

04/07/2024

A retino-cortical model of anticipation

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INRIA
Biovision Team



Supervisor
Bruno Cessac
Alain Destexhe

Financed by Shooting Star ANR



Terrifying boar



40 km/h



40 km/h





40 km/h



Why are you able to anticipate this
terrifying animal?



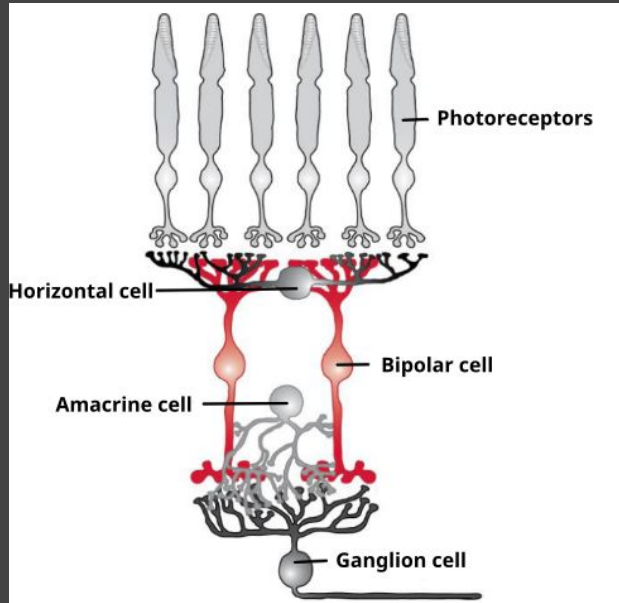
visual anticipation

How to study **visual anticipation** in a
retino-cortical pathway model?

Introduction

Retino-cortical pathway

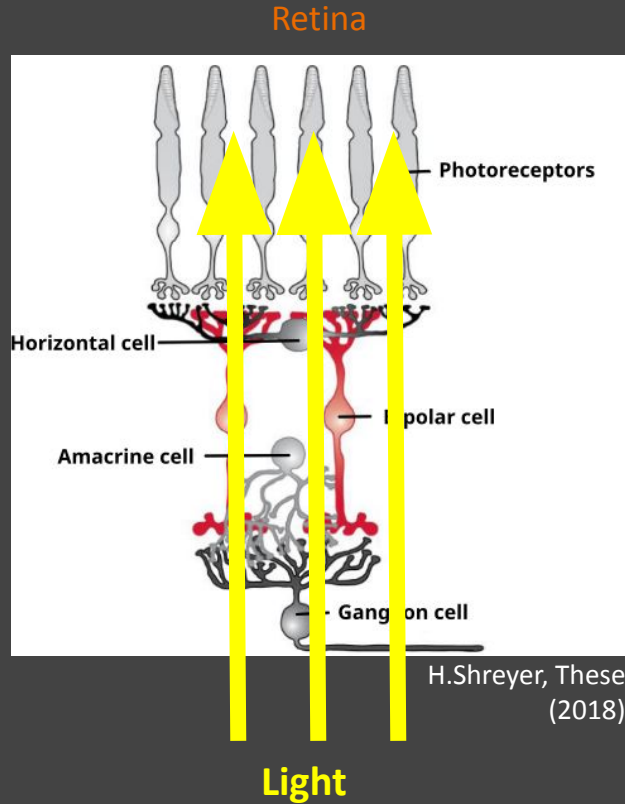
Retina



H.Shreyer, These
(2018)

Introduction

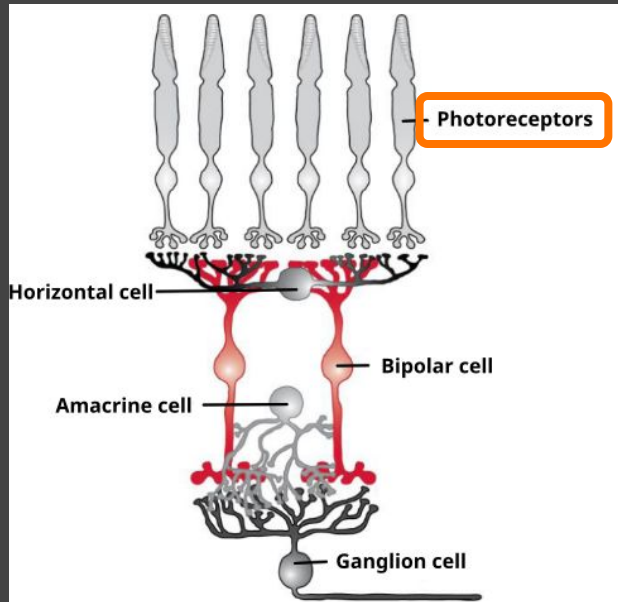
Retino-cortical pathway



Introduction

Retino-cortical pathway

Retina



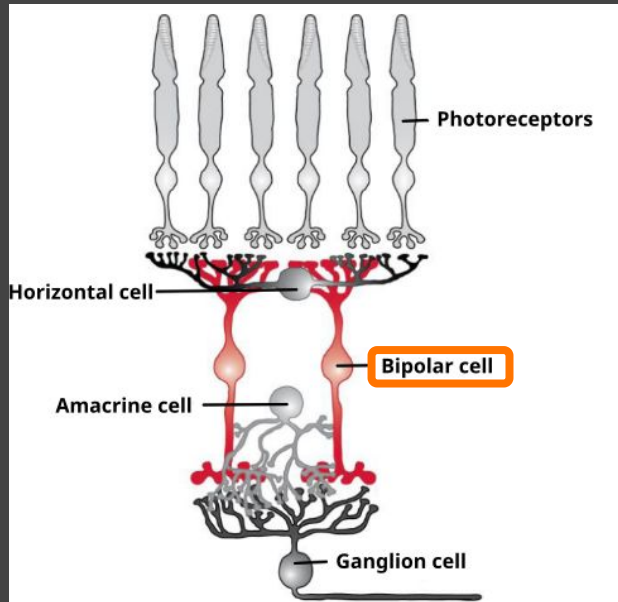
H.Shreyer, These
(2018)

Photoreceptors transform light into electrical signals

Introduction

Retino-cortical pathway

Retina



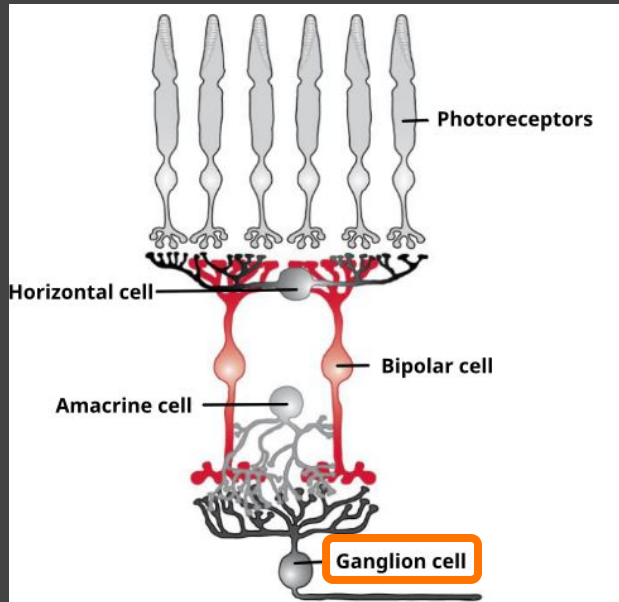
H.Shreyer, These
(2018)

