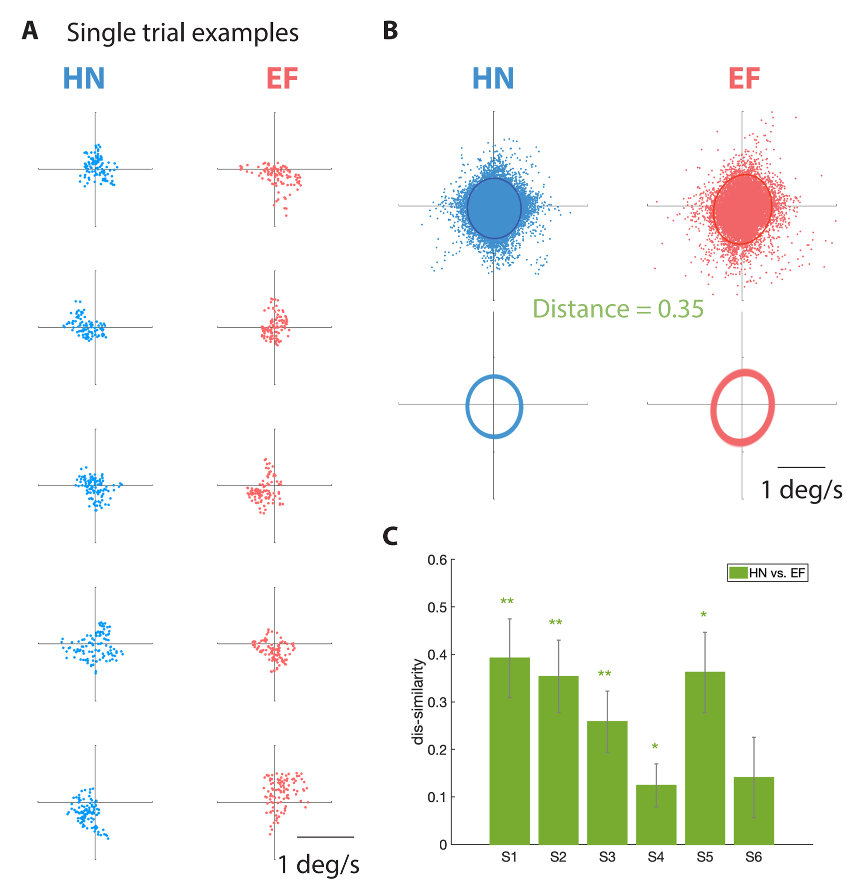


Fig. 1. Drift velocity distributions and statistics
(A) Examples of single drift velocity segments from one subject. Blue: H or N presented. Pink: E or F presented. (B) Top: Drift velocity covariance ellipse from all trials of one subject. Bottom: confidence bands for covariance ellipse obtained by bootstrap resampling. (C) Dis-similarity between HN and EF covariance ellipses from six subjects. Error bars represent 1 standard deviation of the dis-similarity from bootstrap resampling (*p<0.05,**p<0.01).

