

# An Investigation of the Relative Stability of Reactive and Predictive Oculomotor Tracking

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## Abstract

Previously we demonstrated a phase transition between reactive and predictive eye tracking of alternating targets. At the slowest pacing, subjects made a reactive eye movement after the target moved. As the pacing frequency increased, there was an abrupt transition to a predictive response at higher frequencies. When pacing decreased in frequency, a phase transition again occurred, but this transition point was different. This hysteresis suggests that the tracking system has two stable behavioral modes: reactive and predictive. Here we present preliminary data regarding the relative stability of these behaviors as the pacing of the targets are abruptly altered or perturbed.

## Methods

The eye movements of three subjects were recorded while they performed three saccade tasks (A, B and C). Informed consent, according to the local institutional research board, was obtained from each participant. The horizontal movements of the eyes were recorded with a Series 1000 Binocular Infrared Recording System (Microguide), sampled at 1000Hz. Subjects were seated in a stationary chair inside a dark room, and the head was fixed with a chin rest. The targets were two alternating LEDs at  $\pm 15^\circ$  on either side of the vertical midline. Subjects were requested to make saccades between these two targets. Saccades are rapid eye movements which redirect visual fixation from one target to another, such as in reading. The neuroanatomy of how saccades are produced is well understood and they are extensively used to study motor control, cognition and memory, and clinical disorders (Leigh RJ and Kennard C, 2003).

In experiment A, the targets initially alternated at 0.2 Hz, a rate known from our earlier work to promote reactive behavior: saccades with latencies of approximately 180 ms. After this behavior was established (approximately 20 eye movements), the pacing was abruptly changed (perturbed) to 0.3 Hz for a random number of movements. For the rest of the experiment the target pacing alternated between the initial pacing frequency (0.2 Hz) and the perturbing frequency (0.3 Hz) for random amounts of time (5 to 15 movements). There were five periods of target pacing at 0.2 Hz with four perturbations to pacing at 0.3 Hz. Both the initial and the perturbing frequencies in this experiment are known to produce reactive saccades.

Experiments B and C were similar to A in that the initial pacing was always 0.2 Hz. However, the perturbing frequency changed to one near the critical phase transition point found previously (0.6 Hz for experiment B) or to a frequency that promoted predictive behavior (1.0 Hz for experiment C). As in experiment A, target pacing

alternated between the initial pacing frequency (0.2 Hz) and the perturbing frequency (0.6 or 1.0 Hz) for random amounts of time (5 to 15 movements). Perturbations in experiment B are from reactive tracking to a frequency near the phase-transition point. Perturbations in experiment C are from reactive tracking to the predictive range.

The time between saccades (inter-saccade interval, ISI) was measured in each experiment. Any change in ISI upon perturbation allowed us to determine if the subject made a change in saccade rate to the new pacing frequency (reflecting that the original frequency was not stable), or if the subject continued to make saccades at the original (pre-perturbation) frequency (reflecting the stability of the original frequency relative to the perturbing frequency).

## Results

Figures 1, 2, and 3 show the results of experiments A, B, and C respectively for one subject. In each figure, the plots are in chronological order from left to right. In Fig. 1 for example, the experiment begins at the top left plot with initial pacing at 0.2 Hz. There is an interval of 2500 ms between targets at this pacing, which is represented by the dotted black line. The subject's inter-saccade intervals are symbolized by the black dots. The left bottom plot shows the perturbation to 0.3 Hz pacing. Again the interval between targets (1666 ms) is marked by the dark dotted line, but the subject's inter-saccade intervals are symbolized by gray dots. Following the perturbation, the pacing again returns to 0.2 Hz, which is represented in the second plot from the left on the top row. The experiment follows this diagonal pattern (from top plot to bottom, back to the top) through the figure until the last pacing block at 0.2 Hz (the top right plot).

