The impact of scene luminance levels on fixation durations: An examination based on simulations using the CRISP model

R. Calen Walshe and Antje Nuthmann
School of Philosophy, Psychology and Language Sciences
Computational Visual Cognition Lab, Edinburgh, UK

Introduction

Key Questions:

- What mechanism governs the control of fixation durations (FDs) when viewing naturalistic scenes?
- How do these mechanisms adapt to fixation contingent changes that occur to the quality of scene information?

Empirical

A fixation contingent scene luminance change was used to adjust the quality of incoming sensory information on selected fixations (for details see Walshe & Nuthmann, 2014).

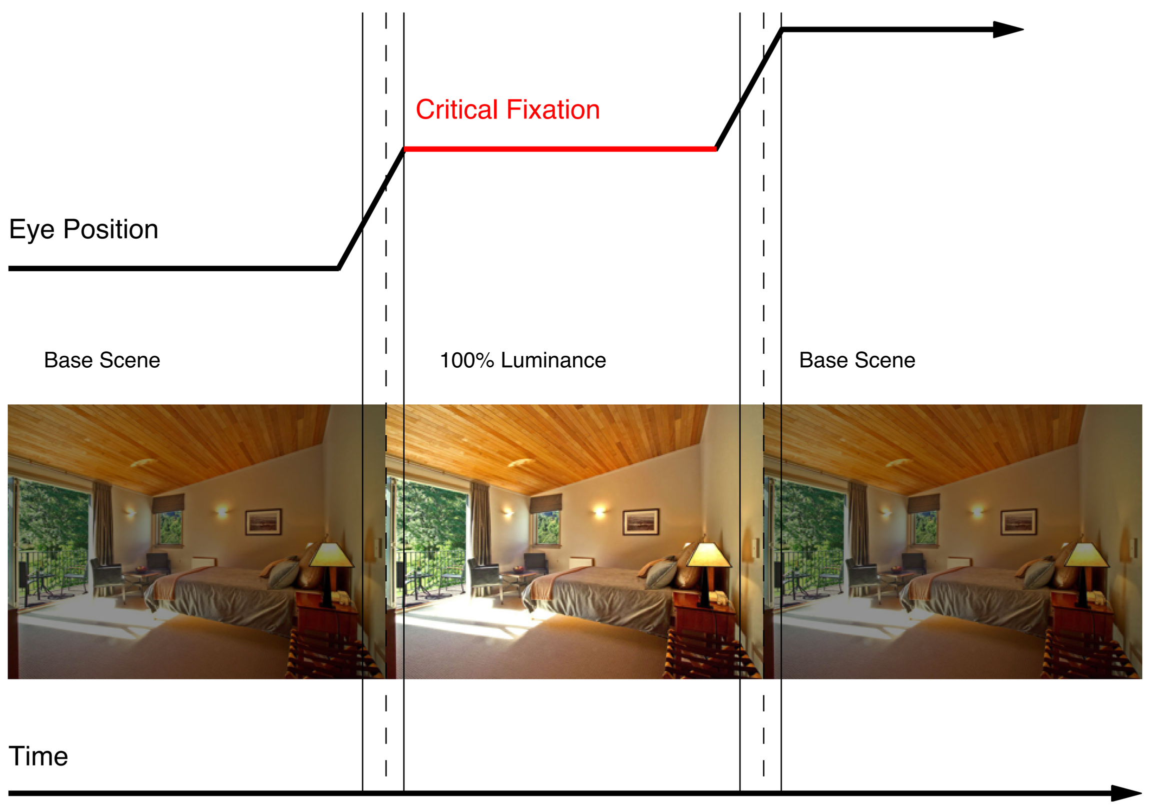

Figure 1

Method & Procedure:

17 Participants viewed 100 naturalistic scenes while encoding the scenes for later recall.
During every 10^{th} saccade the scene was replaced with a scene that was 40% darker or 40% brighter. The direction of the brightness shift was randomized on a given trial. On every trial, two shifts in either direction were completed.