Open-loop vs closed-loop influences on drifts

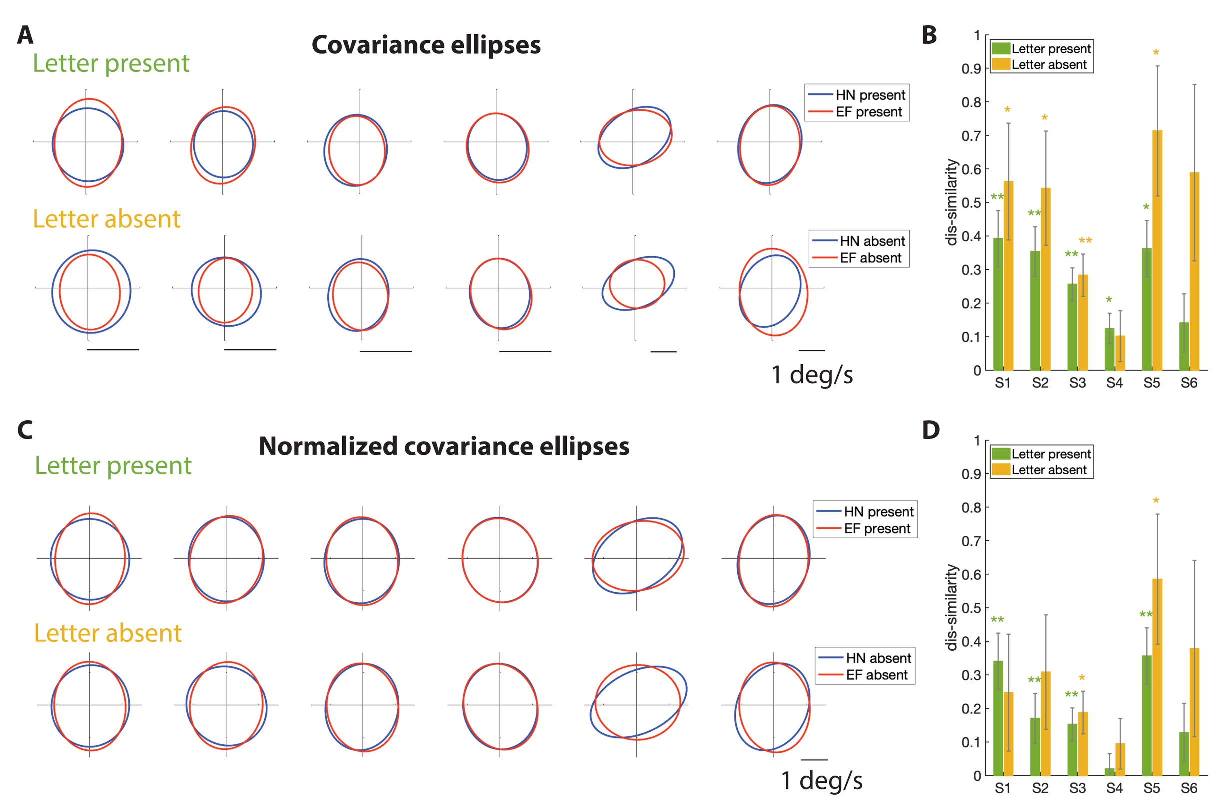


Fig. 2. Drift statistics depend on the letter pair to be discriminated, even when stimulus is absent (A) Top: Drift velocity covariance ellipses from HN trials(blue) and EF trials (red), with letter present. Bottom: Same as top panel but from letter absent trials. (B) Dis-similarity between HN and EF covariance ellipses in each subject. Green: letter present trials. Orange: letter absent trials. (Error bars represent 1 standard deviation. * p<0.05, ** p<0.01) (C & D) Analysis of panels A and B applied to covariance ellipses after normalizing to the same total area.

COMPUTATIONAL ANALYSIS RESULTS

Decoding single-trial trajectories

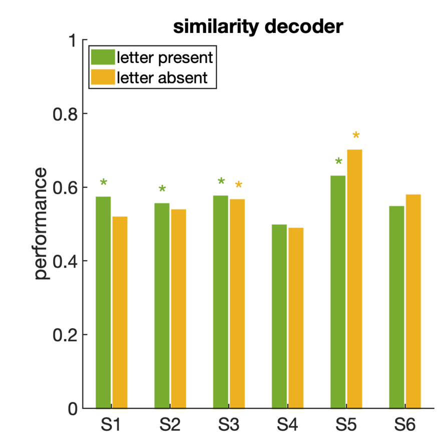


Fig. 3. Decoding single trials via their drifts
Drifts from 300-ms periods of individual trials were decoded into task (HN vs EF blocks) based on the similarity of the single trial covariance estimated form all trials of each condition. Figure shows the performance of the similarity decoder in the six subjects. * marks the cases with fraction correct higher than chance (p<0.05).