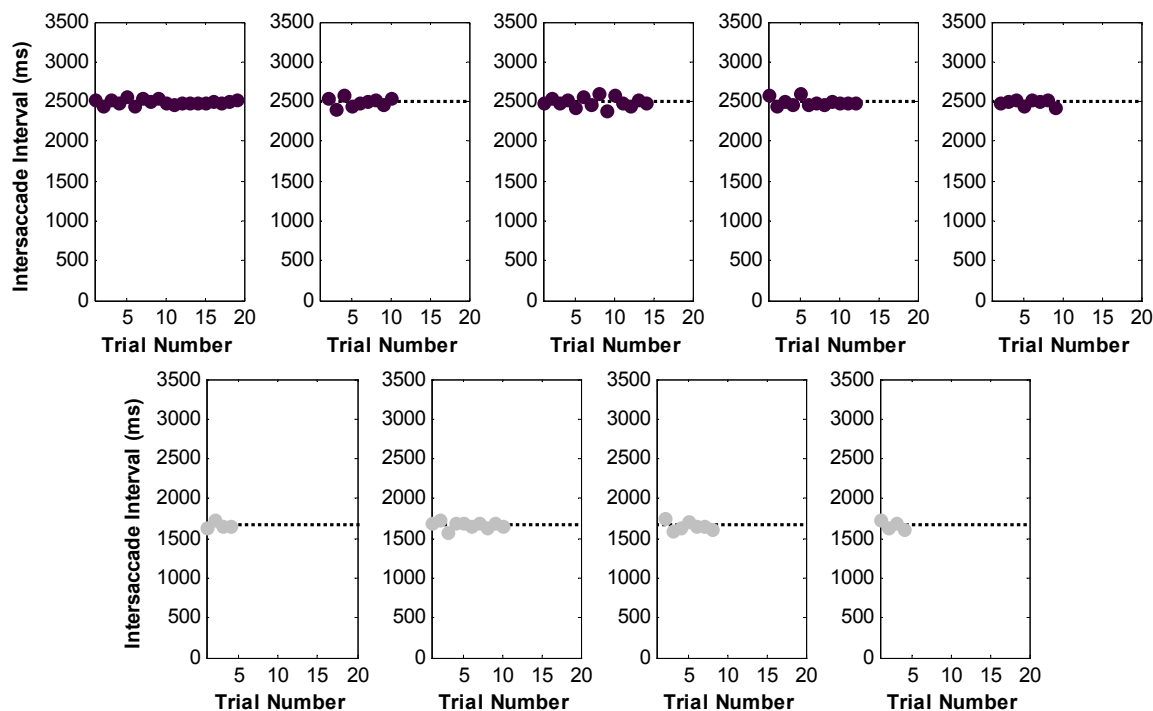


Figure 1: Pacing at 0.2 Hz (top 5 plots) with perturbations to pacing at 0.3 Hz (bottom 4 plots)

