Does visual uncertainty influence saccadic adaptation?

Matteo Lisi[1]
Joshua Solomon[2]
Michael Morgan[2]

[1] Royal Holloway, University of London
[2] City, University of London

Rationale

To maintain the accuracy of saccadic eye movements, the brain is continually calibrating the link between motor commands and visual location.

This is evidenced by studies of saccadic adaptation [1], in which saccades gradually learn to compensate for an artificially induced motor error by adjusting their amplitude by a fraction of the observed landing error.

How does the oculomotor system decide how much of the error should be corrected?

According to probabilistic models of motor learning, adaptation speed should depend on *measurement* noise (e.g. uncertainty in perceiving and localizing visual target) as well as on *process* noise (random fluctuations in the state of the oculomotor plan).

The probabilistic model corresponds to a Kalman filter when noise sources are Gaussian and predicts that adaptation should be slower with higher measurement uncertainty:

Predict:
$$\hat{g}_t = g_{t-1}$$
$$\hat{\sigma}_t^2 = \sigma_{t-1}^2 + \sigma_p^2$$

Time Update

Update:
$$K_t = \frac{\hat{\sigma}_t^2}{\hat{\sigma}_t^2 + \sigma_m^2}$$
$$g_t = \hat{g}_t + K_t(y_t - \hat{g}_t)$$
$$\sigma_t^2 = (1 - K_t)\hat{\sigma}_t^2$$

