Smooth pursuit of flicker-defined motion

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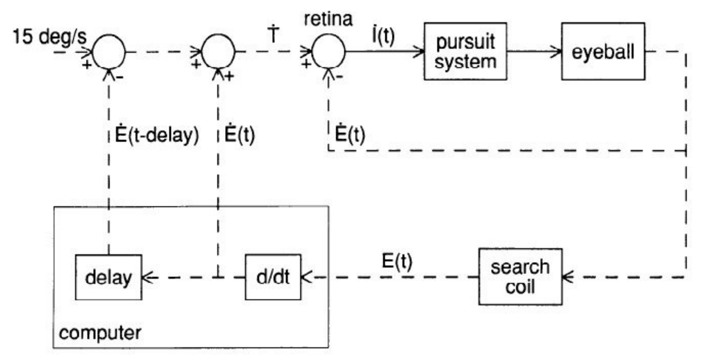
BACKGROUND

Delayed Visual Feedback

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Effect of Changing Feedback Delay on Spontaneous Oscillations in Smooth Pursuit Eye Movements of Monkeys

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15 deg/s
retina
Ṫ
İ(t)
pursuit system
eyeball
Ė(t-delay)
Ė(t)
Ė(t)
delay
d/dt
E(t)
search coil
computer

Figure from Goldreich, Krauzlis & Lisberger (1992).

Theory

$e(t)$	eye position (EP)
$p(t)$	target position
$\dot{e}(t)$	eye velocity (EV)
$\dot{p}(t)$	target velocity
$\ddot{e}(t)$	eye acceleration (EA)
$\ddot{p}(t)$	target acceleration

$p(t) = k$	stationary target
$p(t) = e(t)$	ideal stabilization
$p(t) = e(t-\varepsilon)$	lab stabilization
$p(t) = e(t) + d(t)$	open-loop
$p(t) = e(t) - e(t-\delta_2)$	transient stabilization

$p(t) - e(t)$	retinal position error (RPE)
$\dot{p}(t) - \dot{e}(t)$	retinal velocity error (RVE)
$\ddot{p}(t) - \ddot{e}(t)$	retinal acceleration error (RAE)

$\ddot{e}(t) = k_1\left[p(t-\delta_1) - e(t-\delta_1)\right]$ RPE drives EA

$\ddot{e}(t) = k_2\left[\dot{p}(t-\delta_1) - \dot{e}(t-\delta_1)\right]$ RVE drives EA

$\ddot{e}(t) = k_3\left[\ddot{p}(t-\delta_1) - \ddot{e}(t-\delta_1)\right]$ RAE drives EA

Predictions

$p(t) = e(t) - e(t-\delta_2)$ transient stabilization

$\ddot{e}(t) = k_1\left[p(t-\delta_1) - e(t-\delta_1)\right]$ RPE drives EA

$\ddot{e}(t) = k_1\left[e(t-\delta_1) - e(t-\delta_1-\delta_2) - e(t-\delta_1)\right]$