Photoreceptors transform light into electrical signals

Introduction

Retino-cortical pathway

Retina

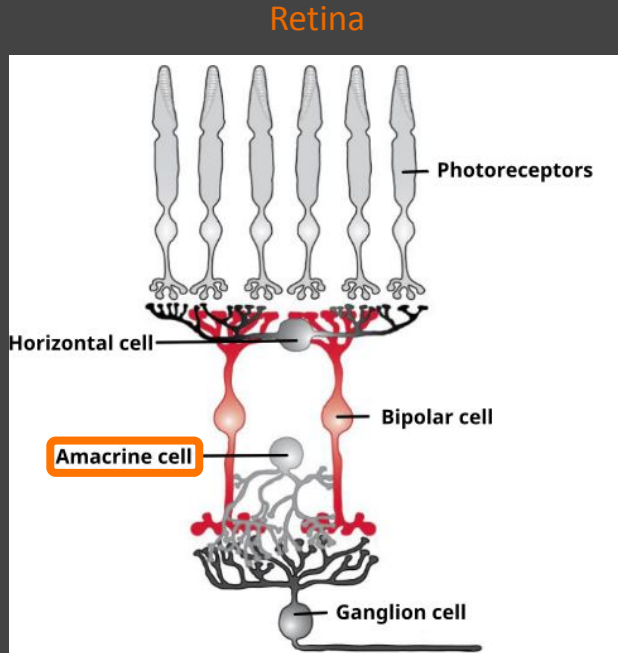


H.Shreyer, These
(2018)

Photoreceptors transform light into electrical signals

Introduction

Retino-cortical pathway



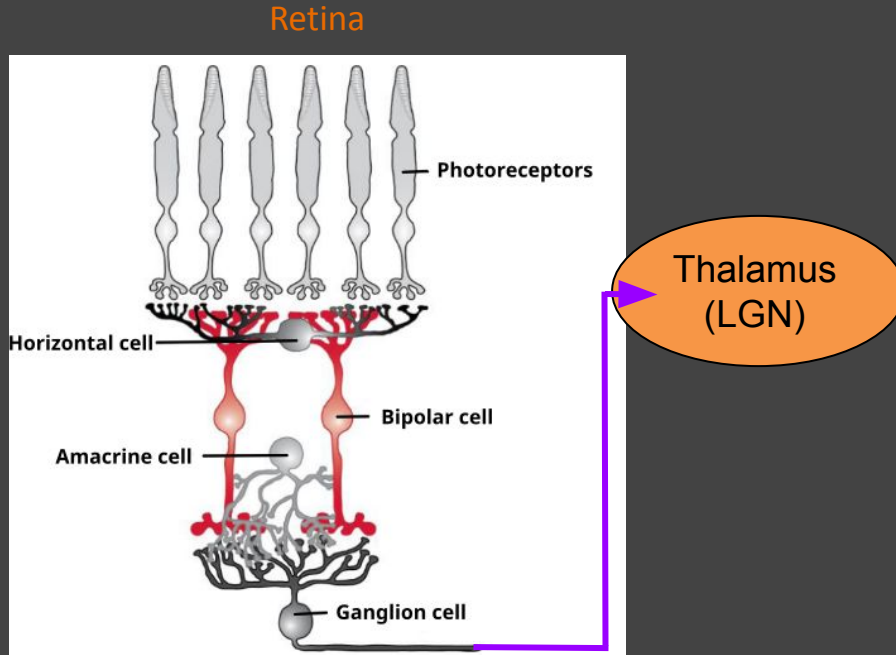
H.Shreyer, These
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Photoreceptors transform light into electrical signals

Amacrine cells have a modulatory effect by lateral inhibition

Introduction

Retino-cortical pathway

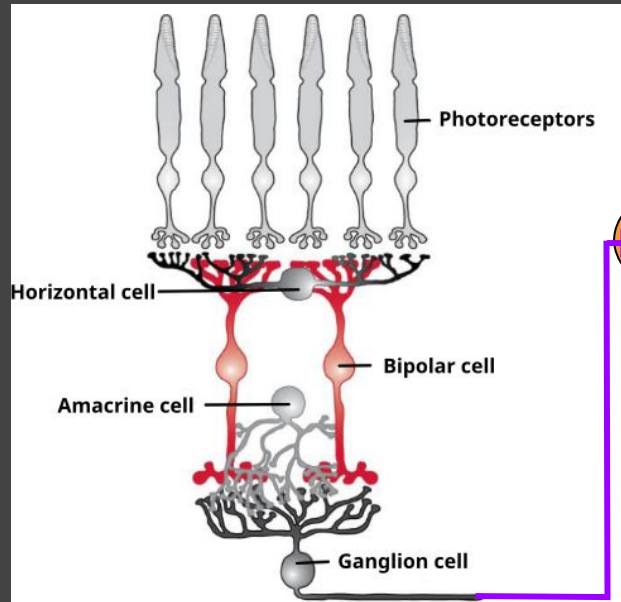


H.Shreyer, These
(2018)

Introduction

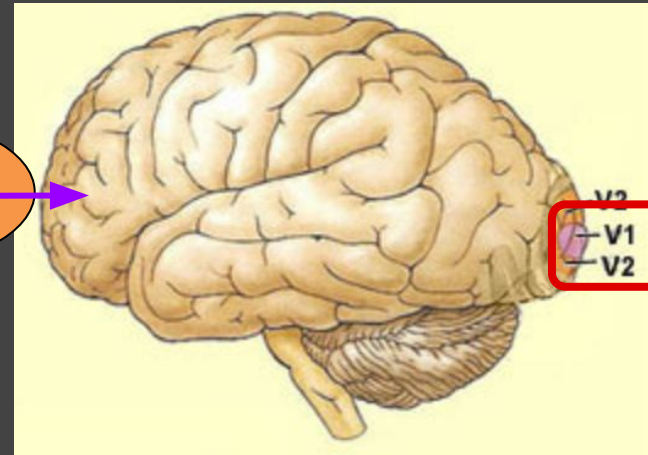
Retino-cortical pathway

Retina



H.Shreyer, These (2018)

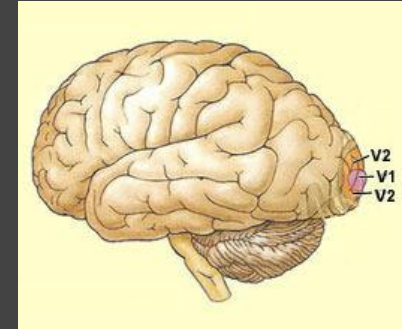
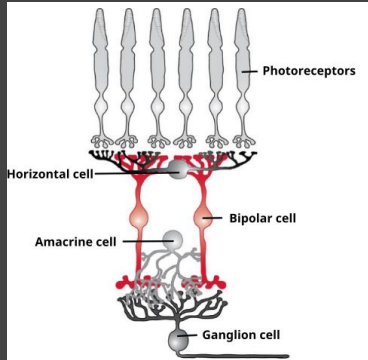
Primary visual cortex localisation



Thalamus (LGN)