Behavioural Results:

- FDs are increased following a saccade-contingent increase and decrease in scene luminance. See Figure 2.
- The shape of the FD distribution depends on experimental context.
- We have argued previously (Walshe & Nuthmann, 2014; also see. Glaholt, Rayner & Reingold, 2014) that such an early shift in the distribution reflects a *surprise* process that results from a mismatch between pre- and post-saccadic stimulus content. The late increase results from *encoding difficulties* due to the decreased luminance.

Simulations

Empirical data vs model fit

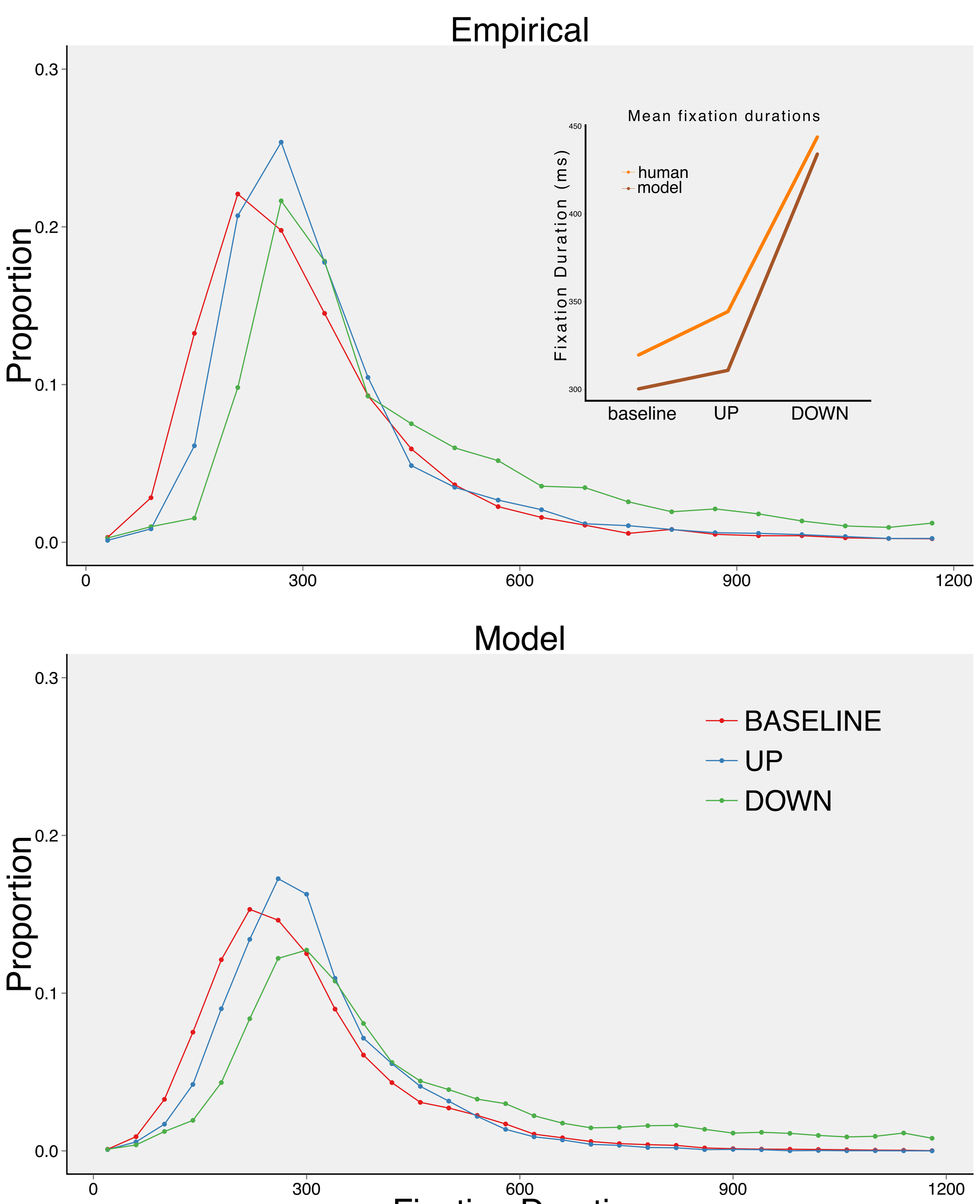

Figure 2

- Simulations capture the qualitative pattern present in the empirical data.
- In the timer model logic, surprise processes result in inhibitory influences on the timeline of saccade programming. Such influences occur immediately (after a 30 ms afferent delay) and last for approximately 100 ms. Encoding influences on the timeline of saccade programming occur at a later stage (approximately 300 ms) and impact only long FDs.

