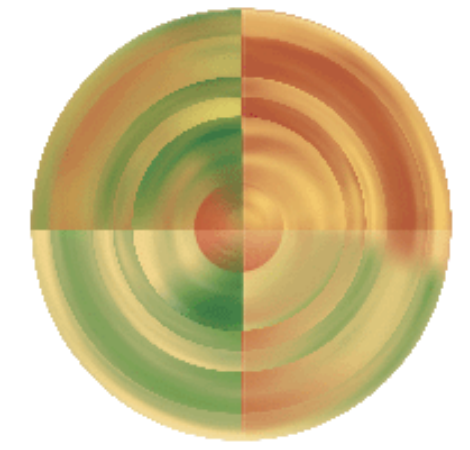


# Improving gaze accuracy and predicting fixation onset with video-based eye trackers

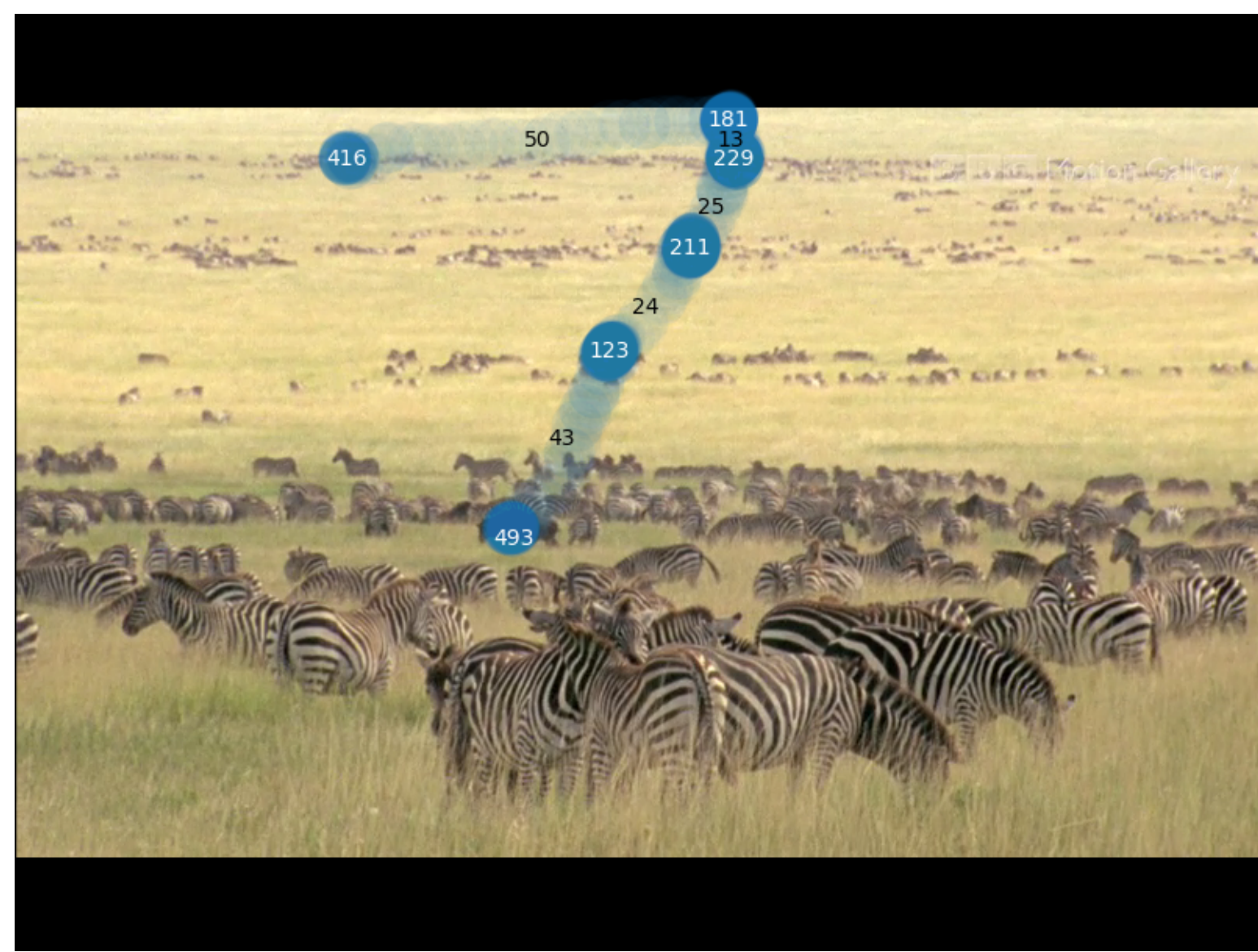


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## Summary

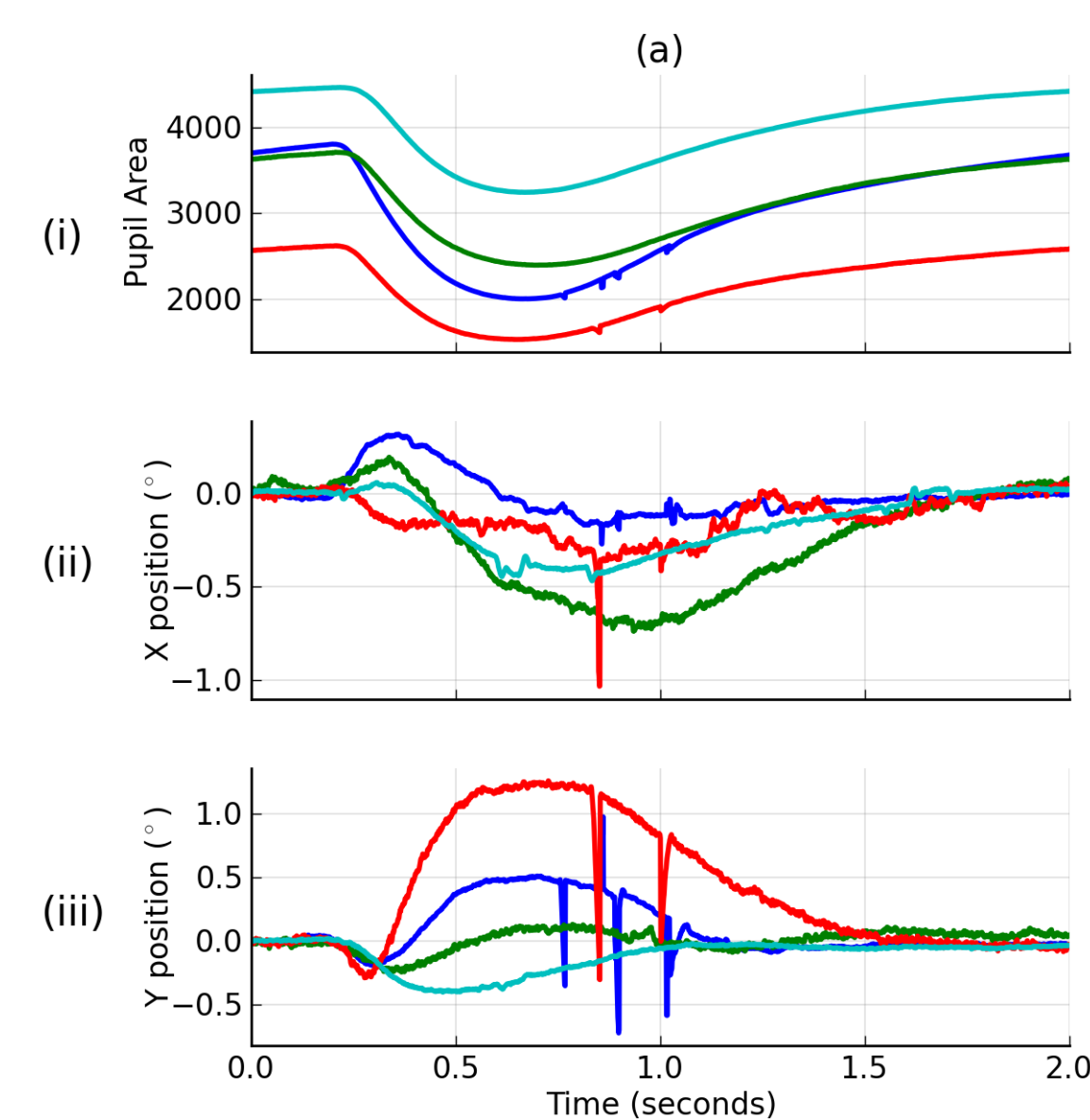
We present two methods which significantly improve current eye tracking technology, with only minor additions to standard experimental protocols:

1. We characterize a significant pupil-size dependent artifact which systematically biases reported gaze position. Our correction procedure results in a 4-fold improvement in accuracy.
2. We describe a simple yet effective method for predicting the next fixation during a saccade in flight, enabling real-time gaze contingent stimuli to be presented at the onset of fixation.



The study of foveal vision requires high resolution in both space and time. In this example the subject was free viewing a nature documentary. Two seconds of gaze data are shown superimposed on a representative frame of the movie that, for illustrative purposes, had minimal background motion. The duration, in milliseconds, of a series of fixations (white) and saccades (black) is also indicated. Marker size corresponds to  $1^\circ$  of visual angle.