$\ddot{e}(t) = -k_1 e(t-\delta_1-\delta_2)$

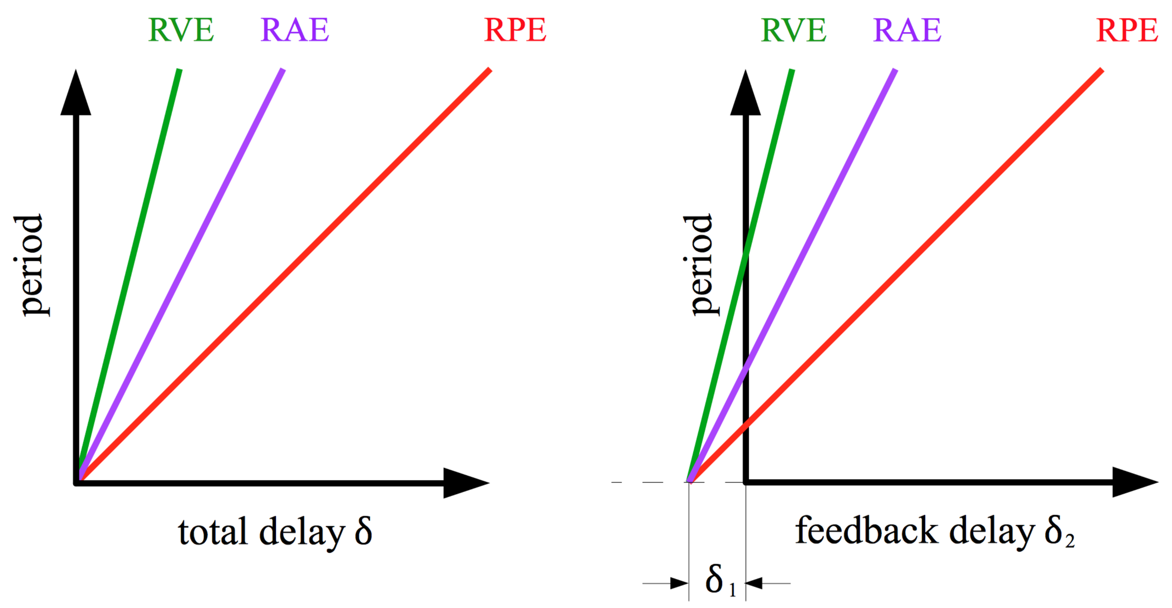
$\ddot{e}(t) = -k_1\, e(t-\delta)$

$e(t) = e^{i\omega t}$ trial solution

satisfied if $k_1 = \omega^2$ and $\lambda = \delta$,

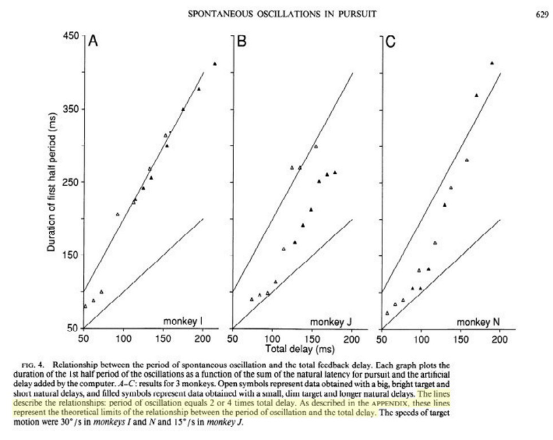
where $\lambda \equiv \frac{2\pi}{\omega}$.

$\lambda = \delta$	RPE drives EA
$\lambda = 4\delta$	RVE drives EA
$\lambda = 2\delta$	RAE drives EA



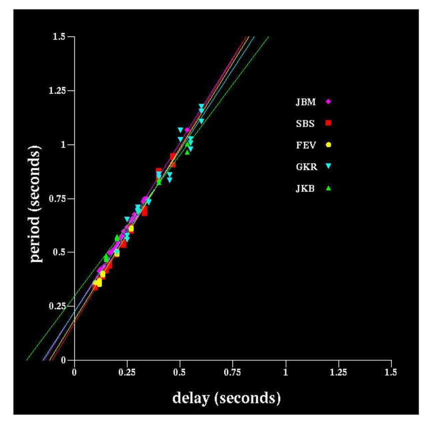
RVE
RAE
RPE
period
total delay δ
RVE
RAE
RPE
period
feedback delay δ_2
δ_1

Results



SPONTANEOUS OSCILLATIONS IN PURSUIT
A
B
C
Duration of first half period (ms)
monkey I
monkey J
monkey N
Total delay (ms)

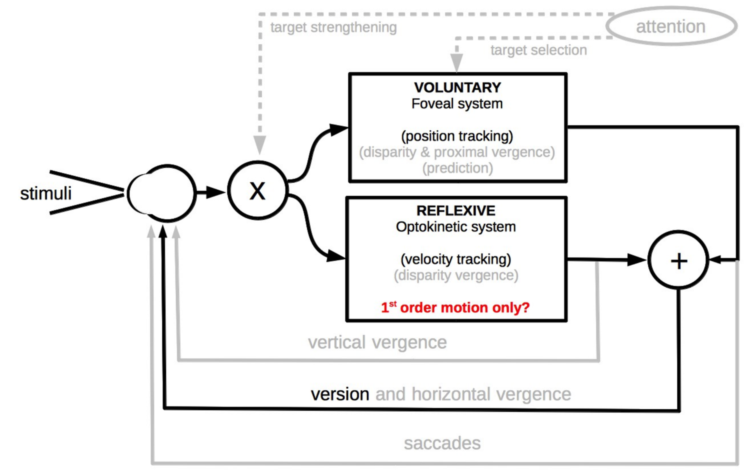
Figure from Goldreich, Krauzlis & Lisberger (1992).



period (seconds)
delay (seconds)
JBM
SBS
FEV
GKR
JKB

Motivation:

Previous work suggests pursuit responses combine signals from voluntary and reflexive pathways with different properties, which respond to different stimuli. The reflexive system appears to respond only to first-order (luminance-defined) motion; here we investigate whether the voluntary system has a different weighting of position and velocity inputs.



target strengthening
attention
target selection
VOLUNTARY
Foveal system
(position tracking)
(disparity & proximal vergence)
(prediction)
stimuli
X
REFLEXIVE
Optokinetic system
(velocity tracking)
(disparity vergence)
1st order motion only?
+
vertical vergence
version and horizontal vergence
saccades

Figure from Mulligan, Stevenson & Cormack (2013), showing proposed architectural model of pursuit control system, with portions relevent to this poster highlighted.