Model architecture

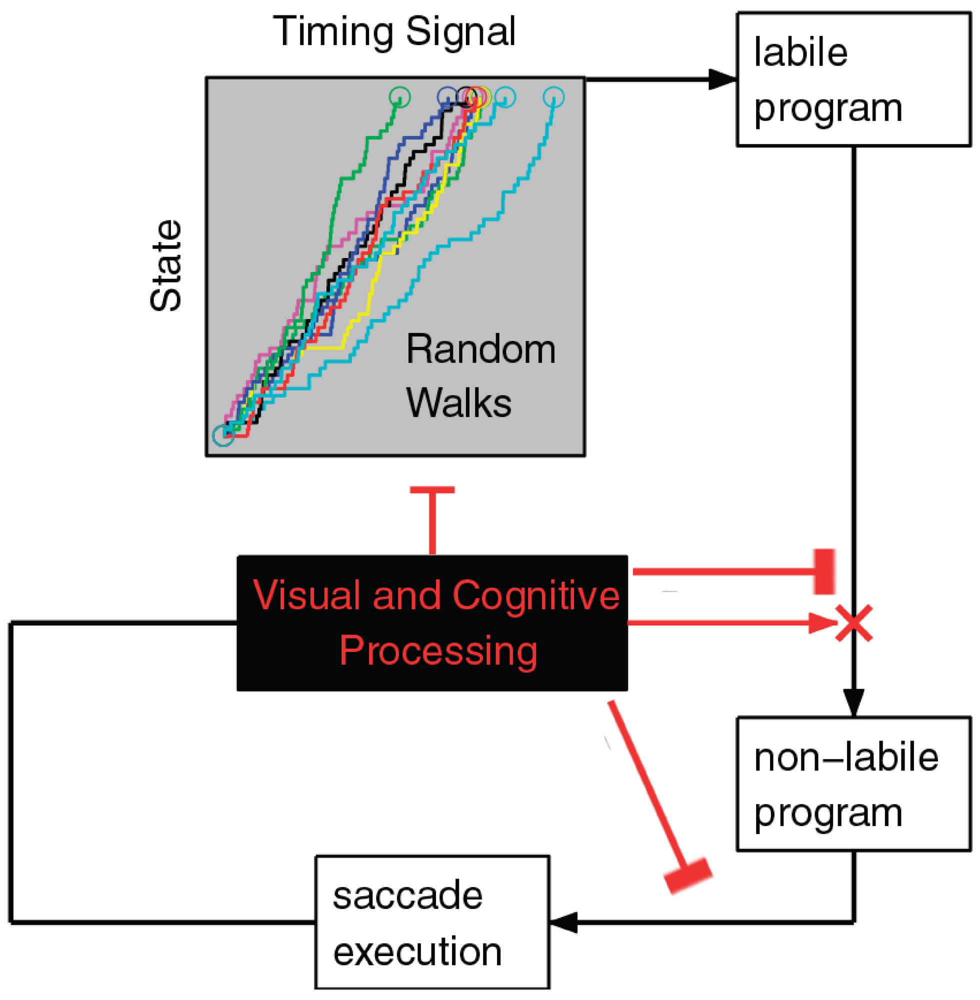

Figure 3

FD distributions grouped by number of cancellations.