## The pupil size dependent gaze measurement artifact



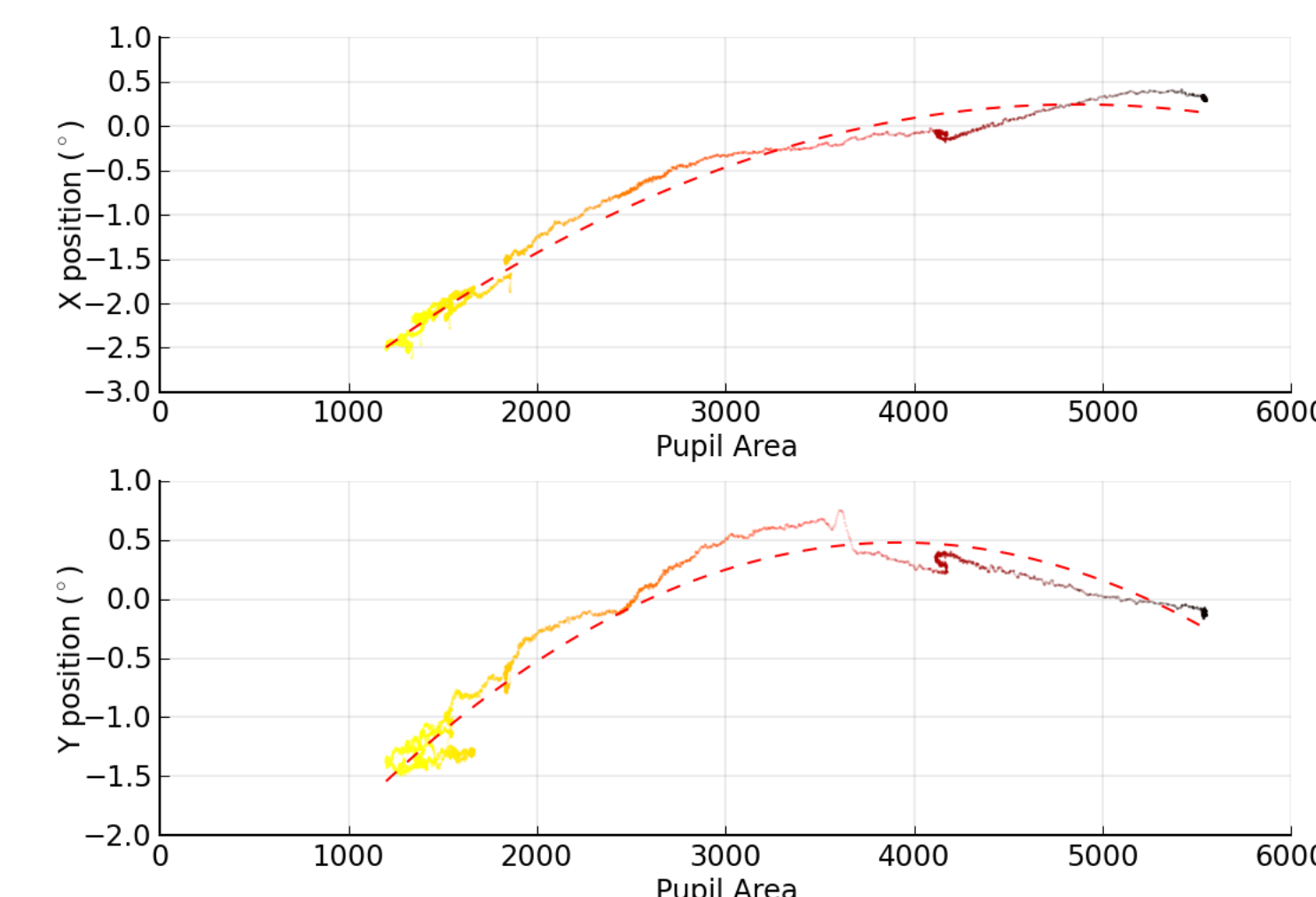
Pupil area and gaze position are highly correlated. (a) Subjects (four shown) fixated a red dot at the center of the screen with a white full screen flash at  $t=0$  to induce changes in pupil size. Each subject's average: (i) pupil area, (ii) X gaze position, and (iii) Y gaze position are shown ( $n=20$  flashes). Sharp deflections are residual blinks.

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*Redwood Center for Theoretical Neuroscience<sup>2</sup>*  
*University of California, Berkeley*



## Pupil Artifact Correction



Corrected gaze position  $x_c, y_c$  is obtained from an eyetracker reported position  $x_r, y_r$  and pupil size  $p_r$  as follows:

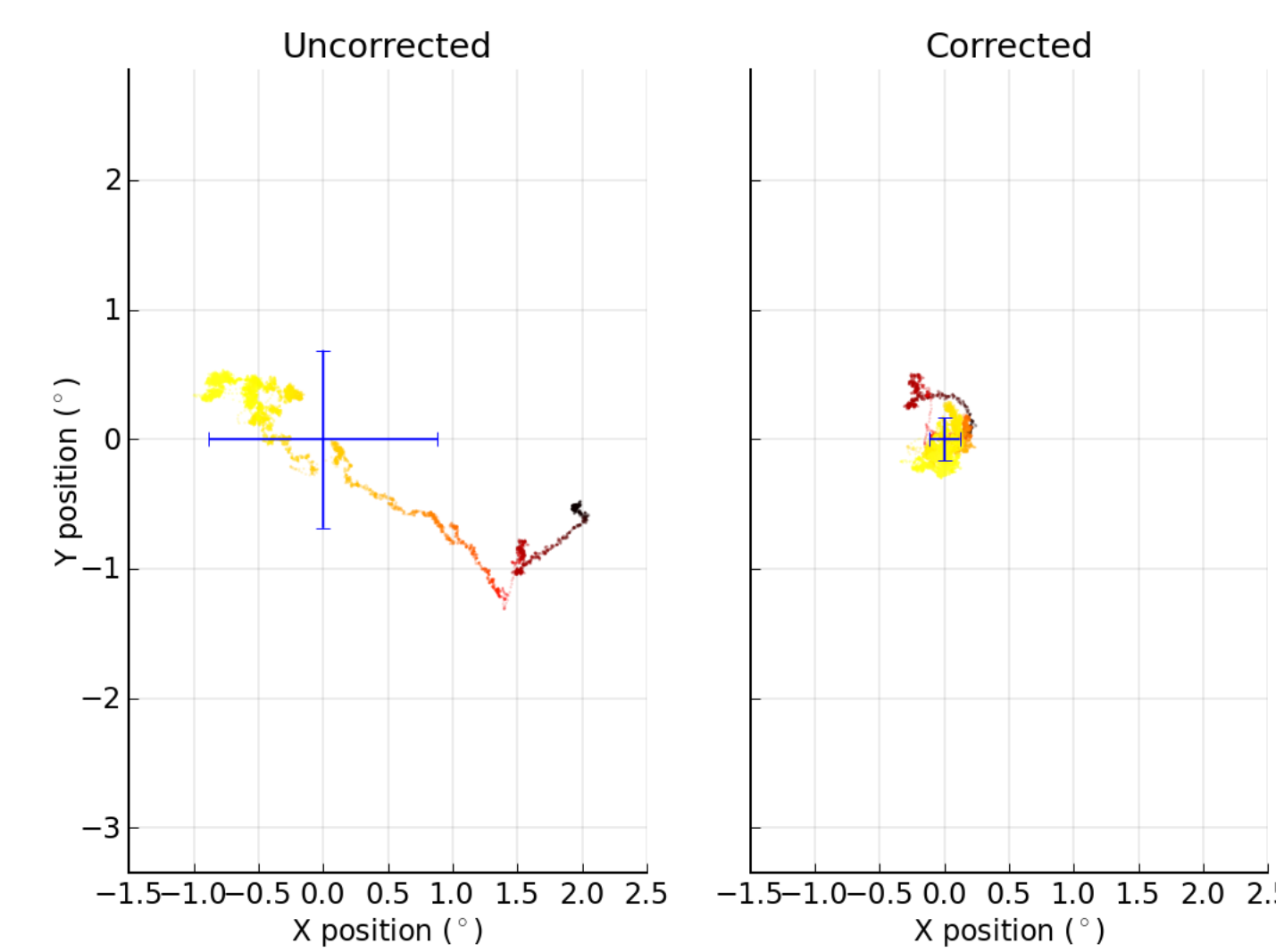
$$x_c = x_r - f_x(x_r, y_r, p_r) \quad y_c = y_r - f_y(x_r, y_r, p_r)$$

where

$$f_x = a_x(x_r, y_r) + b_x(x_r, y_r) p_r + c_x(x_r, y_r) p_r^2$$

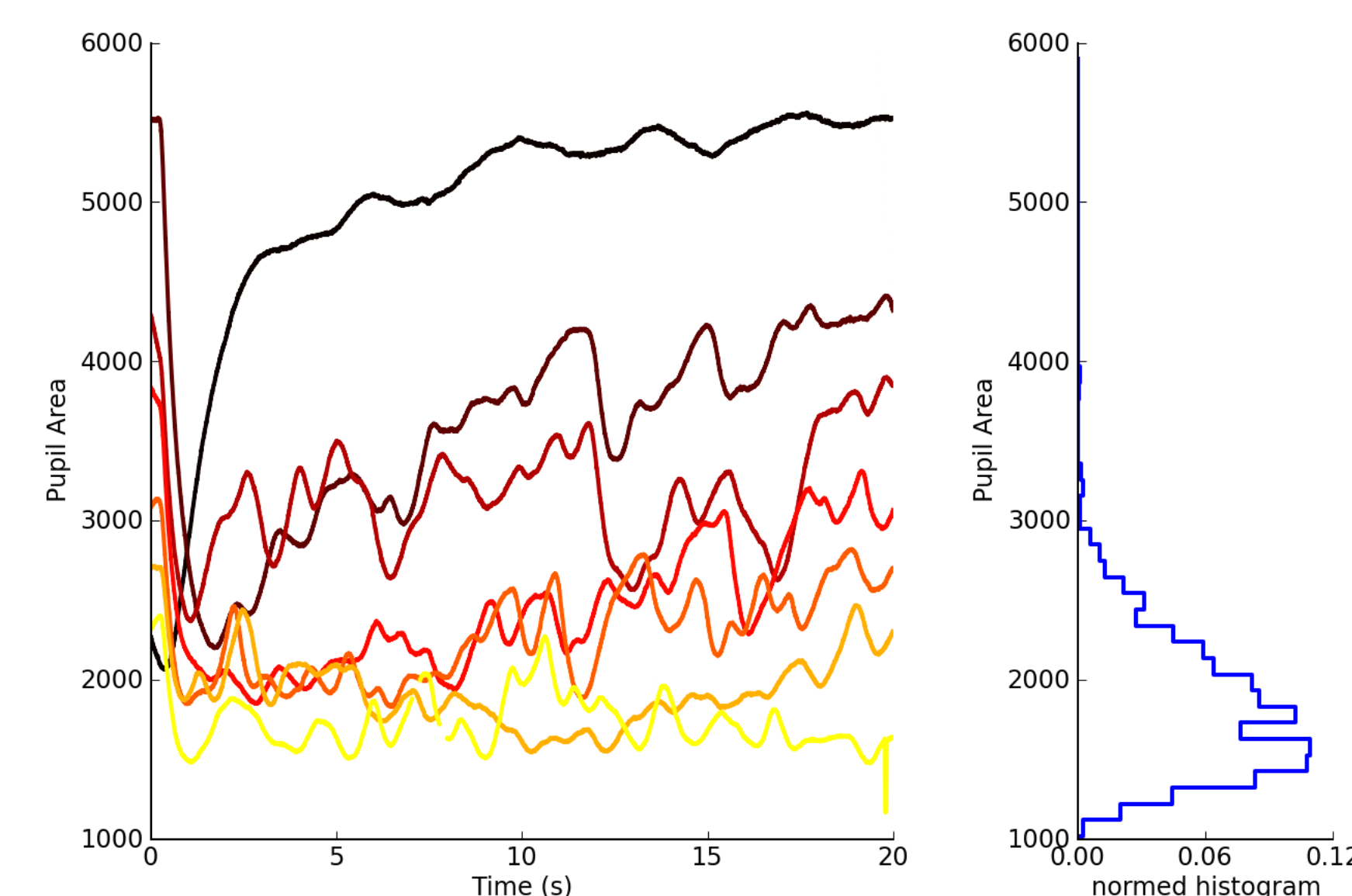
$$f_y = a_y(x_r, y_r) + b_y(x_r, y_r) p_r + c_y(x_r, y_r) p_r^2$$