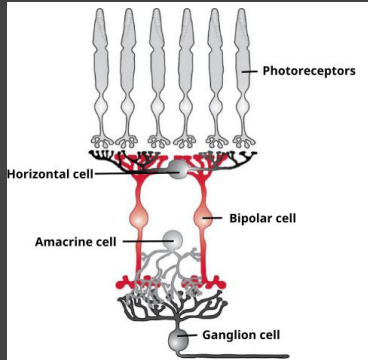
Introduction

Retino-cortical pathway

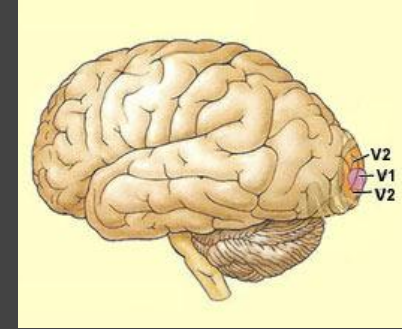


Introduction

Retino-cortical pathway

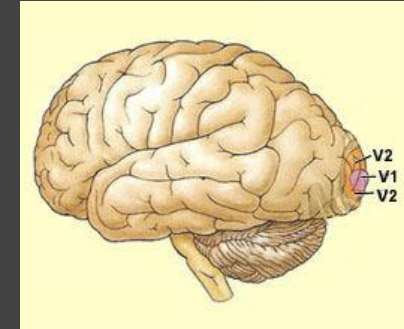
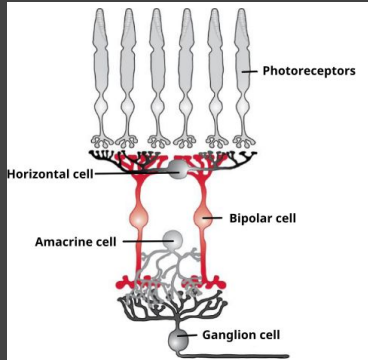


Phototransducing...



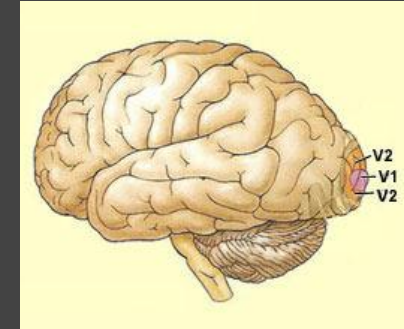
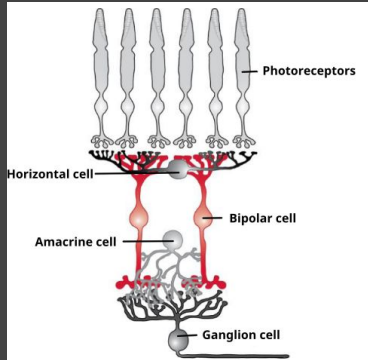
Introduction

Retino-cortical pathway



Introduction

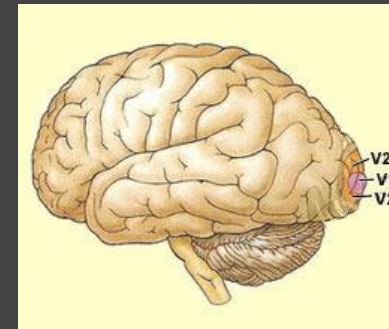
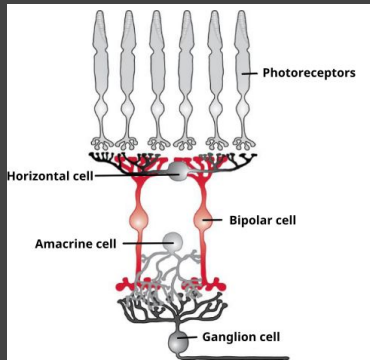
Retino-cortical pathway



Lag of 100ms between retina and cortex

Introduction

Retino-cortical pathway

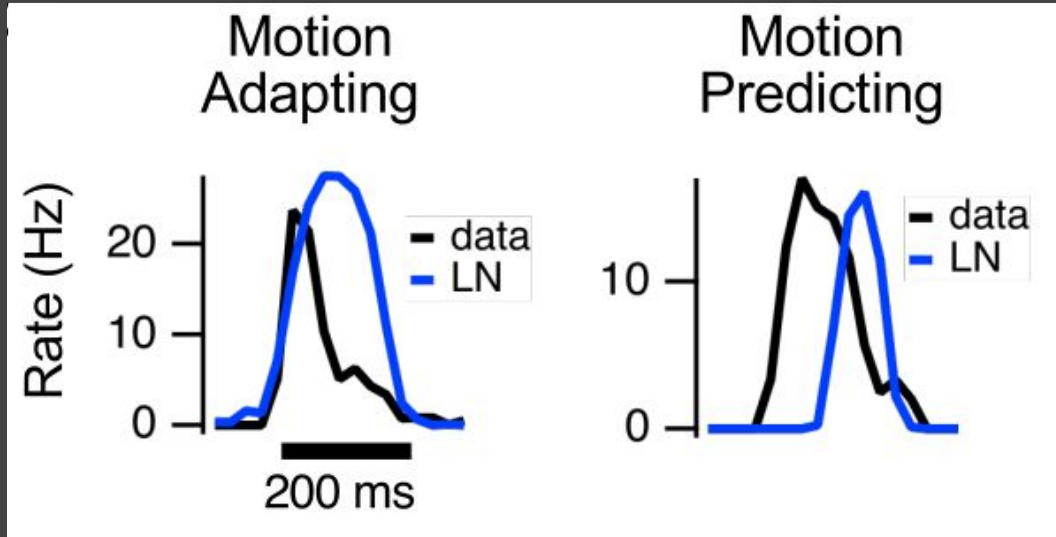
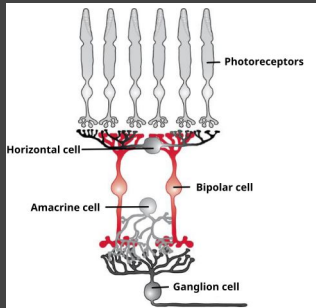


Lag of 100ms between retina and cortex

Three compensatory mechanisms of anticipation

Introduction

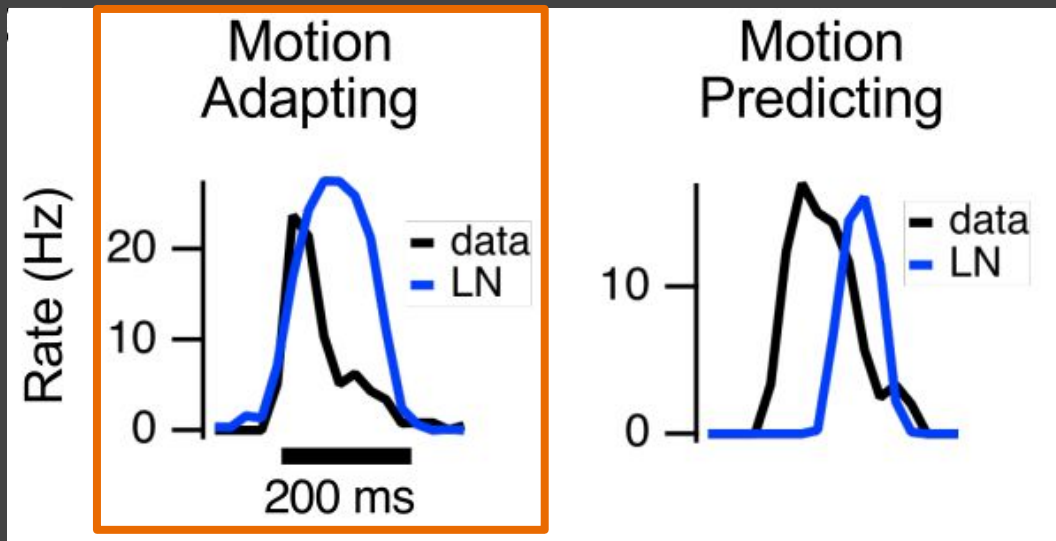
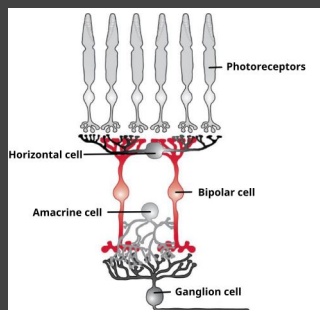
Anticipation in the retina