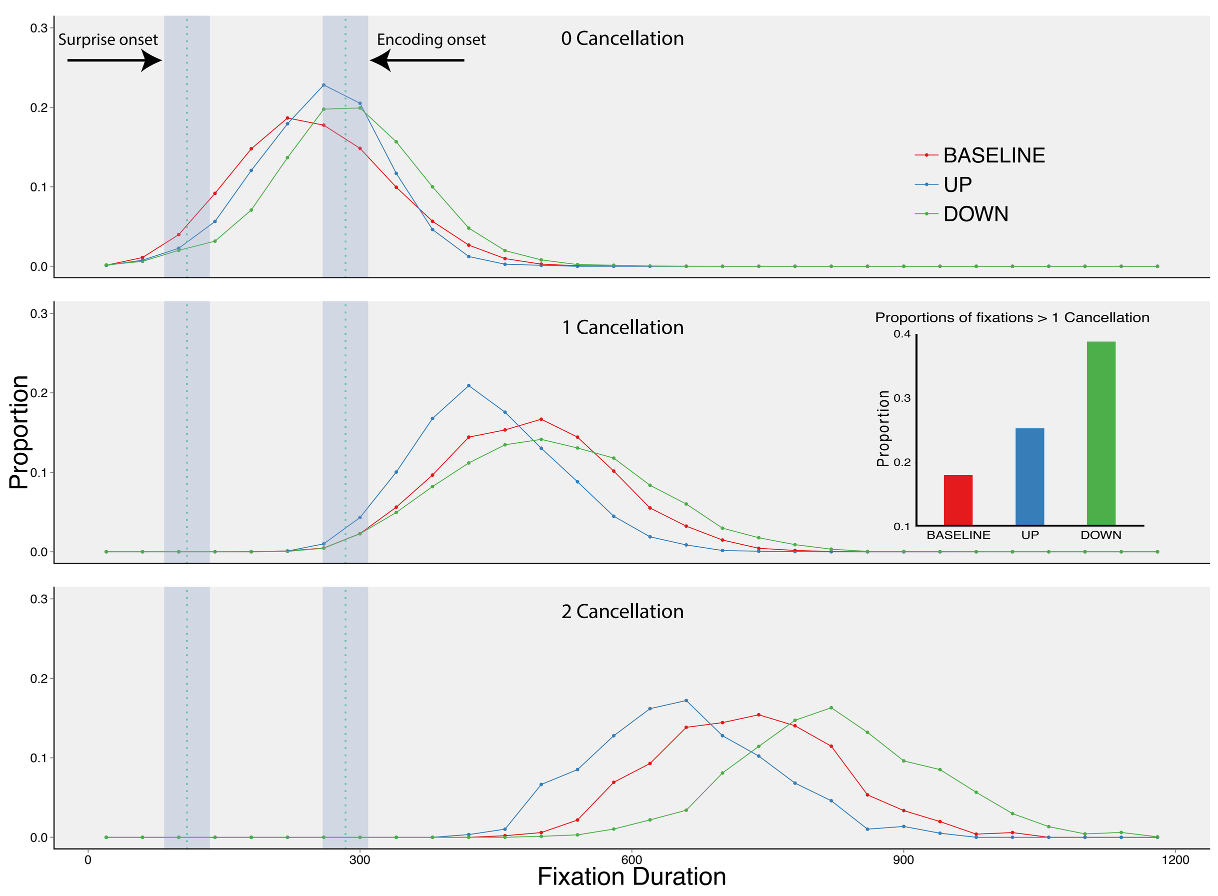

Figure 4

- Fixation that are cancelled are temporally extended. This is reflected in the shifted distributions in the 1 and 2 cancellation fixations.
- The early divergence in distributions in independent of cancellation. The early shift is present even for fixations in which there is no cancellation.
- Encoding modulation acts most strongly on cancelled fixations (they are longer). In the UP, encoding facilitation decreases the impact of cancellation, in the DOWN condition encoding difficulties magnify the impact of cancellation.

Saccade programming times.

