Using the perceptual confirmation-bias to study learning and feedback in fovea and periphery

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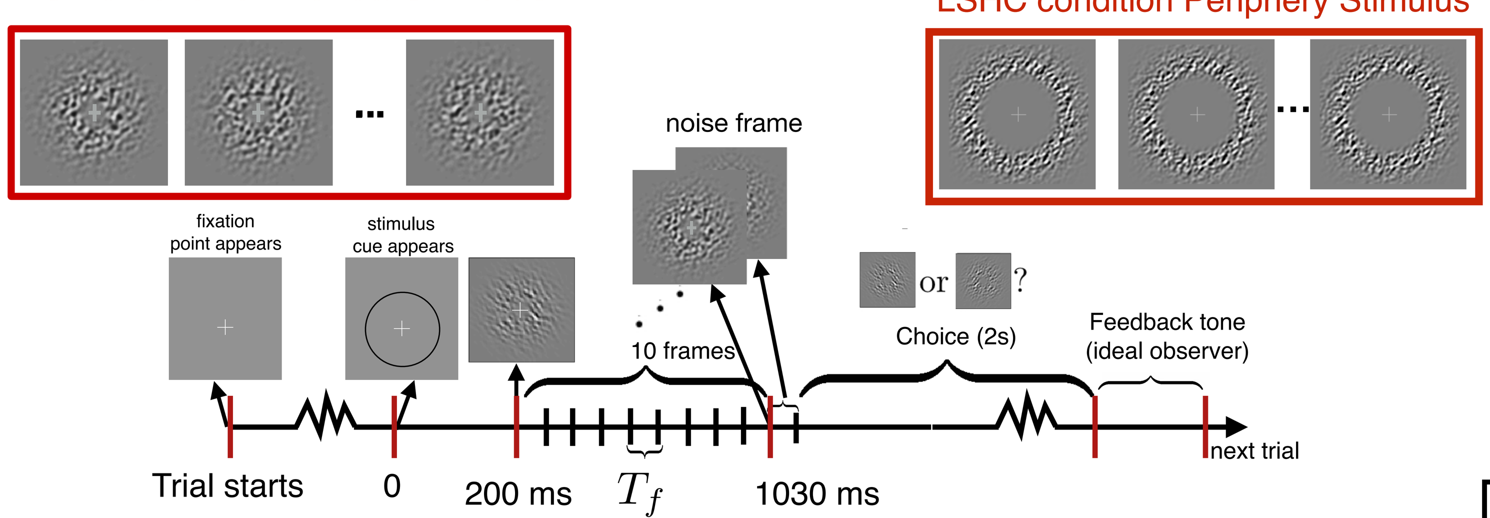
Introduction

- In **evidence integration** tasks, subjects make a categorical decision from a sequence of (typically i.i.d.) sensory information.[1,2,3,4,6,7,9]
- A **psychophysical kernel (PK)** quantifies the 'weight' subjects give to evidence in space or time.
- A perceptual **confirmation bias (CB)** occurs when people upweight information confirming existing beliefs, thus strengthening those beliefs. This is implied by a PK that decreases over time.[4,6]
- We recently showed perceptual CB could be explained by assuming that the brain performs **approximate inference in a hierarchical model in which expectations influence sensory inferences**. These expectations are facilitated by **feedback connections (FB)**.[5]
- We here ask two key questions:
  1. Is FB as strong in the periphery as in the fovea (which has been suggested is not the case)[8,10,11]
  2. Does the brain adapt its inference algorithm to the temporal correlations in the inputs?

