White noise analysis of smooth pursuit eye movements

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Smooth pursuit eye movements allow the stabilization of small moving targets on the retina. The system can be thought of as a negative feedback controller, where the velocity of the target must be matched by that of the eye as closely and rapidly as possible (Rashbass, 1961).

Here, we studied the (steady-state) maintenance phase of pursuit by measuring smooth pursuit eye movements when a target visual stimulus (a high-contrast Gabor) had a velocity determined by white noise superimposed on top of a mean baseline velocity. We estimated the first-order kernels of the system by cross-correlating fluctuations in eye velocity with fluctuations in target speed in saccade-free segments of pursuit. We performed the experiment for a range of baseline velocities and standard deviations of the noise.

We found that (a) the first-order kernels are narrow in time, with half-width half-heights of ~50 ms and a time-to-peak of ~100 ms, (b) there is a 'gain control' mechanism at work, such that the overall gain of the system is modulated by the mean velocity and the standard deviation of the target velocity, (c) the standard deviation of eye velocity is proportional to mean target velocity and only weakly correlated with the standard deviation of the target velocity standard deviation, (d) two basic predictions of linearity between input and output fluctuations hold: the DC gain of the system is proportional to the integral of the impulse response, and the variance in the eye velocity is proportional to the energy of the impulse response multiplied by the variance of the stimulus velocity, (e) smooth pursuit gain decreased from ~1 at low noise levels to about ~0.9 at the highest noise levels tested, for which there was no measurable correlation between eye velocity fluctuations and stimulus velocity fluctuations, suggesting that smooth pursuit movements can be performed even in the absence of first-order visual motion measurements.

Our results show that smooth pursuit maintenance is quasi-linear and amenable to white noise analysis.