M. Menz, D. Lee and S. Baccus, bioRxiv (2020)

Introduction

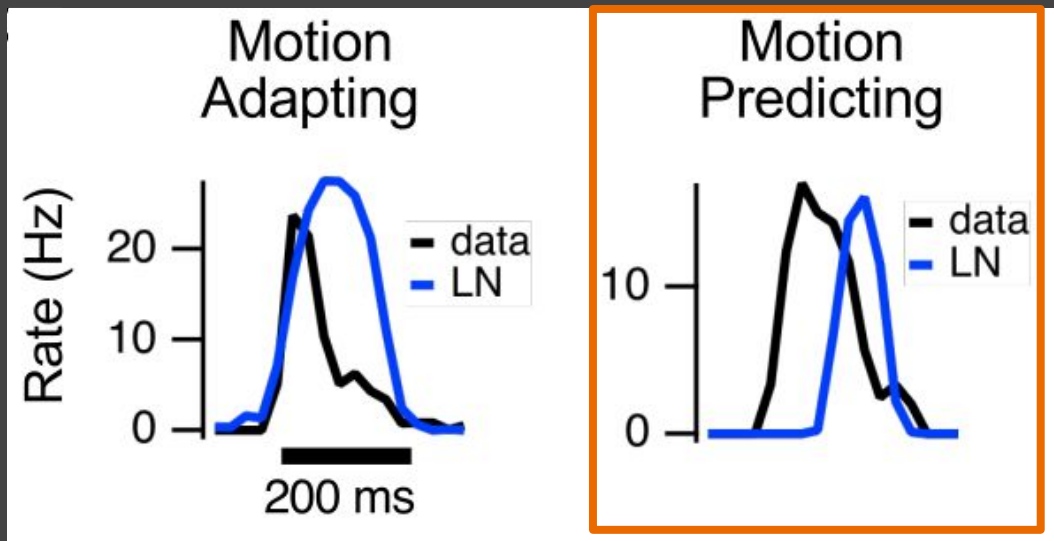
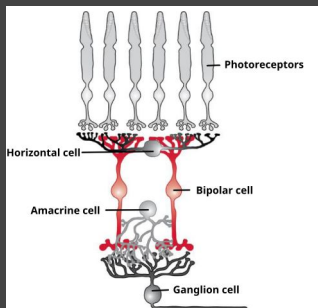
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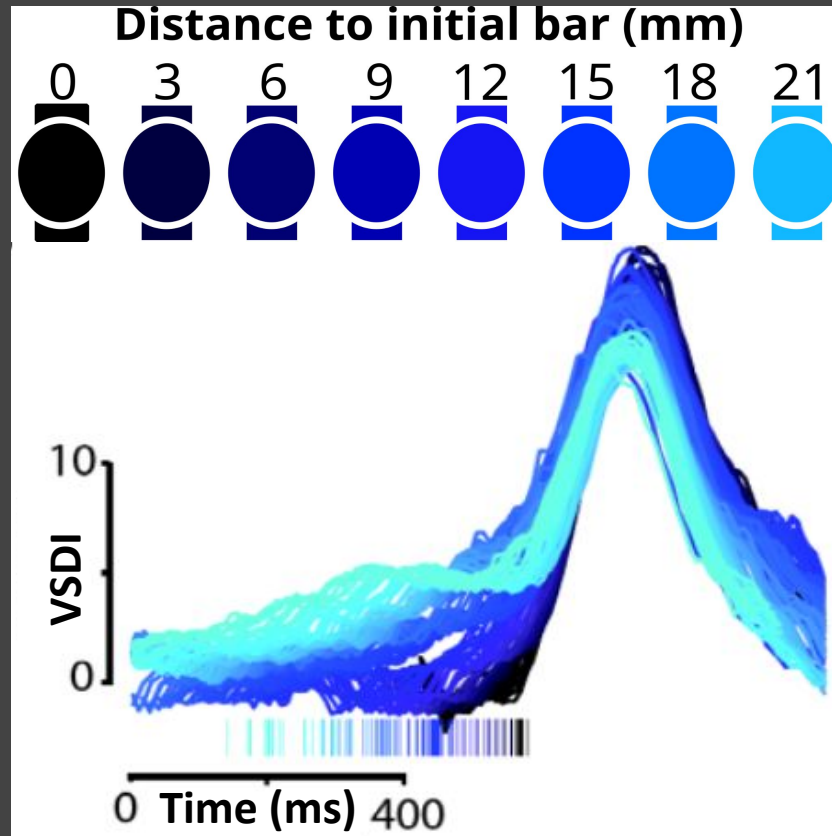
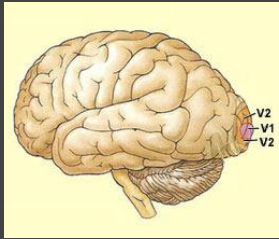
Introduction

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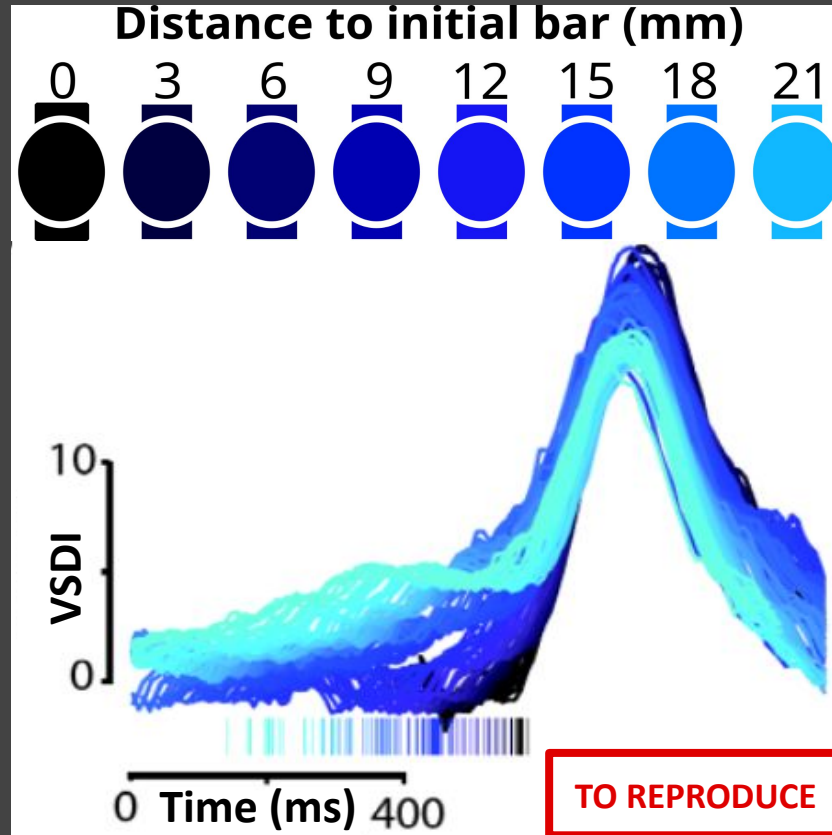
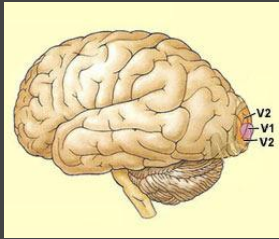
Anticipation by latency in the primary visual cortex (V1)