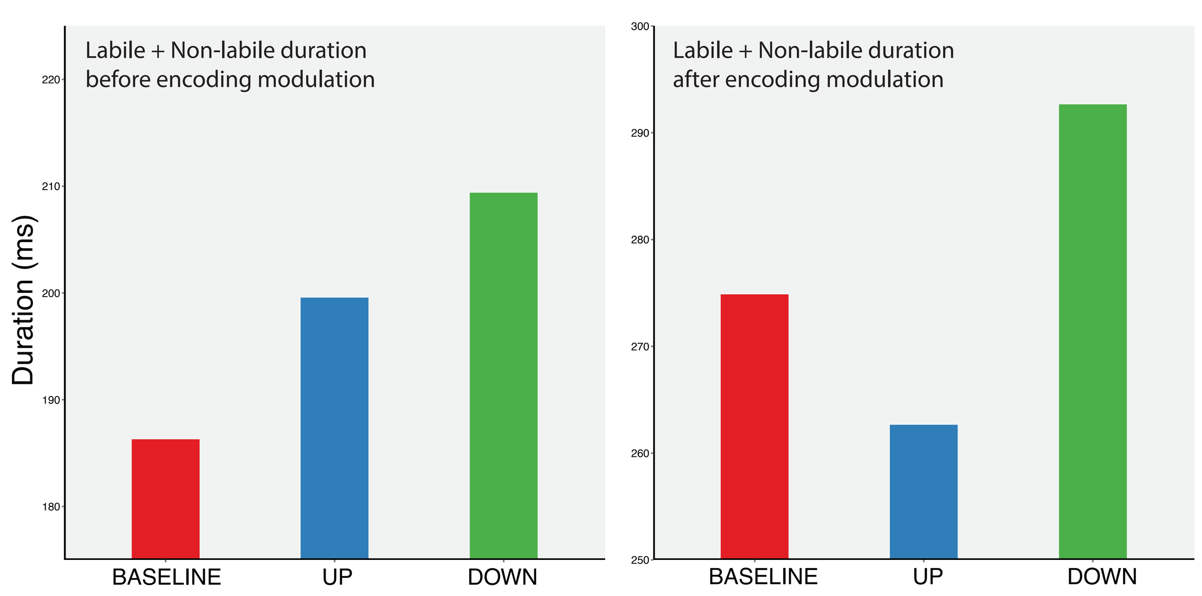

Figure 5

- Saccade programming timelines are influenced by surprise and encoding influences. For fixations terminating prior to the end of the surprise process, saccade programming is longer for both UP and DOWN. Fixations that survive long enough to receive encoding modulation show a decrease in saccade programming time for UP and an increase in saccade programming time for DOWN.