and the coefficients are obtained via lookup in the surface of each parameter.



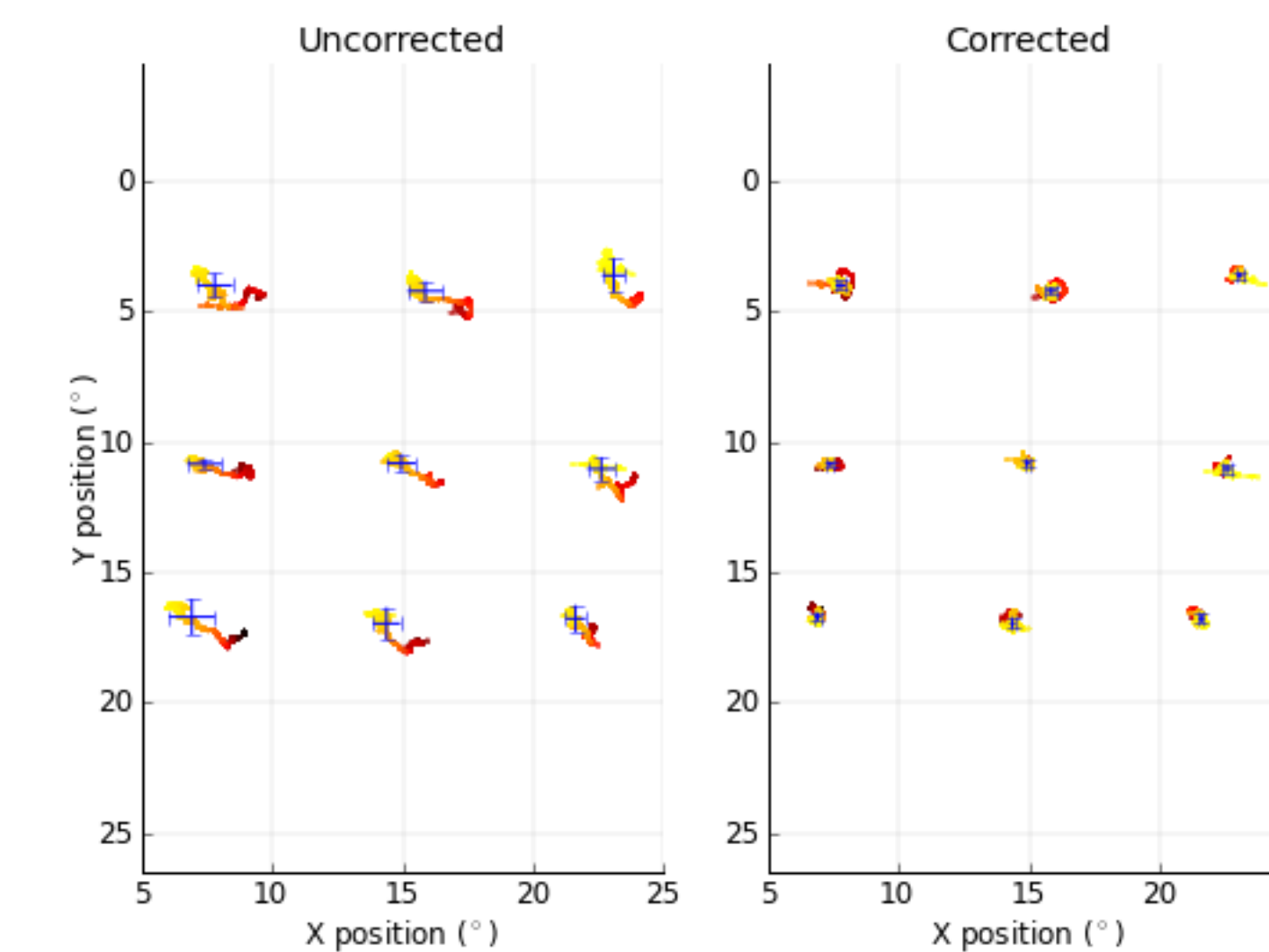
Gaze position during fixation before and after pupil artifact correction. The subject maintained fixation for 10 seconds as the screen luminance was modulated from black to white. Pupil area encoded by color, with largest in black and smallest in yellow. (Left) Uncorrected gaze position as provided by the eye-tracker ( $\sigma_X = 0.88^\circ$ ,  $\sigma_Y = 0.69^\circ$ ) (Right) The same data after applying the pupil artifact correction ( $\sigma_X = 0.12^\circ$ ,  $\sigma_Y = 0.17^\circ$ ).