G. Benvenuti et al.,
bioRxiv (2020)

Introduction

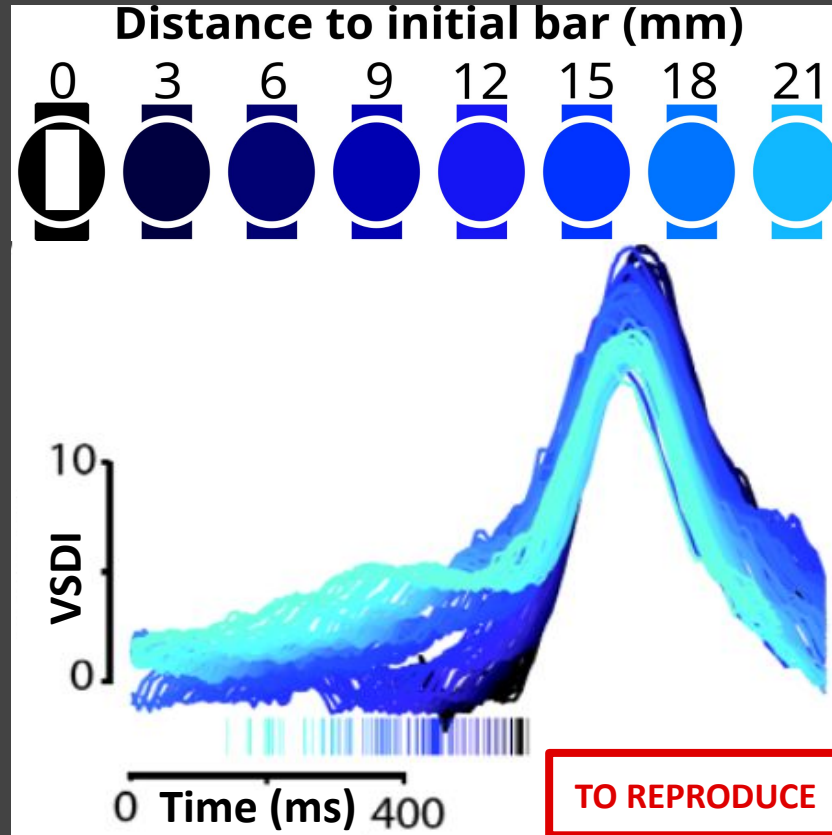
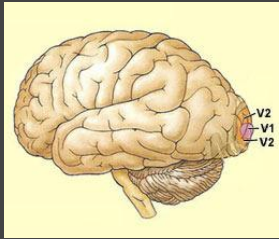
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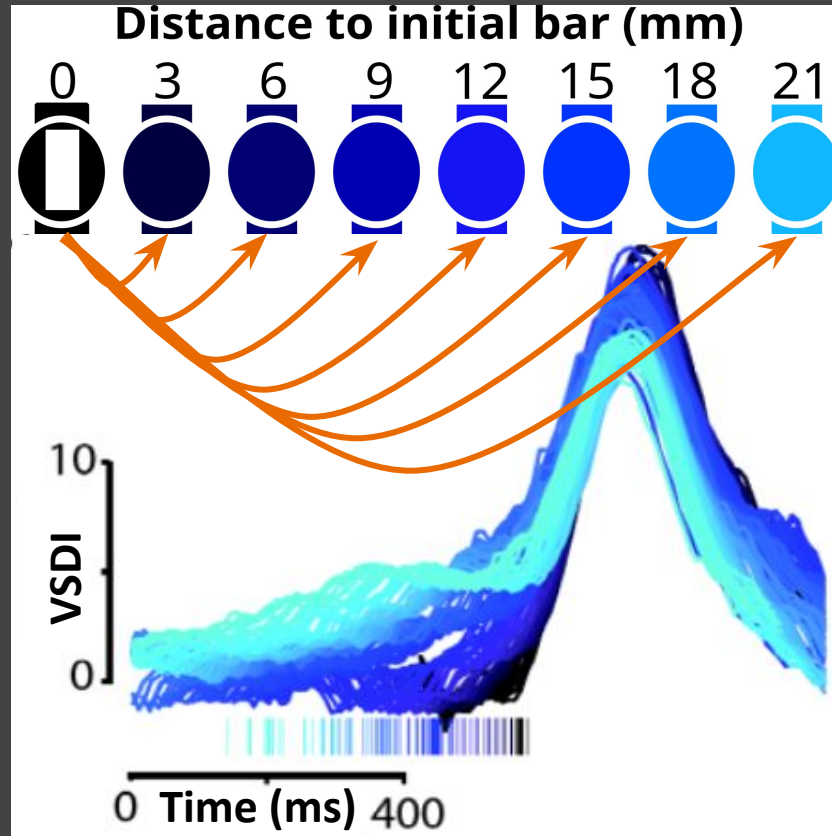
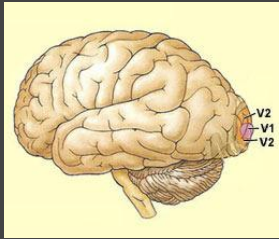
Introduction

Anticipation by latency in the primary visual cortex (V1)



G. Benvenuti et al.,
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Anticipation by latency in the primary visual cortex (V1)

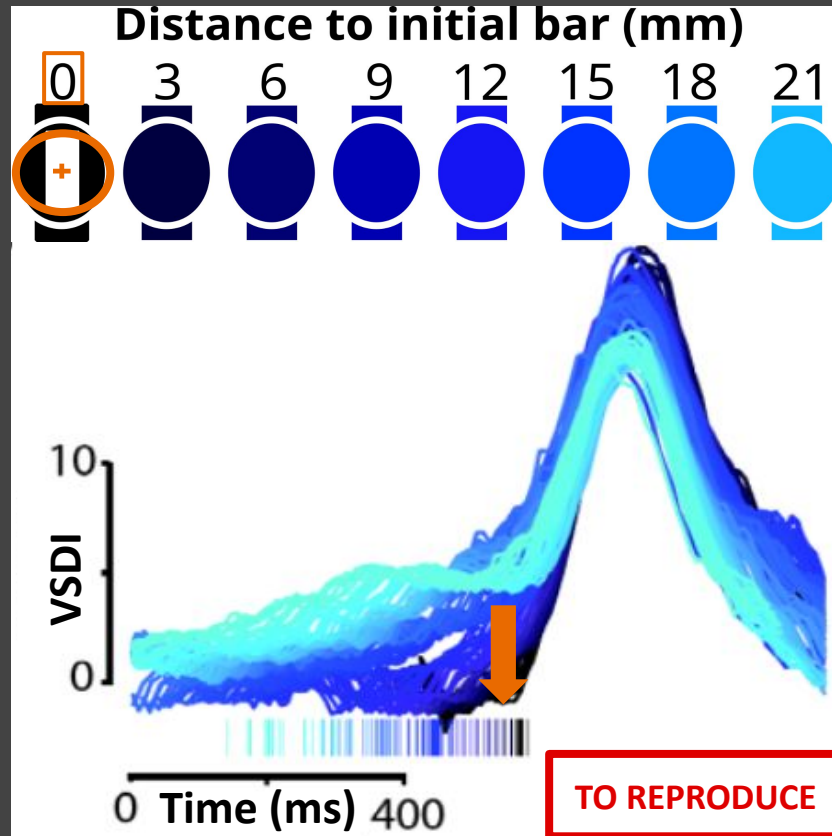
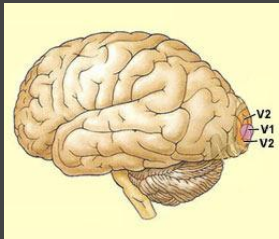


Cortical columns seeing the bar sends excitation to others not already activated by it.