Future Work

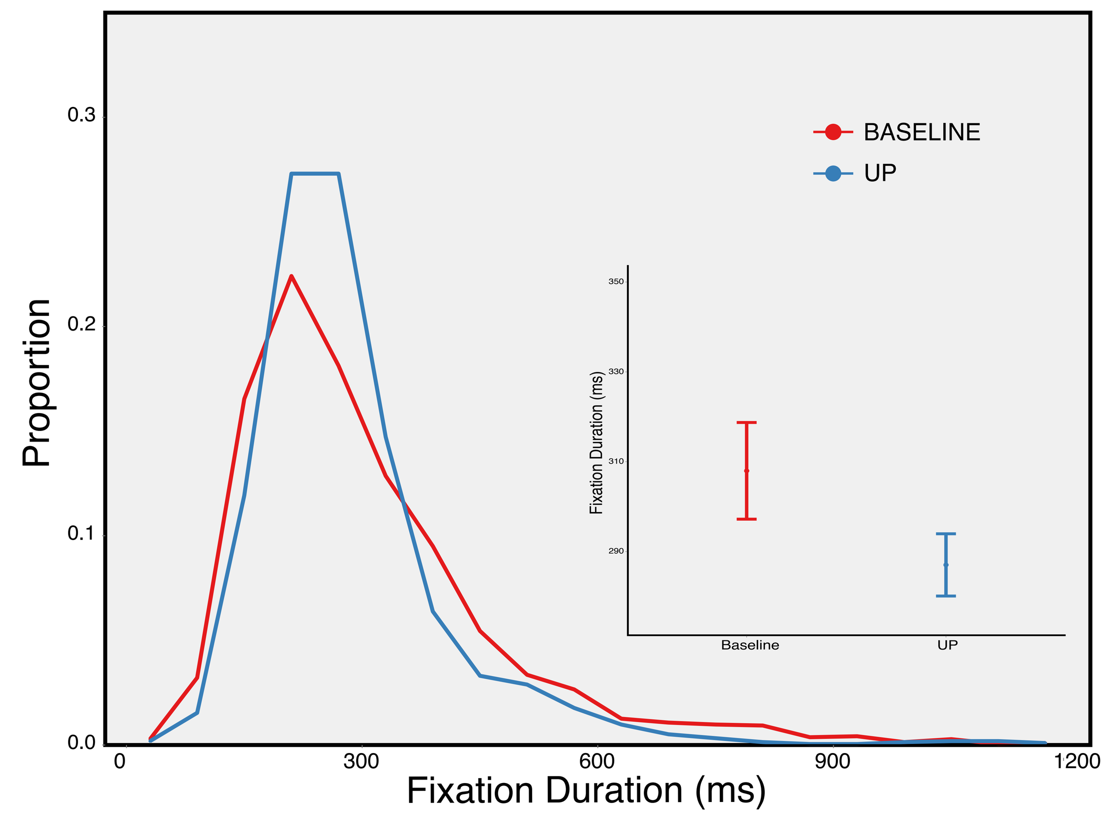

Figure 6

Model Description

State description of random walk model.

$$S_m = (m_1, m_2, m_3, m_4)$$
where $m_1 \in \{0, 1, 2, \ldots, N_j\}$, $m_{1,2,3} \in \{0, 1, 2, \ldots, N_k\}$

For each m, a separate random walk process is defined. In each case, a random walk accumulates towards a threshold value, N_j or N_k. Once the random walk has reached the threshold value, the random walk is reset to its initial state (see appendix Trukenbrod & Engbert, 2014).

Simulation of parallel activated accumulation processes. The time (τ) that the model remains in state S_m before transitioning to state S_n, is sampled from an exponential distribution:

$$\rho(\tau) = W_m e^{-W_m}$$

W_m is the total transition rate, which represents the sum of all single-step transition rates that are possible when the model is in state S_m. W_m is given by the following equation:

$$W_m = w_{tim} + w_{lab} + w_{nlab} + w_{sacc}$$

where

$$w_{tim} = \left\{ \frac{N_j}{T_{tim}} \right.$$

$$w_{lab}(t) = \begin{cases} \frac{N_j}{T_{lab}} \times s & \text{when labile and surprise are active} \\ \frac{N_j}{T_{lab}} \times e & \text{when labile and encoding are active} \\ w_{lab} & \text{when labile is active} \\ 0 & \text{otherwise} \end{cases}$$

$$w_{nlab}(t) = \begin{cases} \frac{N_j}{T_{nlab}} \times s & \text{when nonlabile and surprise are active} \\ \frac{N_j}{T_{nlab}} \times e & \text{when nonlabile and encoding are active} \\ w_{nlab} & \text{when nonlabile is active} \\ 0 & \text{otherwise} \end{cases}$$

$$w_{sacc} = \begin{cases} \frac{N_k}{T_{sacc}} & \text{when saccade programming is active} \\ 0 & \text{otherwise} \end{cases}$$

T specifies the mean duration of the random walk process for a given stage of saccade programming. (i.e. timer, labile, non-labile and saccade execution).

A random walk is selected for accumulation according to the relative transition rates of all active random walks.

Onset of surprise and encoding processes For a given fixation, a surprise begins immediately upon fixation and lasts while $t \leq f(x)$ where $f(x)$ is a Gaussian distributed threshold defined for a given critical fixation. Encoding process are active while $t \geq g(x)$ and last until the critical fixation is terminated, $g(x)$ is a Gaussian distributed threshold.

Cancellation If the timer process reaches threshold while a labile program is active, the labile program that is currently active will be reset to its initial value. The current saccade program is therefore cancelled. Saccade initiation will be delayed in the case that a cancellation is observed.

References

Trukenbrod, H. A., & Engbert, R. (2014). ICAT: A computational model for the adaptive control of fixation durations. *Psychonomic Bulletin & Review.*
Walshe, R.C. & Nuthmann, A. (2014) Asymmetrical control of fixation durations in scene viewing. *Vision Research.* 100, 38-46.

http://www.ppls.ed.ac.uk/people/r-calen-walshe
r.c.walshe@sms.ed.ac.uk