## Pupillary Fluctuations Under Different Viewing Conditions

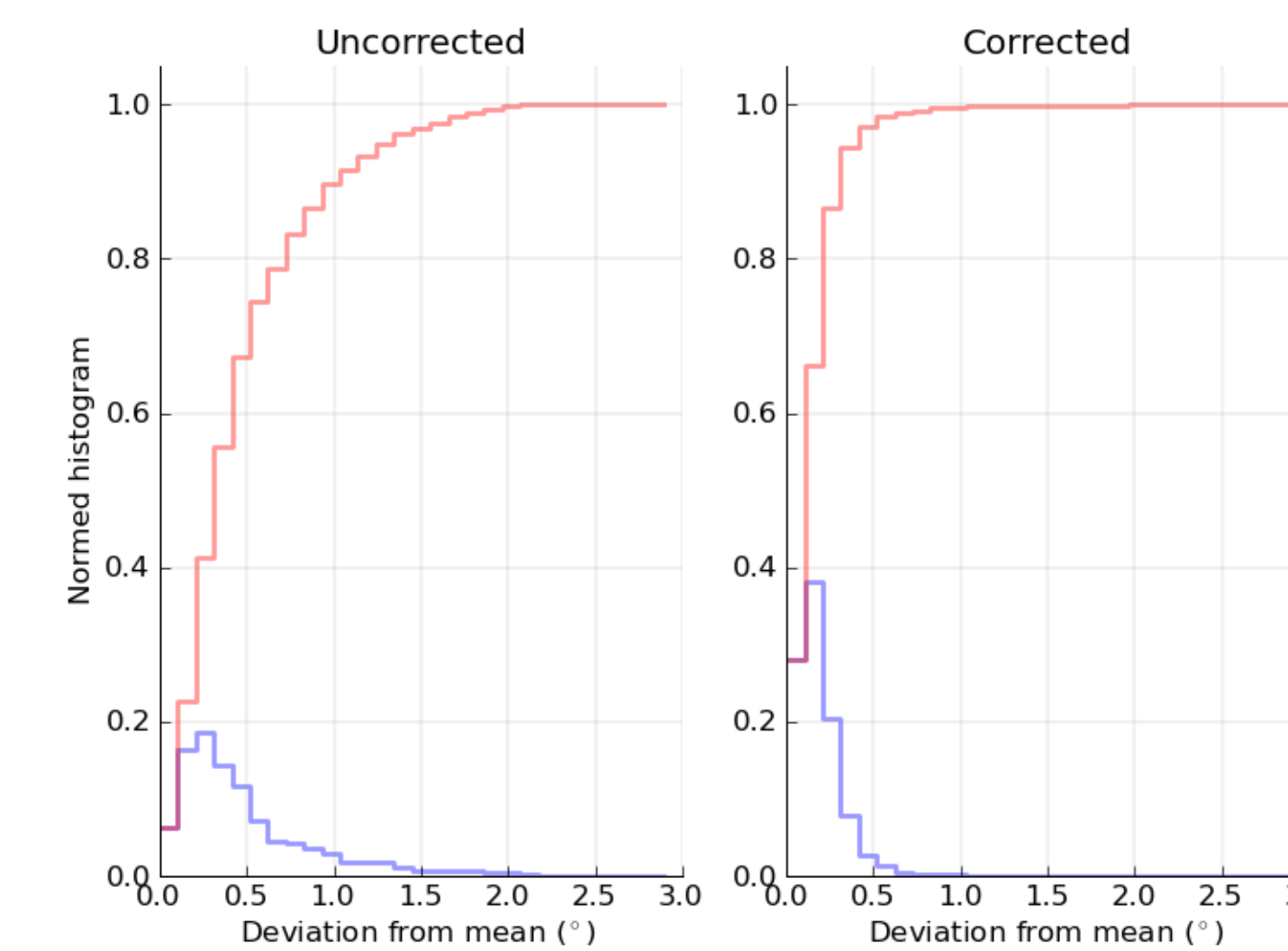


(left) Spontaneous pupil variations while subject fixates on an isoluminant monitor (7 luminances shown color-coded, with black being the darkest). (right) Pupil size during more realistic free-viewing of a movie stimulus.