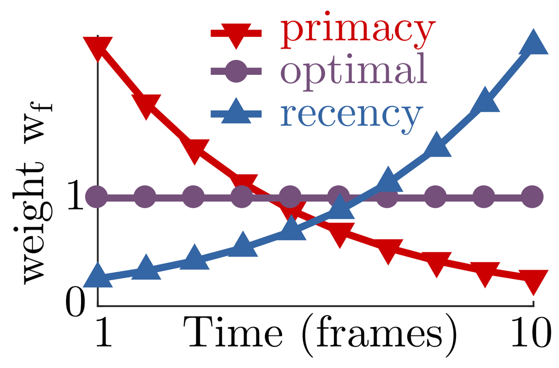
Evidence integration task



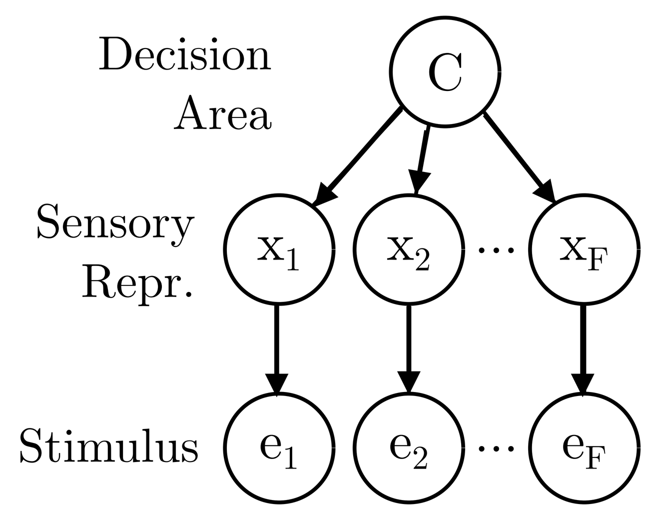
T_f = 83, 42 or 166 ms per frame

Possible PK profiles

$$\log \frac{p(\text{Choice 1})}{p(\text{Choice 2})} \approx \sum_f w_f e_f$$

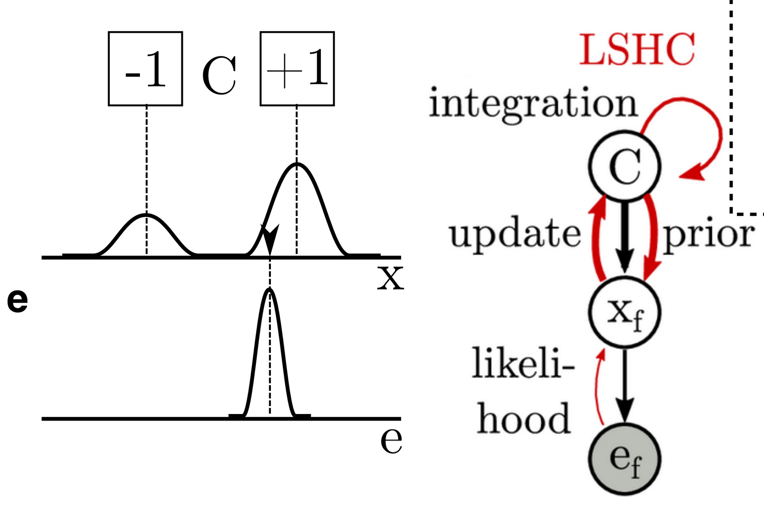


Generative model of the brain



Sampling Model

Generative model:
- **C** = category / decision-area
- **x** = sensory representation
- **e** = evidence



Goal: compute posterior over **C** given **e**

$$p(C|e_1,\ldots,e_T) \propto p(C)\prod_{t=1}^{T} p(e_t|C)$$

...using **online updates**

$$\log\frac{p_t(C=+1)}{p_t(C=-1)} \equiv \log\frac{p(C=+1|e_1,\ldots,e_t)}{p(C=-1|e_1,\ldots,e_t)} \qquad p_0(C)\equiv p(C)$$

$$= \log\frac{p_{t-1}(C=+1)}{p_{t-1}(C=-1)} + \log\frac{p(e_t|C=+1)}{p(e_t|C=-1)}$$

update to log posterior odds each frame

...using **importance sampling** from the **full posterior** to marginalize over the sensory variable **x**