BIG QUESTION:

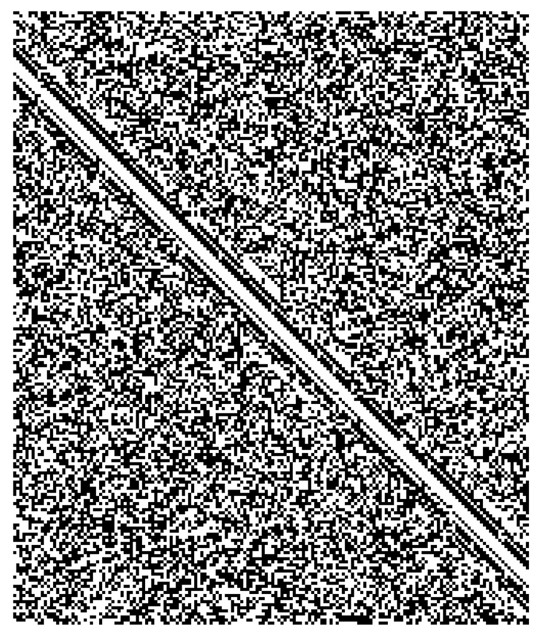
Can we demonstrate a position-driven pursuit response for certain classes of stimuli?

Approach:

Delayed Visual Feedback
(see Background panel at left)

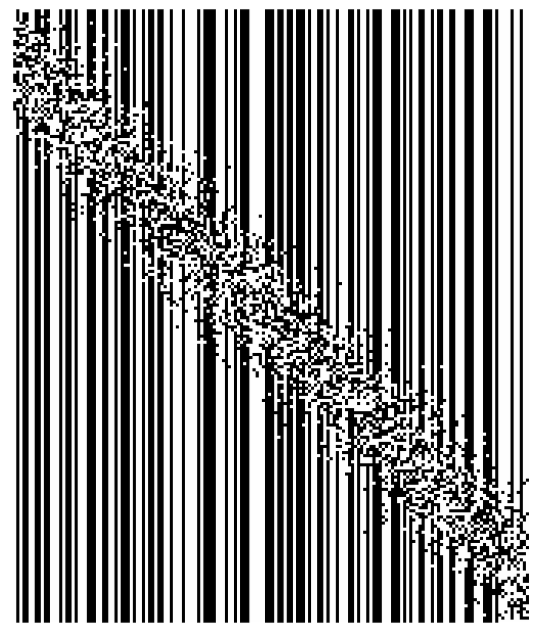
First-order stimuli

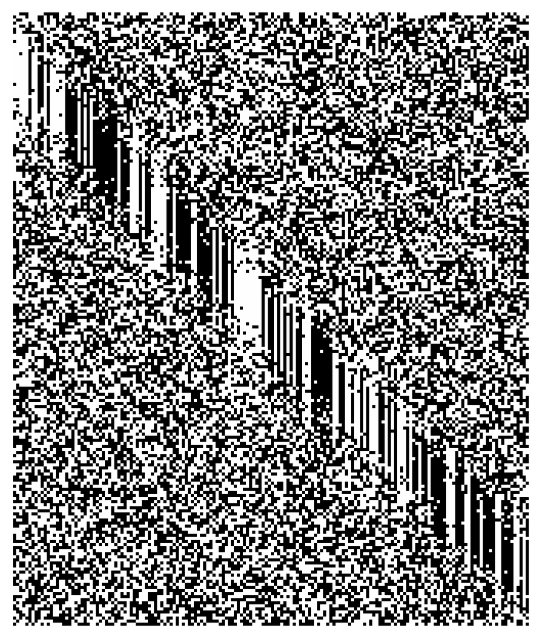




"black" "rigid"