G.Benvenuti et al.,
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Introduction

Anticipation by latency in the primary visual cortex (V1)



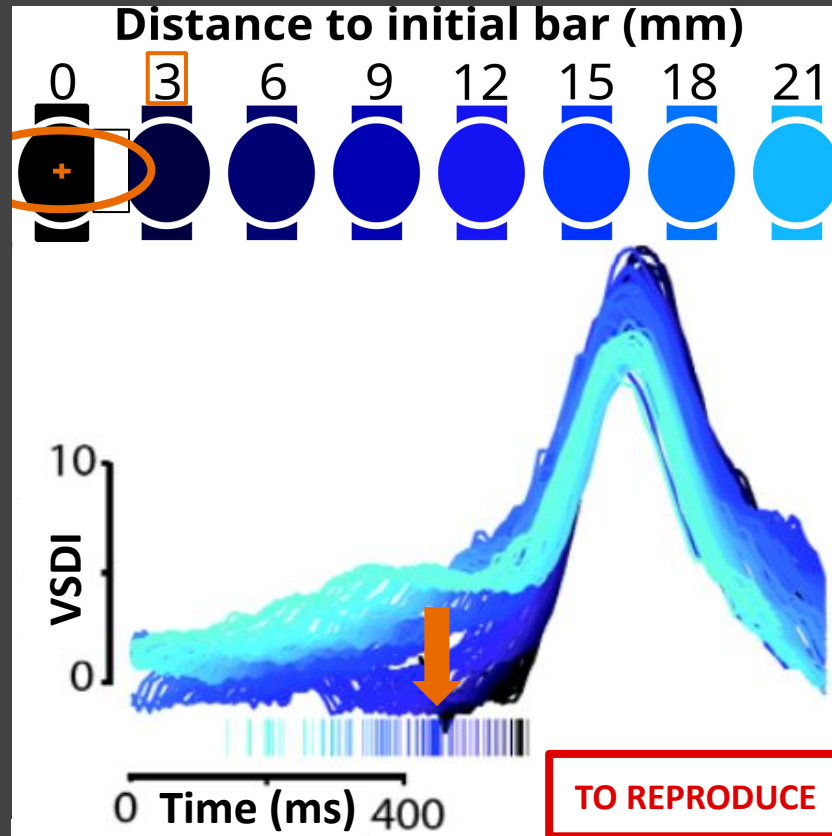
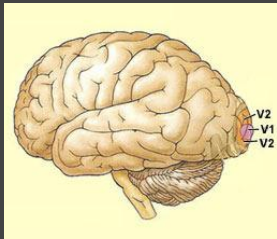
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The moving bar elicits anticipatory wave propagating faster than the bar.

G. Benvenuti et al.,
bioRxiv (2020)

TO REPRODUCE

Anticipation by latency in the primary visual cortex (V1)



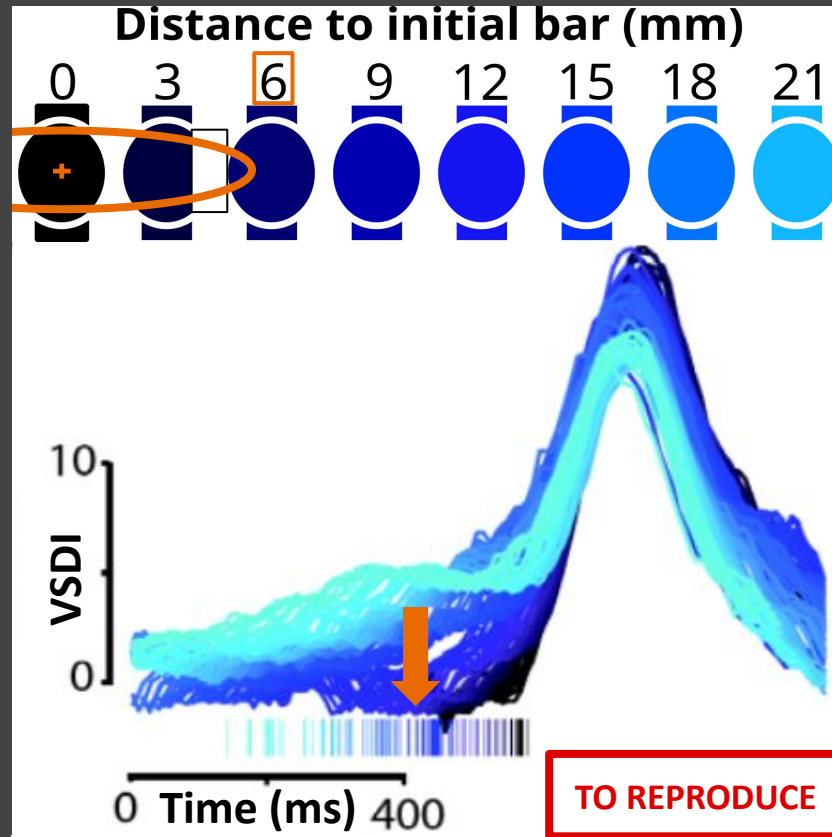
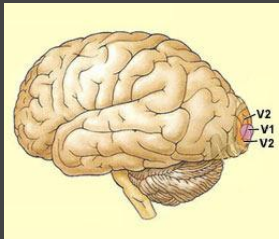
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Introduction

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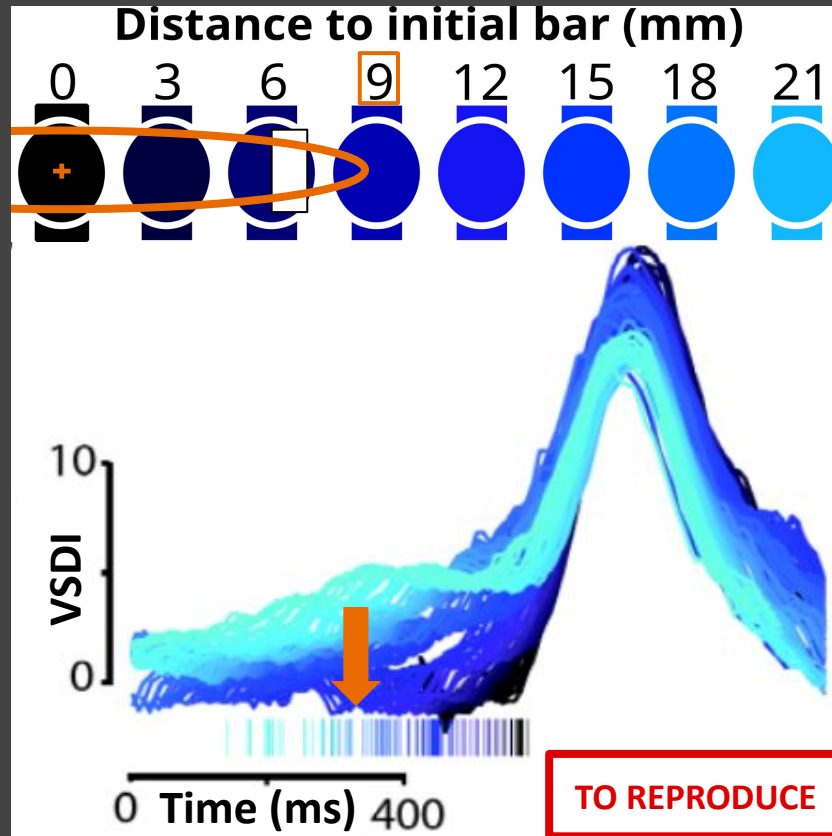
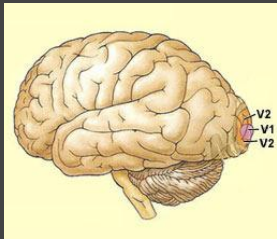