Finding a shared transformation across subjects

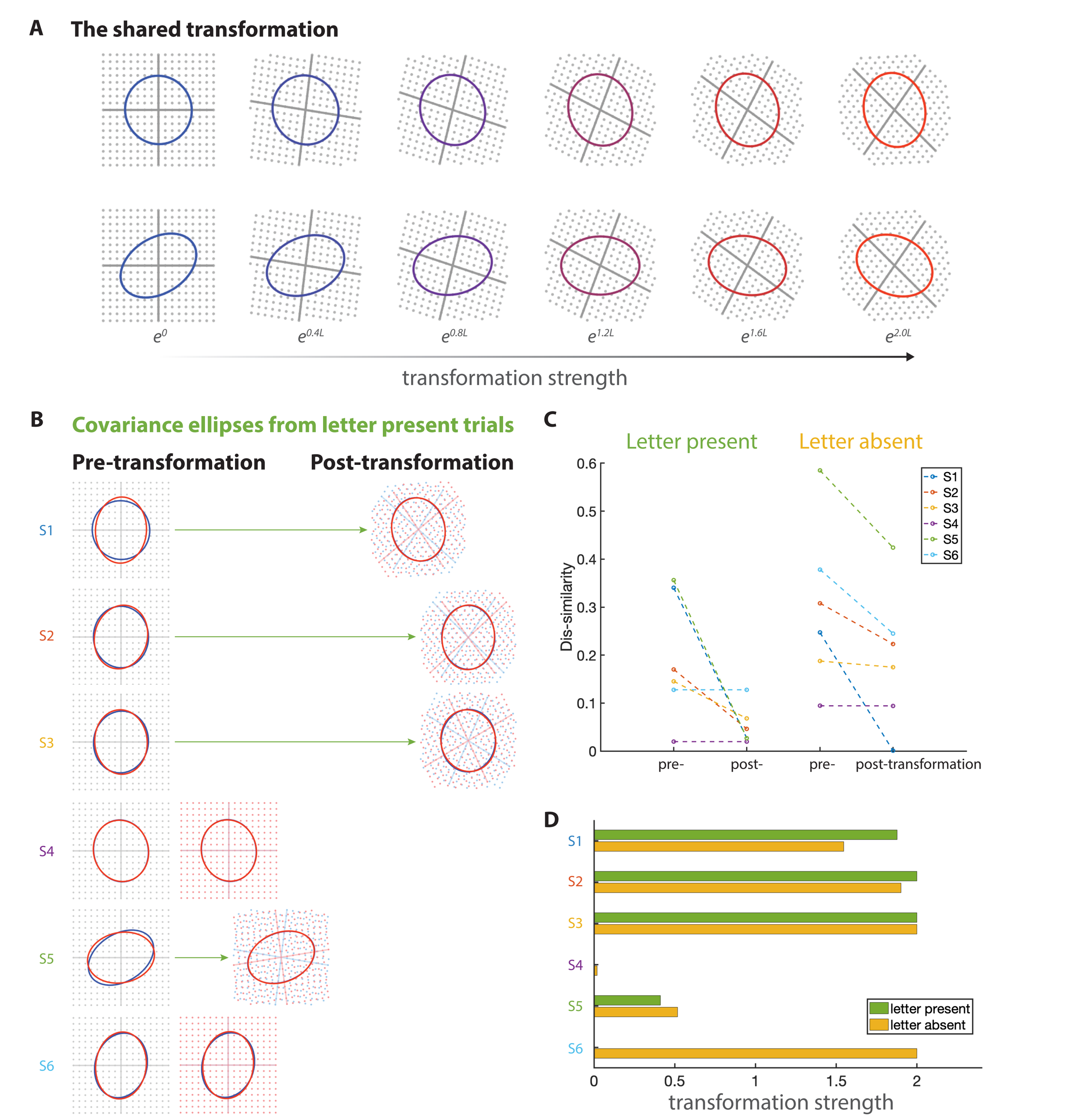


Fig. 4. A shared model across subjects of graded transformations between ellipses
We found that a single coordinate transformation, applied with different strengths, could account for much of the change in drift statistics across all subjects. (A) Visualization of the shared transformation by applying graded amounts to the HN ellipse from subject 1 (top row) and to the HN ellipse from subject 5 (bottom row). (B) HN (blue) and EF (red) covariance ellipses for each subject before and after applying varying amounts of the shared transformation. (C) Dis-similarities of HN and EF covariance ellipses before and after applying the shared transformation. Left: target present trials. Right: target absent trials. (D) The amount of transformation applied in each subject.