Third-order stimuli



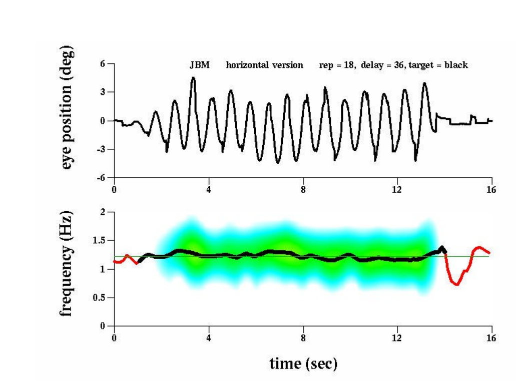


"twinkle" "static"

Space-time plots showing time (top-to-bottom), and one spatial dimension for the four classes of stimuli studied.

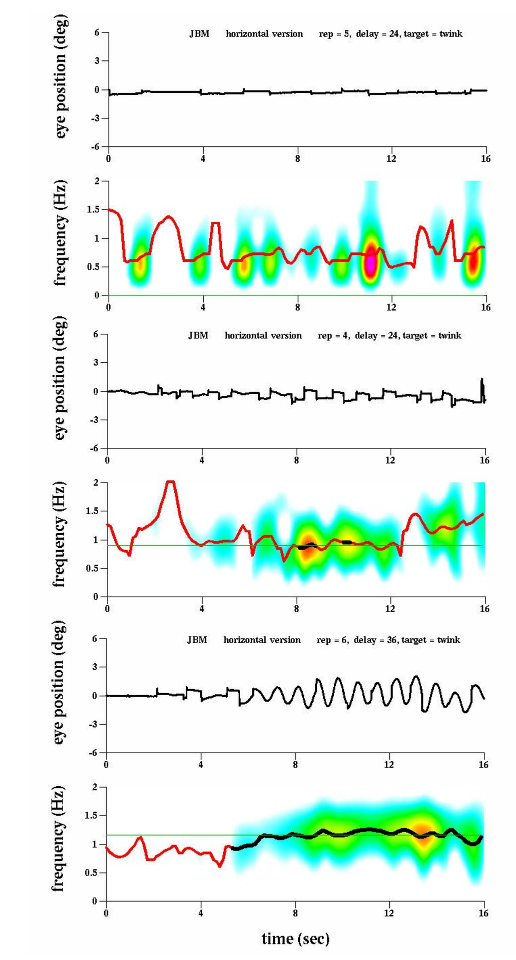
Trials

Vigorous oscillation seen with conventional target



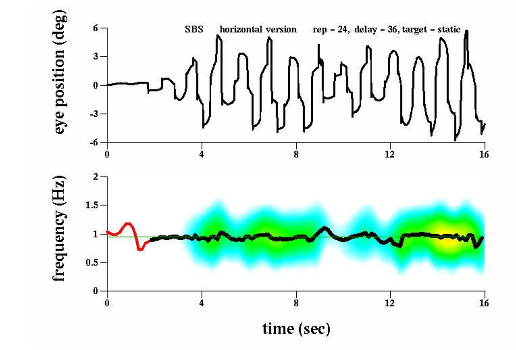
JBM horizontal version rep = 18, delay = 36, target = black
eye position (deg)
frequency (Hz)
time (sec)

Twinkle target oscillates only after learning



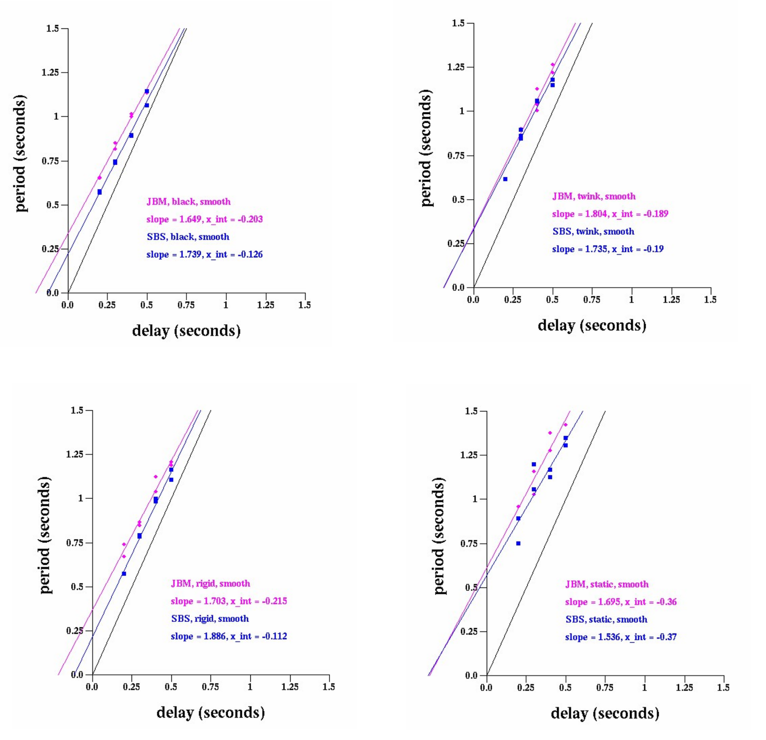
JBM horizontal version rep = 5, delay = 24, target = twink
JBM horizontal version rep = 4, delay = 24, target = twink
JBM horizontal version rep = 6, delay = 36, target = twink
eye position (deg)
frequency (Hz)
time (sec)