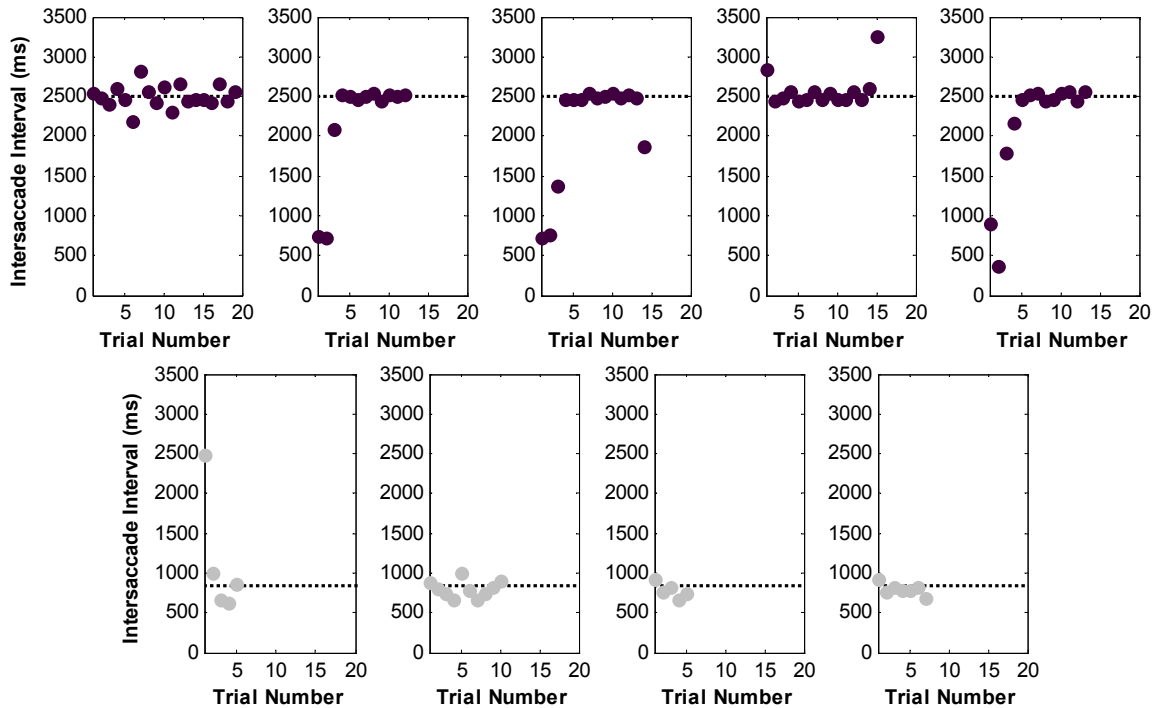


Figure 2: Pacing at 0.2 Hz (top 5 plots) with perturbations to pacing at 0.6 Hz (bottom 4 plots)

In all experiments, subjects were able to match closely the initial timing of the targets as they alternated at 0.2 Hz. An example of this is shown for one subject in the top left plots in Figures 1, 2 and 3. Every black point on these plots represents one ISI, all of which lie closely near the actual interval between target jumps (2500 ms). All subjects were also able to match the timing of the targets at the perturbing frequency of 0.3 Hz (the bottom four graphs of Figure 1) and easily made the transition from pacing at 0.2 to 0.3 Hz. (For example, the first transition is represented by the top left plot at 0.2 Hz pacing and the bottom left plot at 0.3 Hz pacing in Figure 1. The subject's ISI makes a flawless transition 2500 ms to 1666 ms). In our previous experiment (Shelhamer and Joiner, 2003), both 0.2 Hz and 0.3 Hz pacing promoted reactive behavior, and therefore the ease of this transition was expected.

In experiments B and C, subjects generally were not able to match closely the timing of the targets following the abrupt transition from 0.2 Hz to either 0.6 Hz or 1.0 Hz. When the perturbing pacing frequency was near the critical phase transition point, 0.6 Hz, there was a tendency to continue tracking at this frequency despite the change back to 0.2 Hz. This result can be seen for the same subject in the second, third, and fifth plots in the top row in Figure 2. Unlike in experiment A, tracking did not smoothly make a transition back to the original pacing frequency of 0.2 Hz, but rather continued at about 0.6 Hz until it settled to that frequency: ISI initially remained near the actual interval between targets (833 ms) for 0.6 Hz and then gradually reached that of the current interval (2500 ms). This usually took three to four eye movements.

A similar result was consistently found in all subjects for perturbations made to 1.0 Hz. As shown in plots two through five in the first row of Figure 3, tracking tended to remain at the perturbing frequency (inter-saccade interval of 500 ms) until it settled at