$$p(e_t|C=c) = \int p(e_t|x_t)p(x_t|C=c) \approx \frac{1}{S}\sum_{x^{(i)}\sim Q} p(e_t|x_t^{(i)})p(x_t^{(i)}|C=c)/Q(x_t^{(i)})$$

$$Q(x) \propto \sum_c p(e_t|x)p(x|C=c)p_{t-1}^{FB}(C=c)$$

FB determines the strength of feedback connection or top-down connection from **C** to x

$$\log\frac{p(e_t|C=+1)}{p(e_t|C=-1)} \approx \log\frac{\sum p(x_t^{(i)}|C=+1)w_i}{\sum p(x_t^{(i)}|C=-1)w_i}$$

$$w_i = \left(\sum_c p(x_t^{(i)}|C=c)p_{t-1}(C=c)\right)^{-1}$$

S is the number of samples per update to the log likelihood odds.

Final update rule:

$$\log\frac{p_t(C=+1)}{p_t(C=-1)} \approx \log\frac{p_{t-1}(C=+1)}{p_{t-1}(C=-1)} + \frac{\tau_s}{\hat{T}_f}\log\frac{\sum_{i=1}^{S} p(x_t^{(i)}|C=+1)w_i}{\sum_{i=1}^{S} p(x_t^{(i)}|C=-1)w_i}$$

T_f is the experimenter's duration of a stimulus frame

$\hat{T}_f$ is the brain's estimate of stimulus frame duration.

τ_s is the brain's sampling time

Conclusion

We used previous framework and observed,

(1) the brain adapts to the rate at which it receives independent information

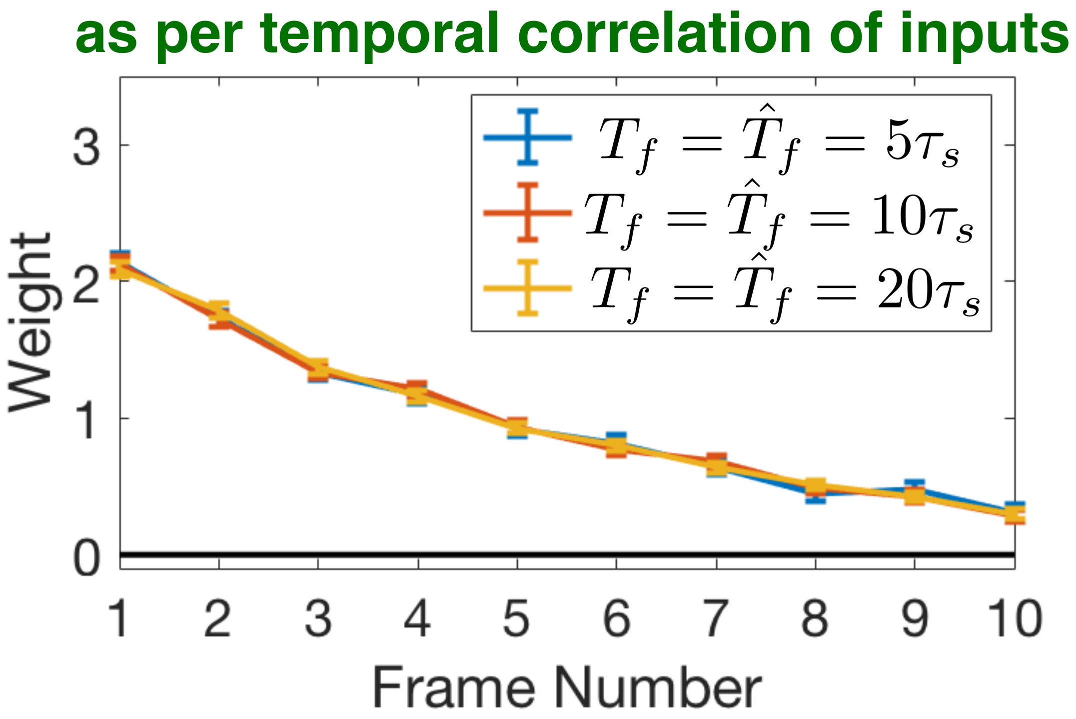
(2) we compared the strength of the primacy effect near the fovea and in the periphery, and did not find a significant difference