## Artifact Correction Across Screen



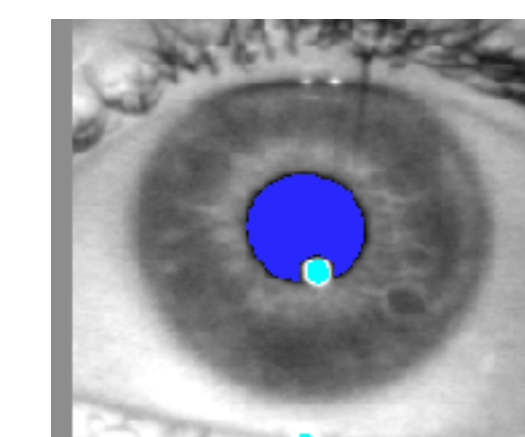
The pupil artifact is viewing location dependent. We corrected for arbitrary screen coordinates by measuring at 9 locations in a 3x3 grid pattern, and interpolating model fit parameters between these locations using quadratic bivariate spline interpolation.



Summary of the extent of artifact and its correction for gaze data of 6 subjects fixating on 9 screen locations. After correction 95% of gaze is within  $0.5^\circ$  of fixation spot, compared with 68% prior to correction. The magnitude of the residual deviations is what would be expected from actual fixational eye movements (microsaccades and drifts).

## Methods

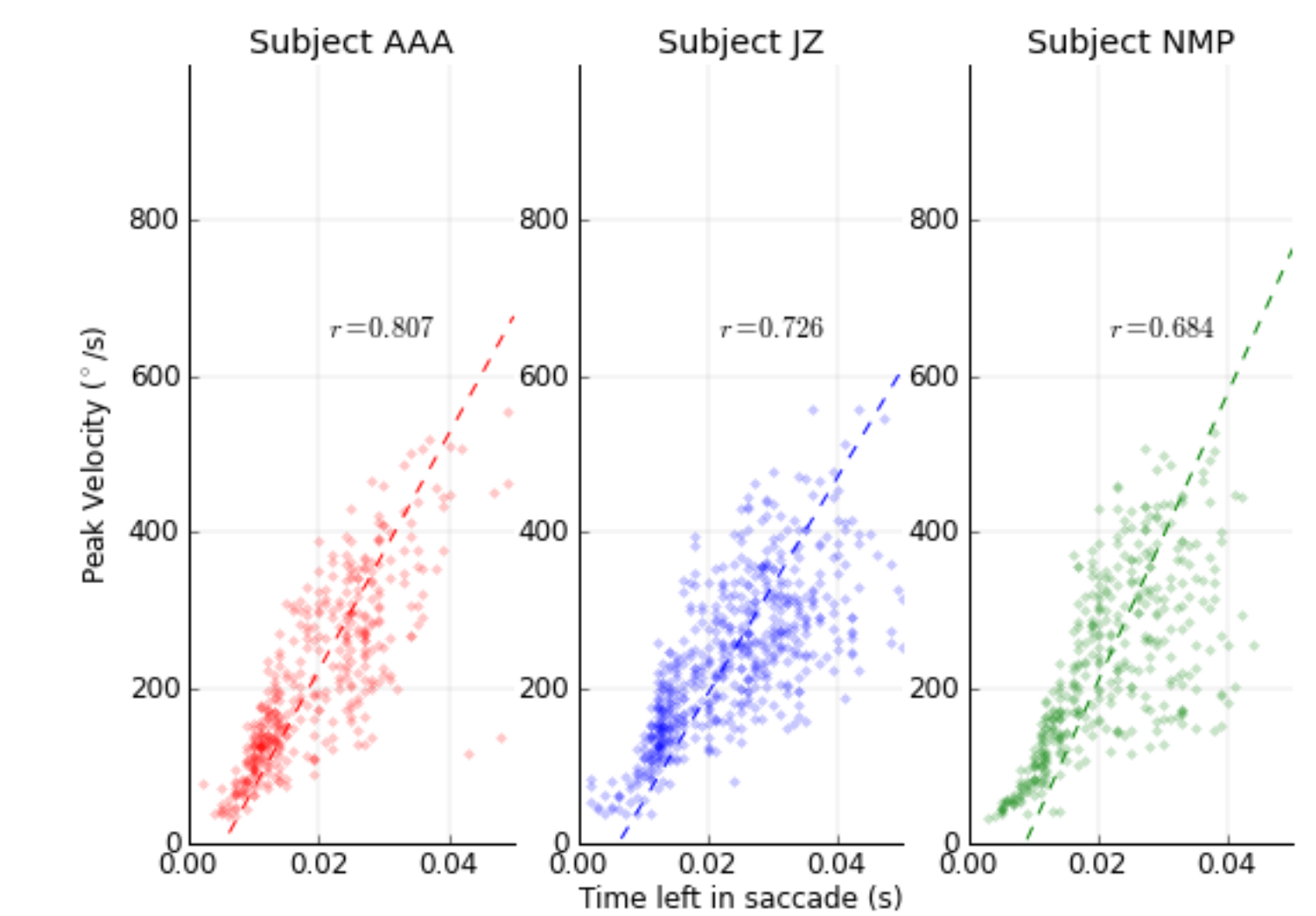
Eyelink 1000 (monocular Tower-mount)  
Iiyama CRT monitor (800x600 @ 200 Hz)  
Visual presentation software:  
Python-based Vision Egg <http://visionegg.org>  
with Dimstim library <http://www.swindale.ecc.ubc.ca/dimstim>