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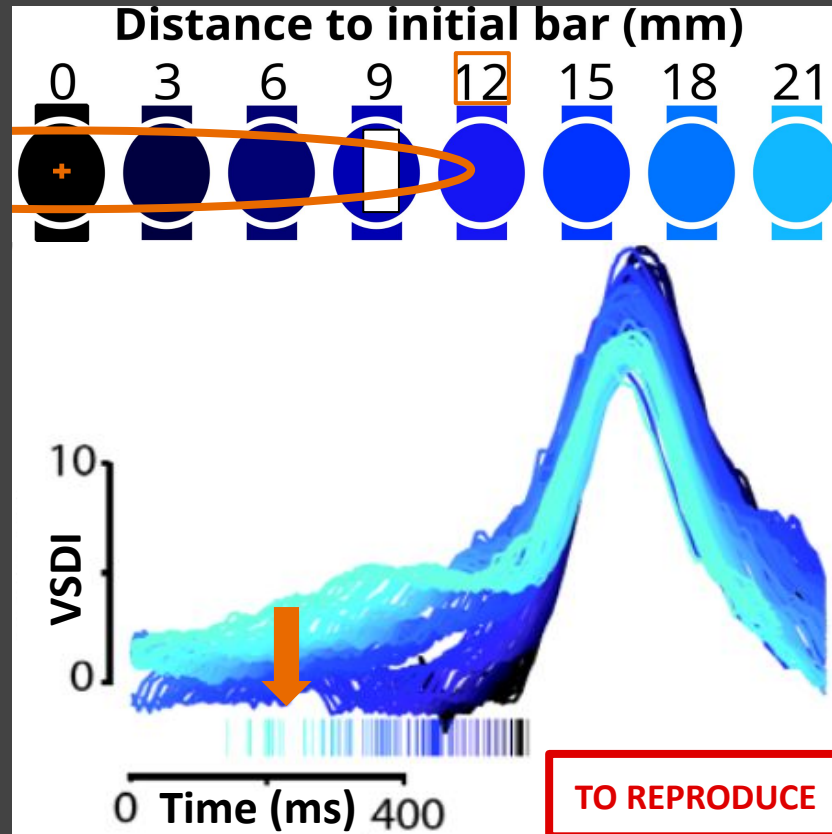
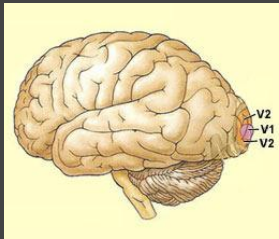
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Introduction

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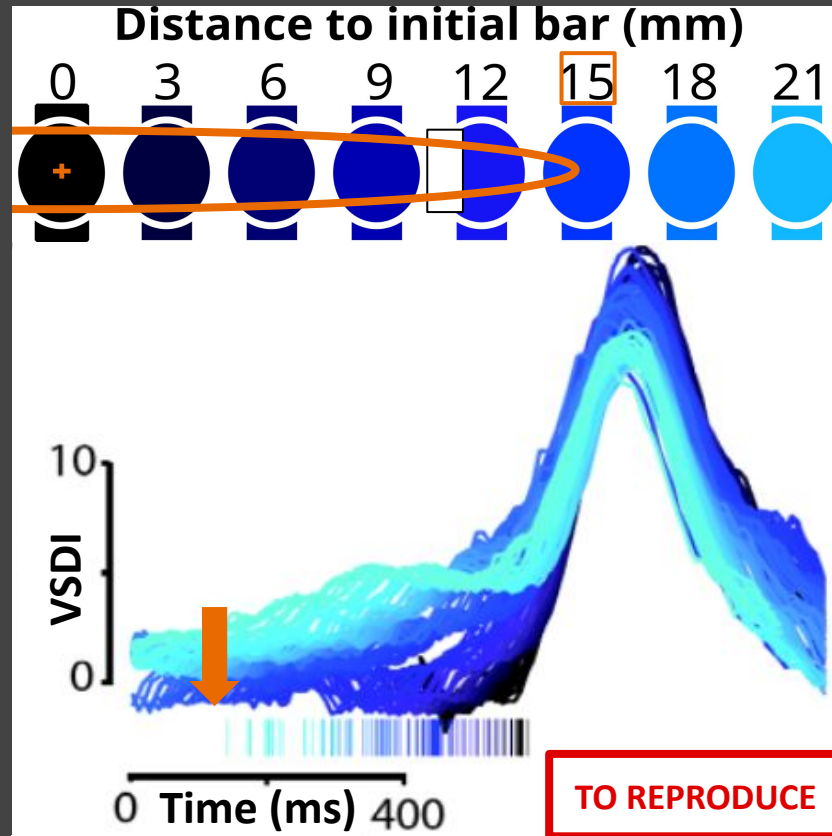
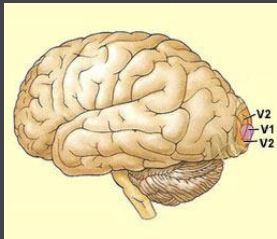
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Introduction

Anticipation by latency in the primary visual cortex (V1)



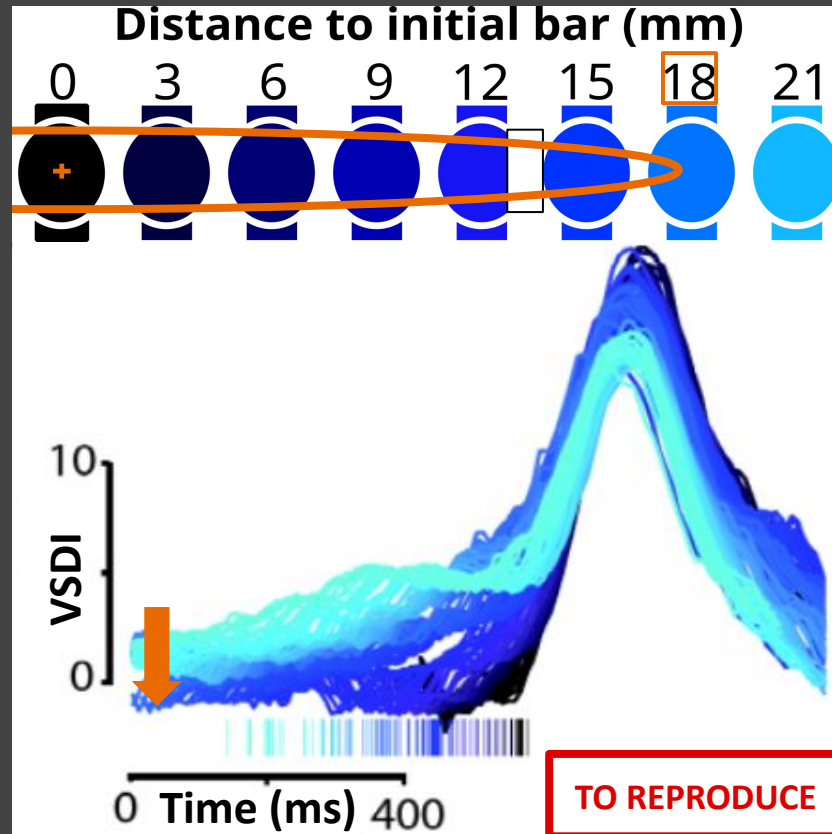
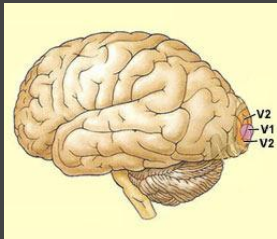
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Introduction