MICROSACCADE RESULTS

Task knowledge guides microsaccades

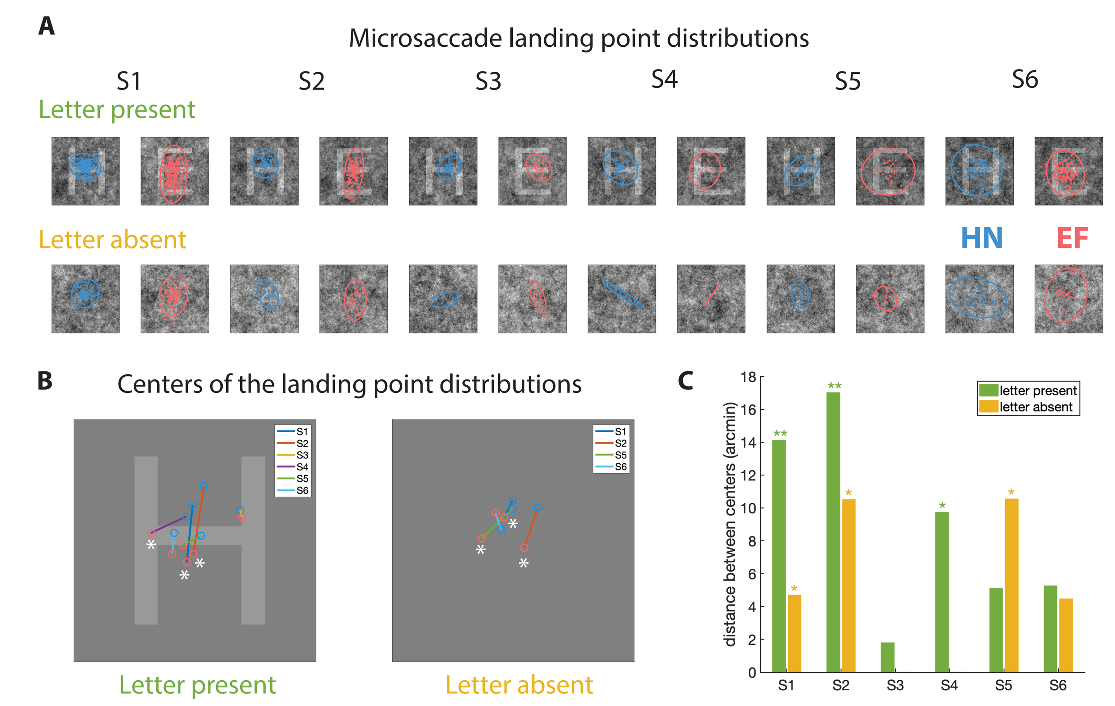


Fig. 5. Comparison of microsaccade landing points between HN and EF blocks
(A) Microsaccade landing points on each target, along with minimum-area ellipses covering 95% of the landing points. (B) Centers of landing point ellipses in HN trials (blue circles) and EF trials (red circles). * labels the statistically-significant differences (see panel C for significance level).(C) Euclidean distances between the centers of HN and EF distributions. Green: letter-present trials. Orange: letter-absent trials. Null distributions obtained by shuffling and significant difference are represented by * for p<0.05 and ** for p<0.01. No data are shown for letter-absent trials of subjects 3 & 4 because of the low number of microsaccades. Similar results were observed for microsaccade starting positions.

SUMMARY

- Ocular drifts – the small, persistent, and seemingly involuntary eye movements made during fixation – are under cognitive influence.
- Their dominant direction is influenced by specific task knowledge.
- This influence occurs even in the absence of visual information, showing open-loop control.
- Cognitive drift modulations can be sufficient to predict the task in which the subject engaged solely from the eye trajectories.
- Drift velocity differences between the two kinds of letter-pair trials (HN, EF) could be accounted for by a shared transformation of drift velocity distributions, indicating a common strategy across subjects.

ACKNOWLEDGEMENT

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