Contact information:

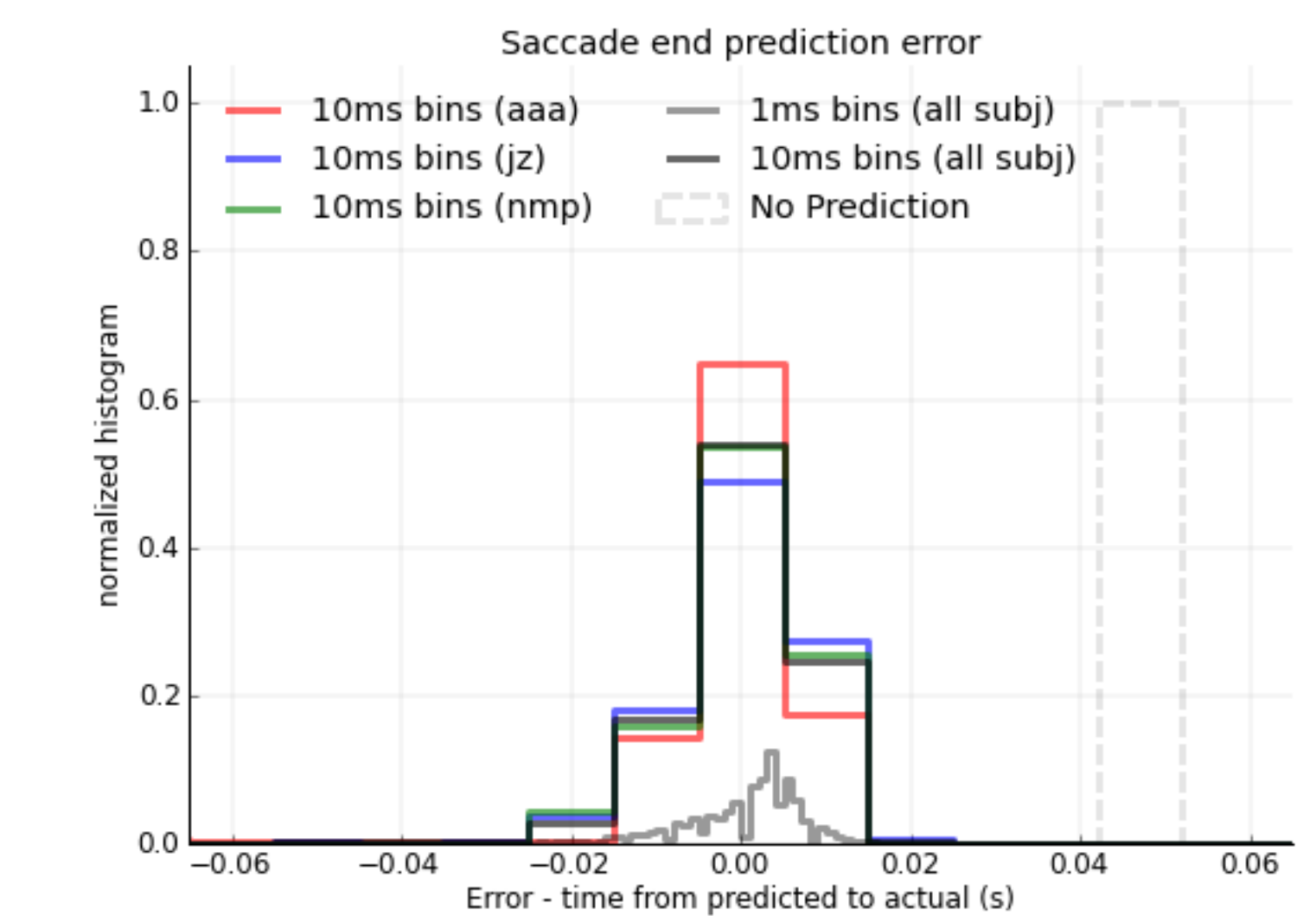
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## Modeling Onset of Fixation



There is a strong linear relationship between peak eye velocity and time left in a saccade from this peak. Lines were fit to minimize x-error and used for predicting fixations onsets from peak velocities computed online.

## Accurate Real-time Prediction of Fixation Onset



Histogram of fixation prediction errors relative to actual fixations ( $t=0$ ) during free viewing of the BBC nature documentary. Three representative subjects and the average performance for 5 subjects (10ms bins in black), with average performance also plotted using finer 1ms bins (gray). Overall, 59% of the predictions lie within one screen refresh ( $\pm 5$  ms) of actual onset (center bin) and 95% of the predictions lie within  $\pm 15$  ms (three center bins). 'No prediction' shows the online fixation detection capability of the native eye-tracker.

## Acknowledgments

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