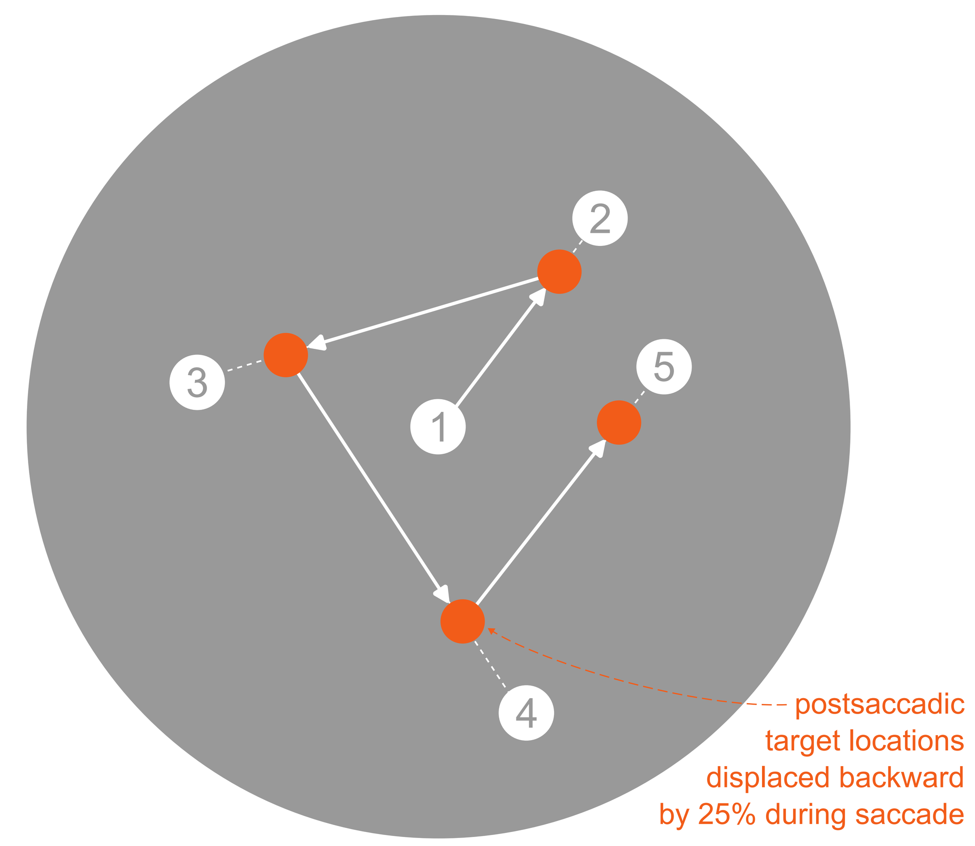
Measurement Update

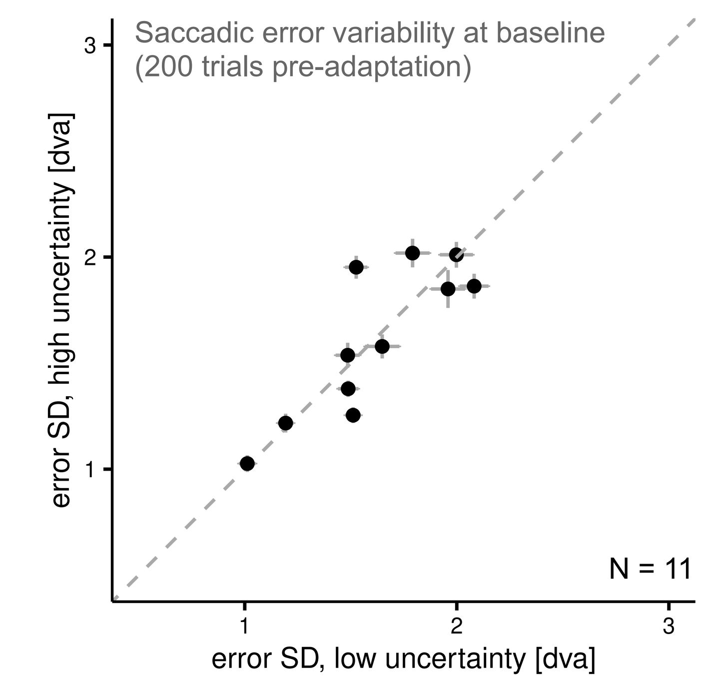
g_t state variable (e.g. parameter of oculomotor plant that scales the saccadic amplitude)
y_t noisy observation of the state variable (e.g. observed saccadic gain)
σ_t^2 uncertainty around state variable at trial t
σ_m^2 measurement variance
σ_p^2 process noise variance
K_t learning rate (Kalman gain)

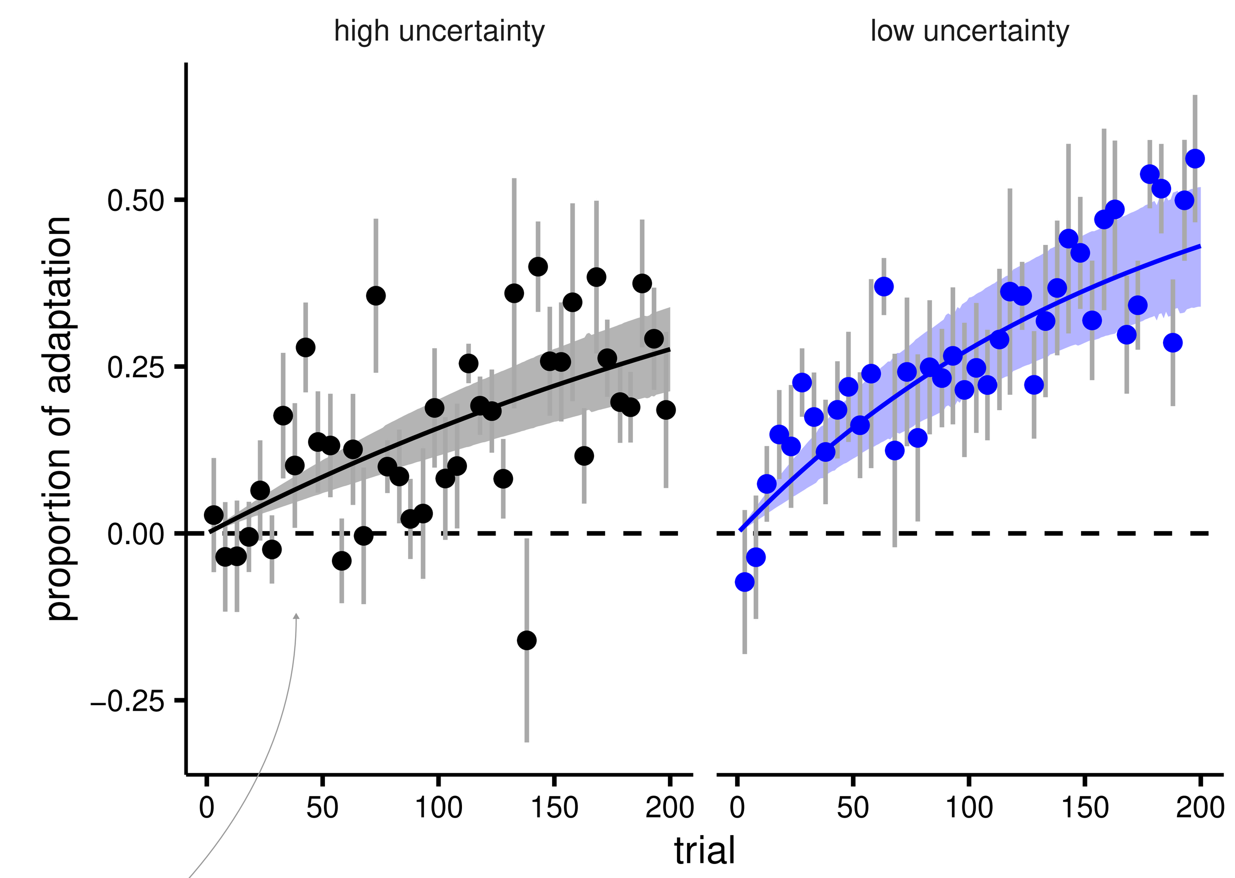
While there is evidence that motor adaptation for other types of movement conforms to this prediction (e.g. hand reaching [3]), studies of adaptation in the saccadic system have concluded that it is not influenced by visual uncertainty [4]. Here we re-examined this conundrum using stimuli that have been recently shown to influence location uncertainty [6] and two types of adaptation protocol: classical and global [5].