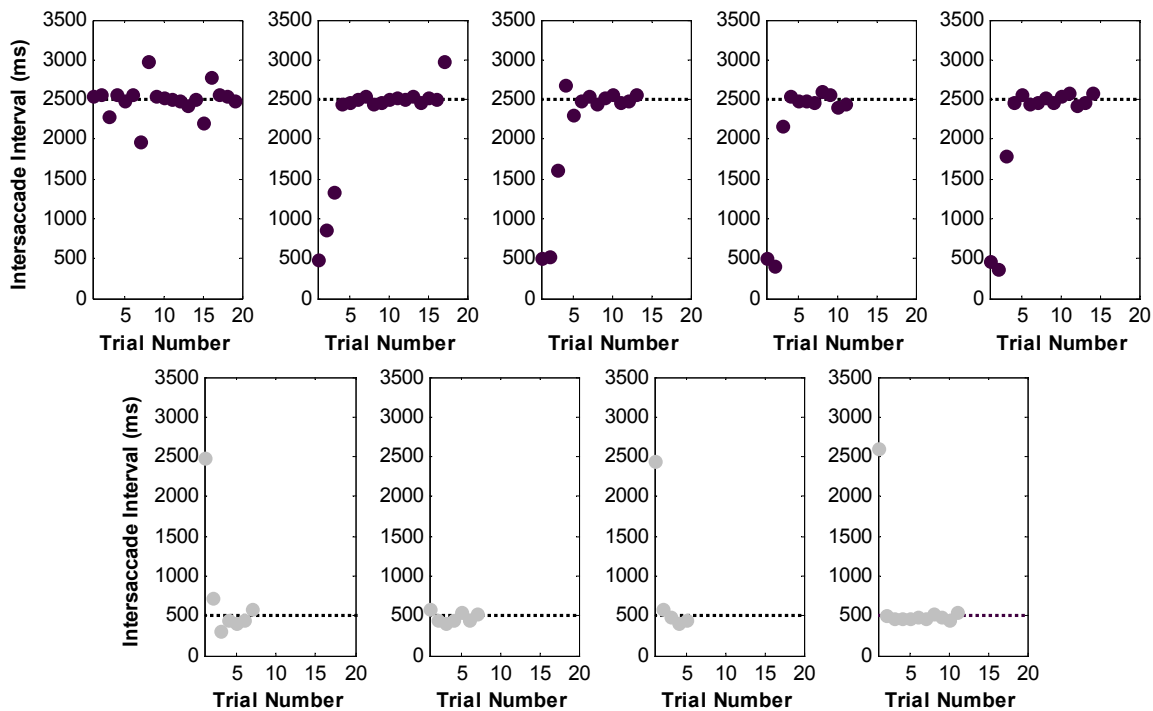


Figure 3: Pacing at 0.2 Hz (top 5 plots) with perturbations to pacing at 1.0 Hz (bottom 4 plots)

0.2 Hz pacing, or 2500 ms between saccades. Similar to the results of experiment B, the subject usually needed three to four eye movements until pacing changed to 0.2 Hz. This result suggests that pacing at the critical phase transition point (0.6 Hz) and higher (1.0 Hz) promotes a relatively more stable behavior than does pacing at 0.2 Hz.

## Conclusions

We provide preliminary data suggesting that there are two stable behavioral modes in the saccadic eye-movement system: a reactive mode in which the eyes lag behind the target, and a predictive mode in which the eyes anticipate the target's movement. This approach has physiological significance. There have been recent studies (Gaymard *et al.*) proposing two partially overlapping pathways for the production of reactive and predictive/memory saccades. In addition, the predictive/memory saccades are speculated to be produced in a neural predictive loop. That is, once in this predictive/memory pathway, a sequence of predictive saccades would be elicited. This closely follows the results of our study. When predictive behavior is promoted by perturbations to 0.6 or 1.0 Hz pacing, subjects did not make smooth transitions back to 0.2 Hz pacing. They tended to stay tracking at the faster pacing frequency and often made multiple eye movements at this pacing until they slowed back to 0.2 Hz. This would suggest that prediction is more stable than reaction in the saccadic system. Under a perturbation, the saccadic system will tend to keep making predictive saccades for a longer period than it will make reactive saccades.

There is evidence from other motor systems that humans prefer making repetitive (rhythmic) motions when circumstances allow it. For example, studies

examining elbow oscillations (Sternad et al., 2002) have made distinctions between discrete and rhythmic movements, as well as their interaction. Our results suggest that reactive and predictive saccades could be considered discrete and rhythmic processes respectively: Pacing at 0.2 Hz can easily transition to 0.3 Hz pacing, both of which promote reactive behavior. This indicates that each movement is independent of prior eye movements, representative of a discrete process. Furthermore, perturbations to higher frequencies (0.6 and 1.0 Hz) result in a sequence of faster eye movements even after pacing has returned to the slower frequency. These movements seem to depend on prior eye movements, and thus could be considered a rhythmic process. Our subjects often prefer these faster paced targets, noting that they are easier to follow. There seems to be a preference for rhythmic behaviors, and this result is a reflection of that observation. If reactive and predictive saccades are found to be distinct stable states of the saccadic eye system, present models of oculomotor control (Schmid and Ron, 1986) may need to be revised in order to incorporate the preference for one behavior over another.

## References

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