References

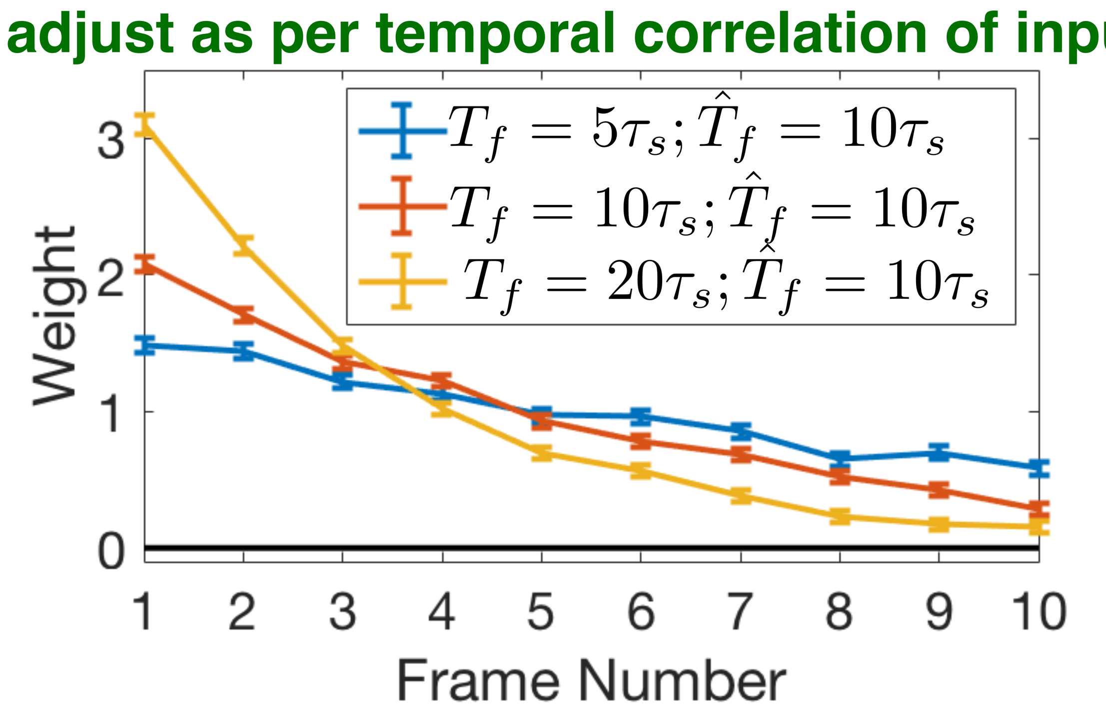
[1] Brunton, B. W., Botvinick, M. M., & Brody, C. D. (2013). Rats and humans can optimally accumulate evidence for decision-making. Science, [2] Drugowitsch, J., Wyart, V., Devauchelle, A.-D., & Koechlin,E. (2016). Computational Precision of Mental Inference as Critical Source of Human Choice Suboptimality. Neuron, [3] Gold, J. I., & Shadlen, M. N. (2007). The neural basis of decision making. Annual review of neuroscience [4] Kiani, R., Hanks, T. D., & Shadlen, M. N. (2008). Bounded integration in parietal cortex underlies decisions even when viewing duration is dictated by the environment. The Journal of neuroscience [5] Lange, R. D., Chattoraj, A., Beck, J., Yates, J., & Haefner,R. (2018). A confirmation bias in perceptual decision-making due to hierarchical approximate inference. bioRxiv, [6] Nienborg, H., & Cumming, B. G. (2009). Decision-related activity in sensory neurons reflects more than a neuron's causal effect. Nature [7] Nienborg, H., & Cumming, B. G. (2014). Decision-related activity in sensory neurons may depend on the columnar architecture of cerebral cortex. The Journal of neuroscience [8] Strasburger, H., Rentschler, I., & Juttner, M. (2011). Peripheral vision and pattern recognition: A review. Journal of vision [9] Wyart, V., Gardelle, V. D., Scholl, J., & Summerfield, C. (2012). Rhythmic Fluctuations in Evidence Accumulation during Decision Making in the Human Brain. Neuron [10] Zhaoping, L. (2017). Feedback from higher to lower visual areas for visual recognition may be weaker in the periphery: Glimpses from the perception of brief dichoptic stimuli. Vision research [11] Zhaoping, L., & Ackermann, J. (2018). Reversed depth in anticorrelated random-dot stereograms and the central-peripheral difference in visual inference. Perception