Global saccadic adaptation

In the global adaptation protocol [4], the target moves in a random walk



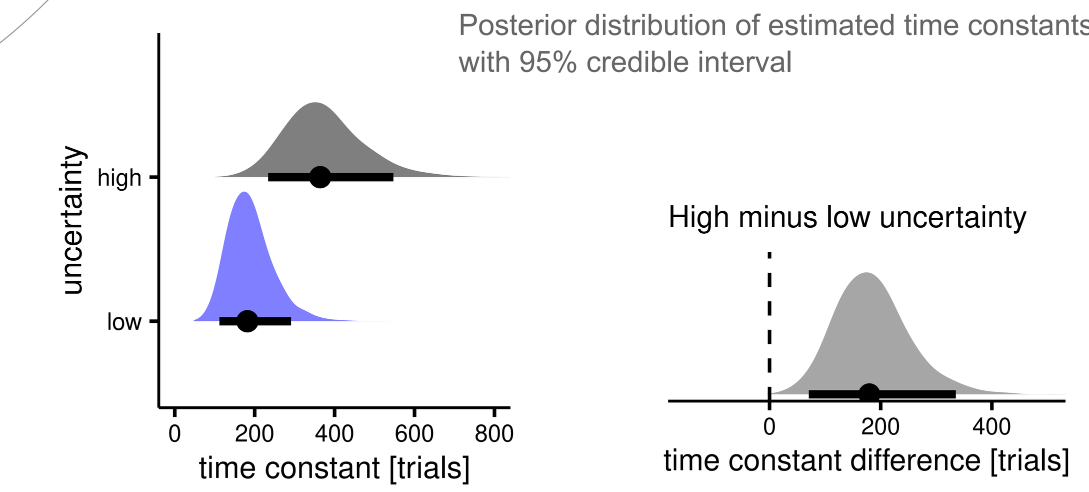




Data analyzed with a multilevel Bayesian model. Exponential curves are group-level predictions with 95% credible intervals

High and low uncertainty sessions run on separate days (1 week apart), order counterbalanced

Target distance: 4 - 12 dva
Intra-saccadic step: -25% of initial distance



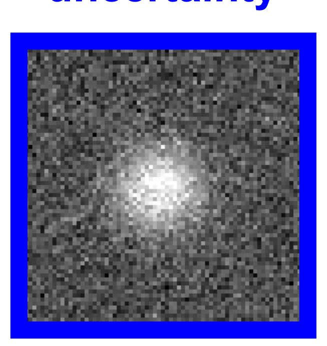
Stimuli

Saccadic targets were Gaussian luminance blobs superimposed on a noise background

- pixel size ≈0.1 degrees of visual angle [dva]
- noise SD was 14.73 cd/m^2 for classic adaptation and 10.21 cd/m^2 for global adaptation