"Static" target show mixed response

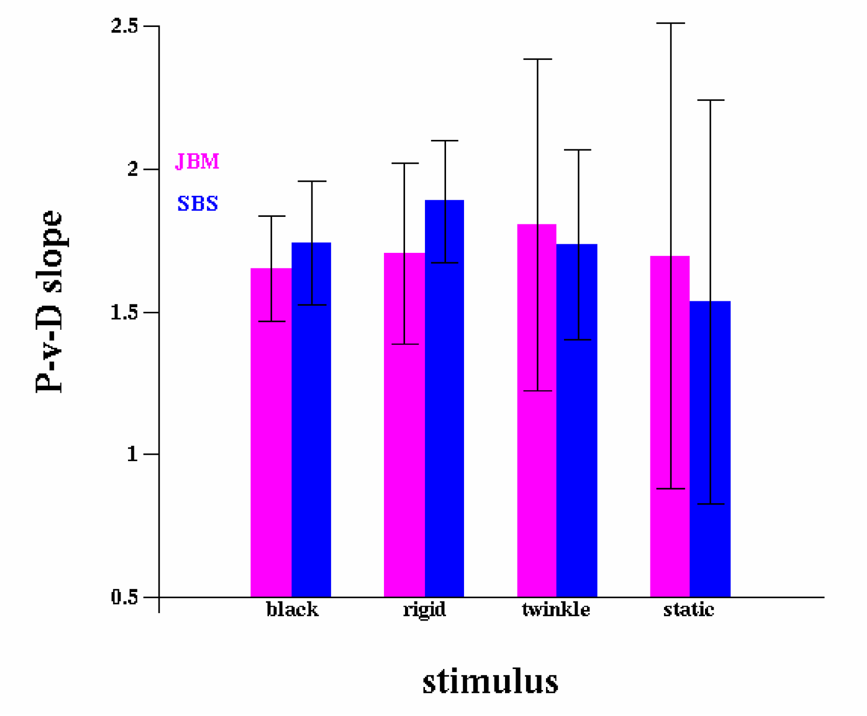


SBS horizontal version rep = 24, delay = 36, target = static
eye position (deg)
frequency (Hz)
time (sec)

Results



JBM, black, smooth
slope = 1.649, x_int = -0.203
SBS, black, smooth
slope = 1.739, x_int = -0.126
JBM, twink, smooth
slope = 1.804, x_int = -0.189
SBS, twink, smooth
slope = 1.735, x_int = -0.19
JBM, rigid, smooth
slope = 1.703, x_int = -0.215
SBS, rigid, smooth
slope = 1.886, x_int = -0.112
JBM, static, smooth
slope = 1.695, x_int = -0.36
SBS, static, smooth
slope = 1.536, x_int = -0.37
period (seconds)
delay (seconds)



JBM
SBS
P-v-D slope
black
rigid
twinkle
static
stimulus

Conclusion

Can we demonstrate a position-Driven pursuit response for certain Classes of stimuli?

TODAY'S ANSWER: Not yet...

References

Goldreich, D., Krauzlis, R. J., and Lisberger, S. G. (1992). "Effect of changing feedback delay on spontaneous oscillations in smooth pursuit eye movements in monkeys." J. Neurophysiol., **67**(3), 625-638.

Mulligan, J. B., Stevenson, S. B., and Cormack, L. K. (2013). "Reflexive and voluntary control of smooth eye movements." in Rogowitz, B.E. Pappas, T.N., and de Ridder, H. (eds.), *Human Vision and Electronic Imaging XVIII*, Proc. SPIE, v. 8651.