Sensory Processing Delays Measured with the Eye-Movement Correlogram

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The smooth pursuit system causes the eyes to move to cancel "retinal slip" of a target and presumably uses the results of visual motion computations to control motor output. The overall latency of this system can be thought of as having two components: an input-processing component that depends on stimulus properties, and a motor output component that does not.

This poster presents a method for assessing pursuit latency that we call the *eye movement correlogram*. The subject is instructed to maintain fixation of a target that moves on a pseudo-random trajectory, designed to make prediction impossible.[1] The trajectories are computed by integrating a white noise velocity profile. Some low-pass filtering may be applied to the velocity signal before integration to smooth the trajectory. The subjects' eye movements are recorded, and the signals are differentiated to produce eye velocity. Saccades are detected using a velocity criterion, and values of the smooth velocity are interpolated in the neighborhoods of saccades. The resulting smooth velocity signal is cross correlated with the stimulus velocity. When averaged across a number of trials (each having a different random trajectory), an impulse response-like function is revealed, which is the correlogram. The time at which the peak of this function occurs can be interpreted as the latency of the pursuit system.

The method has the advantage of high sensitivity to weak signals, while being relatively insensitive to calibration artifacts. Because correlation is performed in the velocity domain, absolute positional calibration is not required, although rough calibration of velocity is required for proper function of the saccade-cutter.

There is ample evidence that the chromatic system is temporally sluggish.[2,3] Therefore, we expect that the pursuit latency for purely chromatic (isoluminant) targets will be long compared to that for luminance-defined targets. When the correlogram is measured for an isoluminant "red" target (modulated on the R-G axis, with constant S-cone stimulation), the responses are slightly weaker and delayed 50–100 milliseconds compared to the achromatic responses. More dramatic results are obtained with an S-cone-isolating "blue" stimulus. The subjective appearance of these stimuli is markedly different from both achromatic and red–green stimuli: the high

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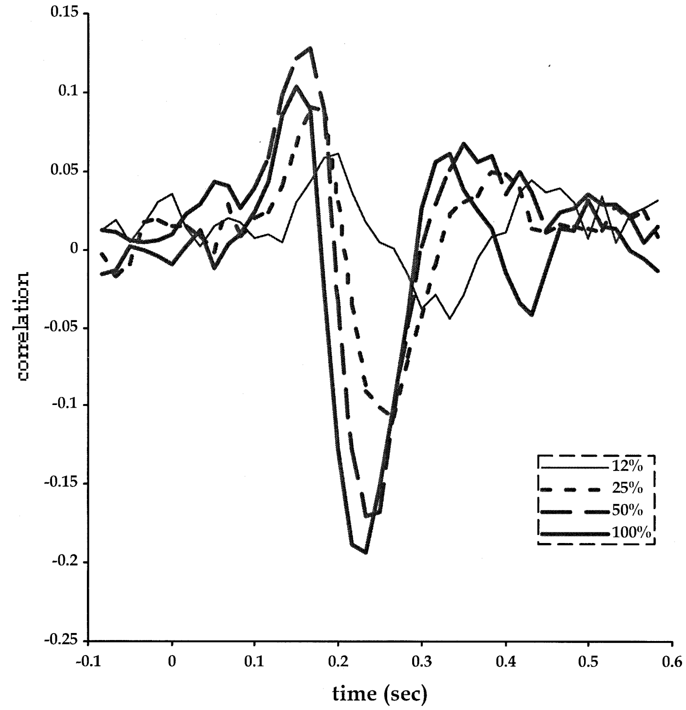

FIGURE 1. Average correlograms for tracking a small, bright Gaussian spot at 100% contrast (*heavy solid trace*), 50% contrast (*heavy dashed trace*), 25% contrast (*heavy dotted trace*), and 12% contrast (*light solid trace*). The latency of the response is reduced by approximately 20 milliseconds for each factor of 2 reduction in contrast, and as contrast is reduced below 50% a reduction in signal strength is seen.

temporal frequencies of the motion are virtually invisible. Nevertheless, the correlogram does reveal a small response, delayed 100–200 milliseconds relative to the achromatic response.

Proper equation of contrast and the exclusion of luminance artifacts are constant worries in the study of chromatic phenomena. To test the hypothesis that the chromatic responses might have been mediated by a sluggish response to a low-contrast luminance artifact, correlograms were measured for a series of reduced contrast achromatic targets. As contrast is reduced, the response becomes both weaker and slower, with the peak delayed by approximately 20 milliseconds for reach reduction by a factor of two (FIG. 1).

Current theories propose multiple mechanisms processing the motion of achromatic patterns: a "first-order" system that responds directly to luminance, a "second-order" system that responds to derived properties such as local contrast and flicker, and a "third-order" system that has very little in common with the other two.^{4} We have compared correlograms for pursuit of a normal, luminance-defined spot and a second-order target defined by locally flickering a stationary random dot texture.

The response to the flicker-defined stimulus is significantly weaker and delayed by approximately 100 milliseconds.

The results described above for chromatic and flicker-defined targets were obtained from a single subject and have been reported in preliminary form previously.[5,6] These data were collected using a video ophthalmoscope, which provides excellent positional resolution and good rejection of head movement artifacts.[7] Unfortunately, this system requires use of a dental impression to stabilize the subject's head, and good images cannot be obtained from many subjects without dilating the pupil. Our recent work has therefore concentrated on replicating these findings using a simpler system in which the subject uses a chin/forehead rest, and cameras image the pupil and other anterior structures. Although the signal-to-noise ratio is somewhat poorer than in the ophthalmoscope system, correlograms for luminance-defined targets have been reliably obtained for three subjects.

In summary, the eye movement correlogram is a promising method for revealing the time course of the early stages of visual processing. The preliminary findings described here merely scratch the surface of the classes of stimuli that may be investigated with this technique.

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