Identical for all participants

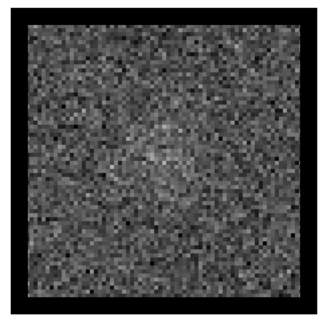
low uncertainty



Classic adaptation
147 cd/m^2 peak luminance
6.84 contrast-to-noise ratio

Global adaptation
102 cd/m^2 peak luminance
6.71 contrast-to-noise ratio

high uncertainty



Peak luminance adjusted individually in a pre-test session

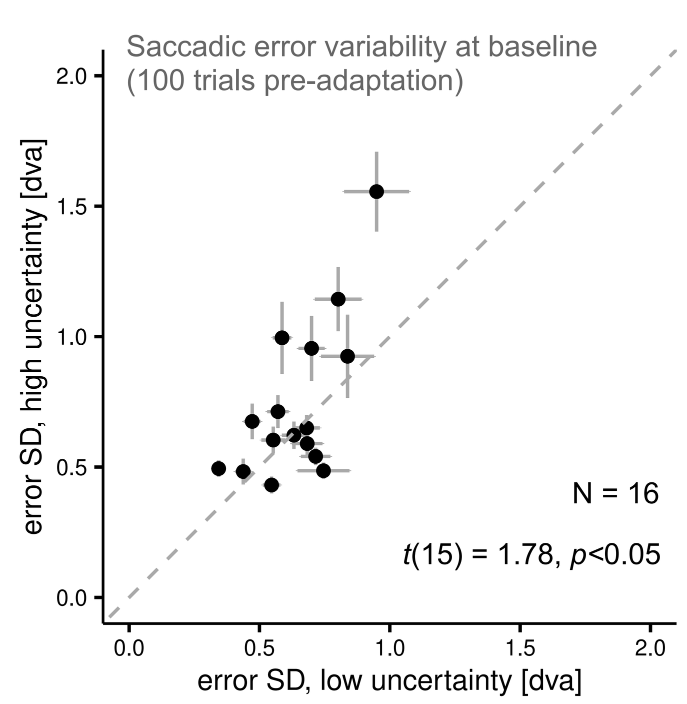
Classic adaptation
64.05 (SD = 2.76) cd/m^2 peak luminance
1.19 (0.19) contrast-to-noise ratio

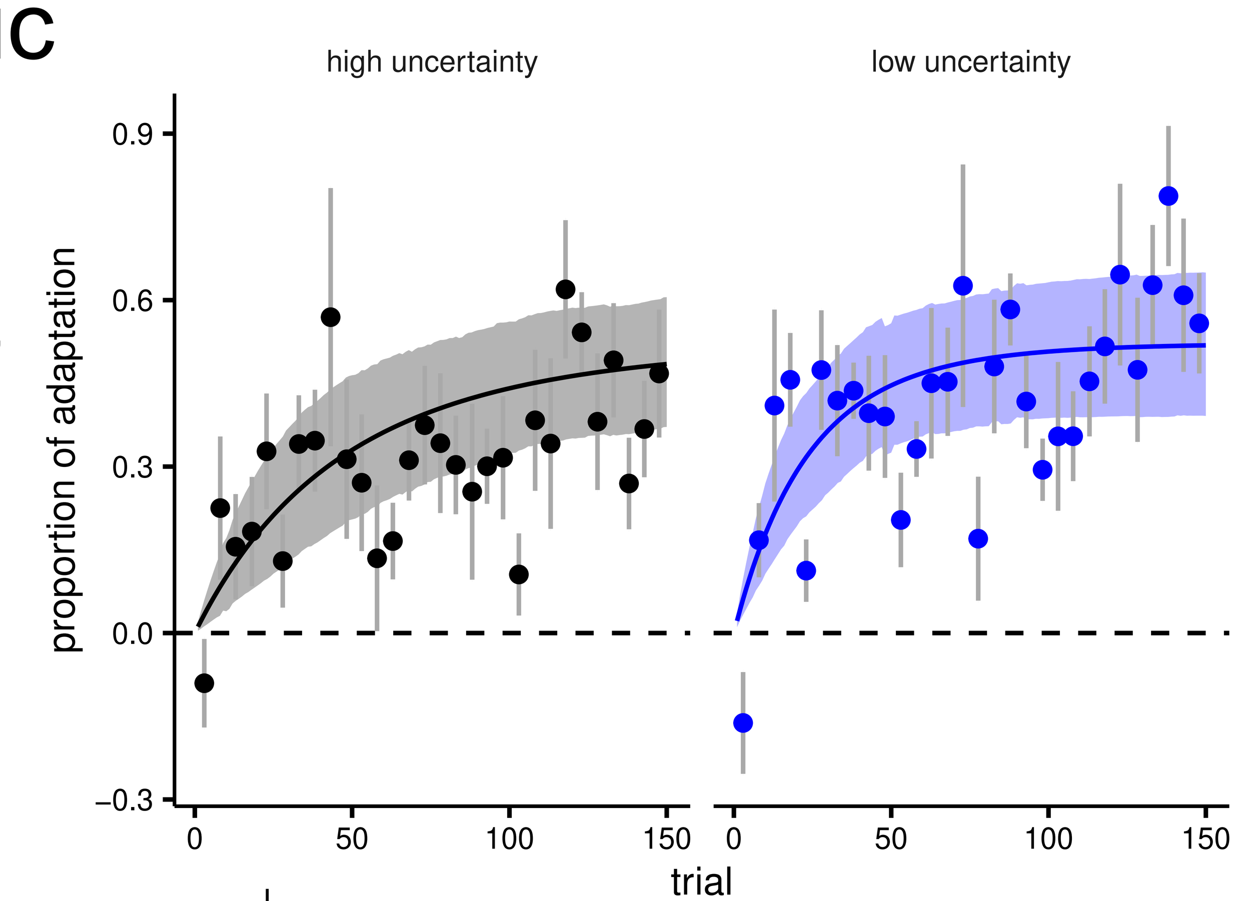
Global adaptation
43.33 (4.15) cd/m^2 peak luminance
0.97 (0.41) contrast-to-noise ratio