Model simulations

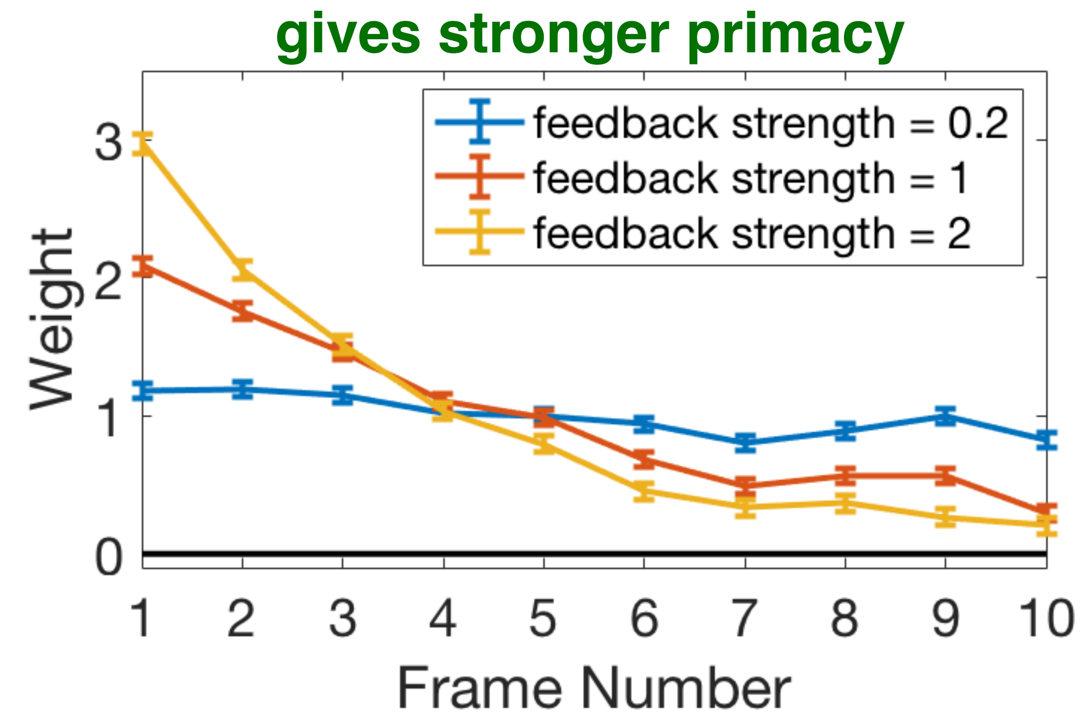
PK unchanged when the brain adjusts as per temporal correlation of inputs



PK changes when the brain does not adjust as per temporal correlation of inputs

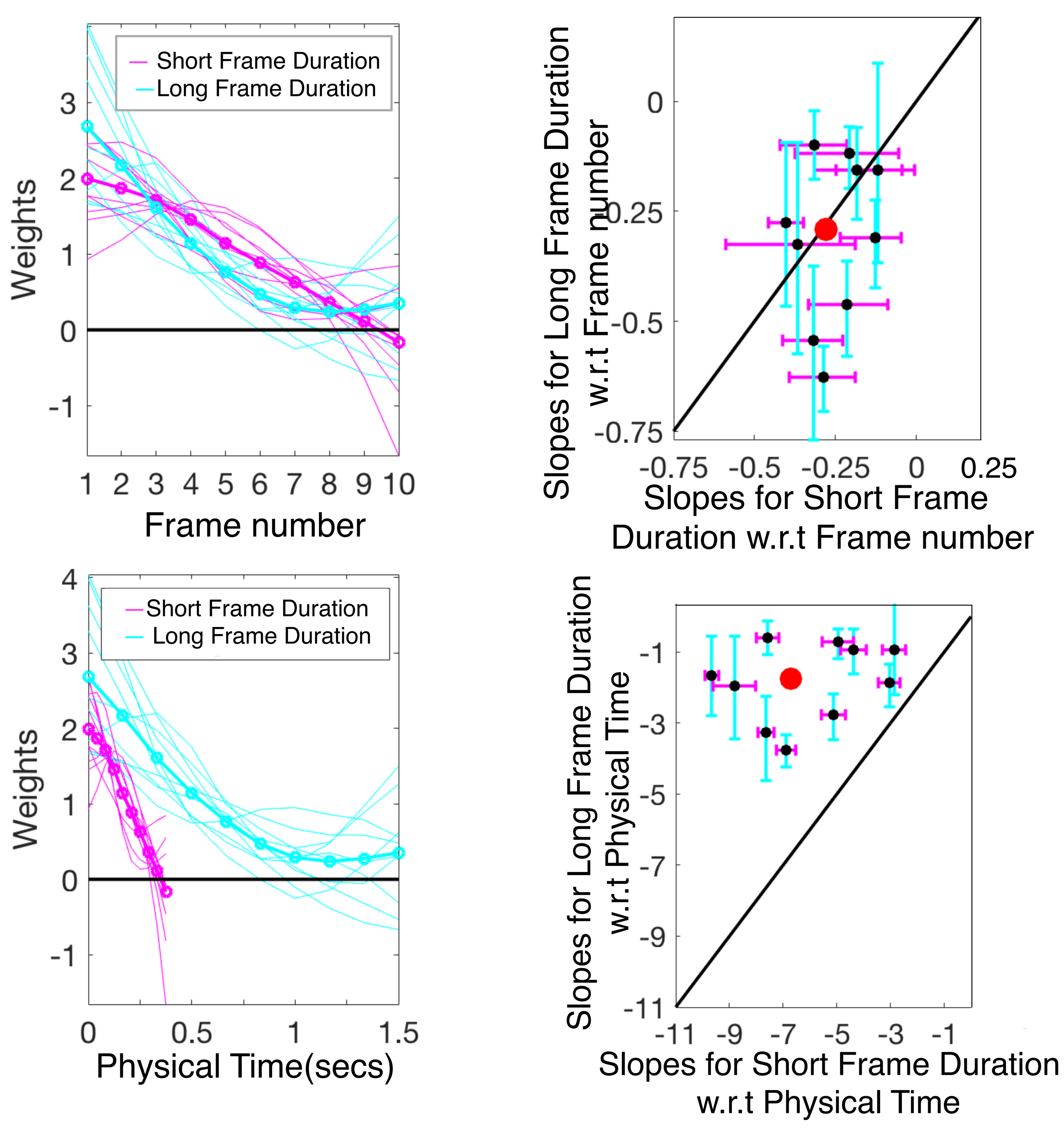


Stronger top-down feedback gives stronger primacy



Experimental observations

Study1: Vary the duration of each stimulus frame
Observation: No significant difference in PK slope



Study2: Show temporal stimuli in fovea vs periphery
Observation: No significant difference in PK slope