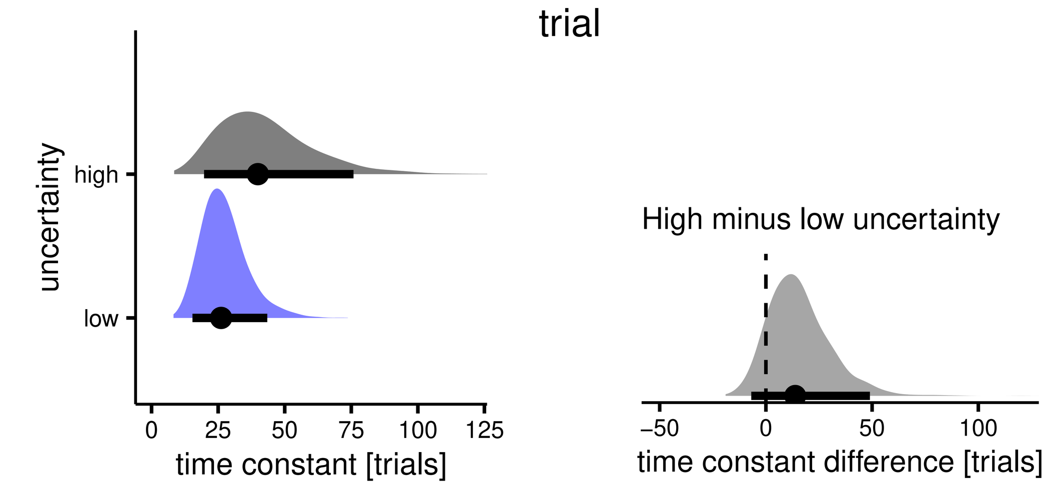
Classical saccadic adaptation

High and low uncertainty sessions run on separate days (1 week apart), order counterbalanced

Target distance: 11 dva
Intra-saccadic step: -1 dva







Summary

- Little or no evidence for an effect of uncertainty on adaptation rate in classical saccadic adaptation paradigm. This may be because the target location is highly predictable and saccades are strongly influenced by expectation [5].
- In a global saccadic adaptation paradigm [4] the target moves in a random-walk preventing precise expectations about its future locations. Here we find a strong effect of target luminance contrast on adaptation rate (as predicted by probabilistic models of motor learning [3]).
- However, the global saccadic adaptation paradigm failed to provide evidence for an effect of luminance contrast on saccadic variability (but: small N, data collection not yet complete).
- It is possible that 'true' uncertainty of saccadic system about its post-saccadic landing errors was greater than what suggested by saccadic variability. (The noise background was resampled at the same time of intra-saccadic target step, and this may have increased uncertainty.)

References

[1] McLaughlin SC (1967). Parametric adjustment in saccadic eye movements. *Perception & Psychophysics 2*, 359–362.
[2] Korenberg AT, Ghahramani Z (2002). A Bayesian view of motor adaptation. *Current Psychology of Cognition 21* (4/5), 537-564.
[3] Burge J, Ernst MO, Banks MS (2008). The statistical determinants of adaptation rate in human reaching. *J. Vis 8*(4),20.
[4] Souto D, Gegenfurtner KR, & Schütz AC (2016). Saccade adaptation and visual uncertainty. *Frontiers in Neuroscience, 10*, 227
[5] Rolfs M, Knapen T, Cavanagh, P (2010). Global saccadic adaptation. *Vision Research 50*, 1882–1890.
[6] Lisi M, Solomon J, Morgan M (2019). Gain control of saccadic eye movements is probabilistic. *PNAS 116*(32),16137-16142

contact: matteo.lisi@rhul.ac.uk https://mlisi.xyz