Anticipation by latency in the primary visual cortex (V1)

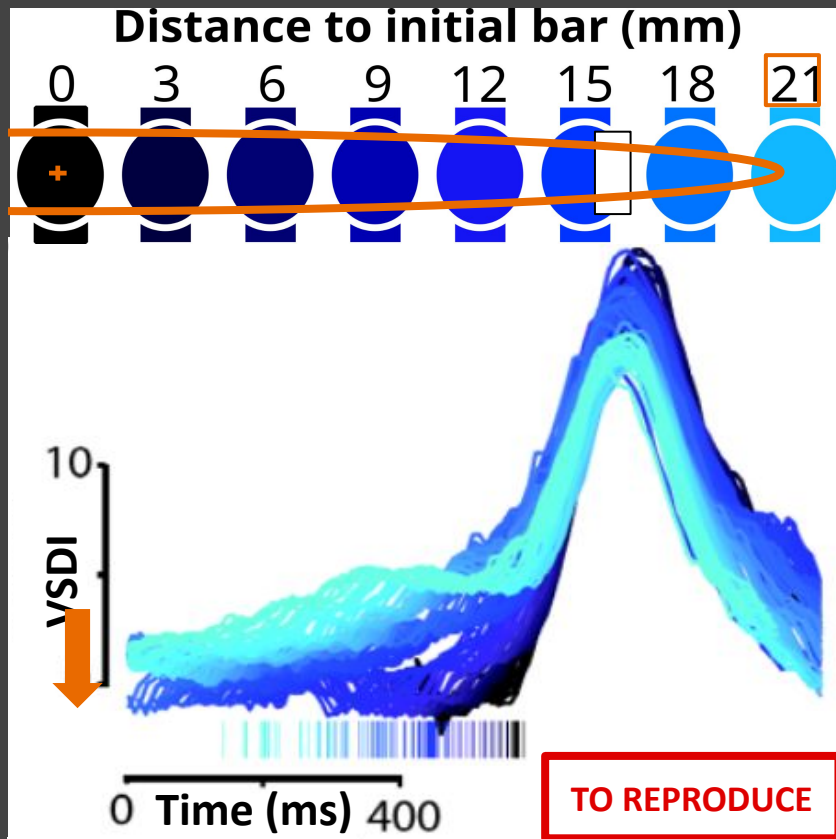
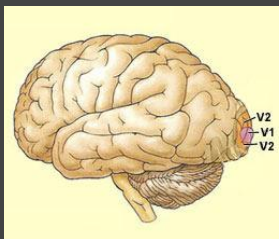


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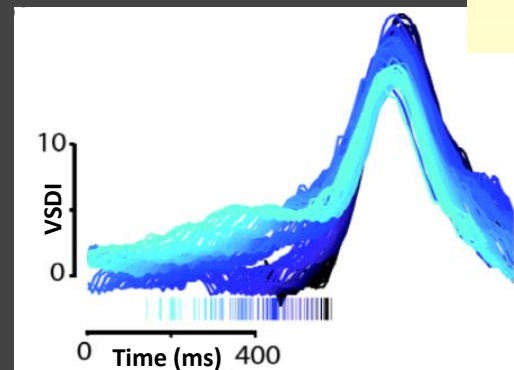
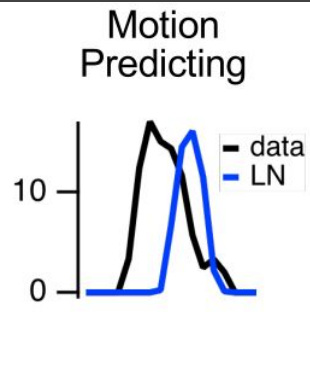
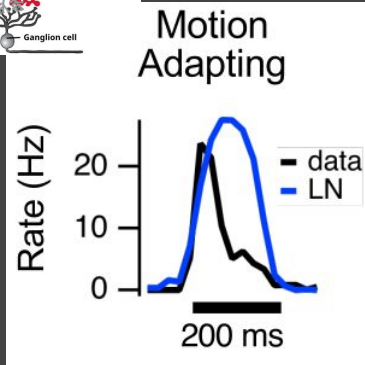
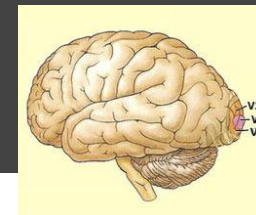
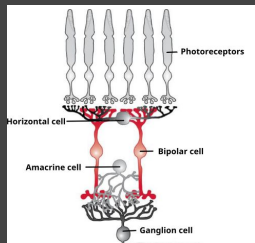
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Introduction

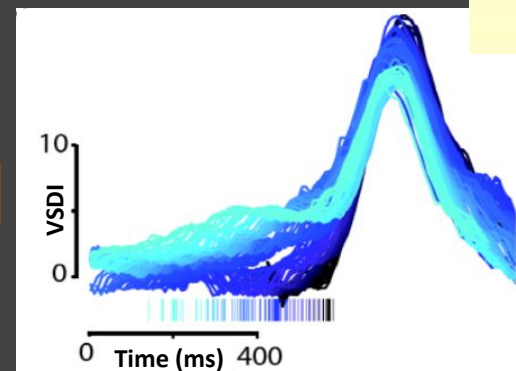
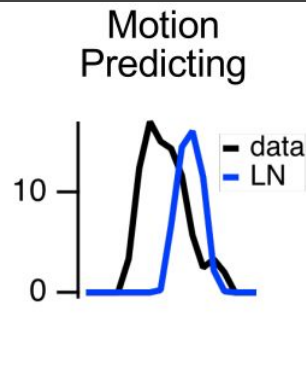
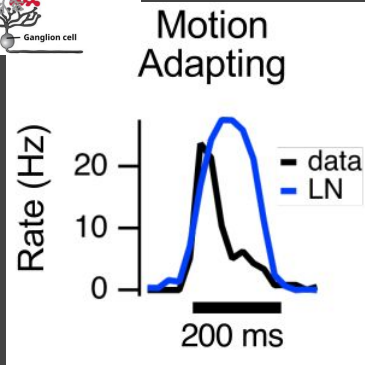
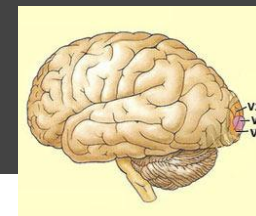
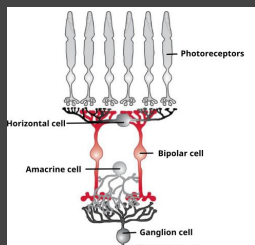
Visual anticipation



How do retinal and cortical anticipation interact?

Introduction

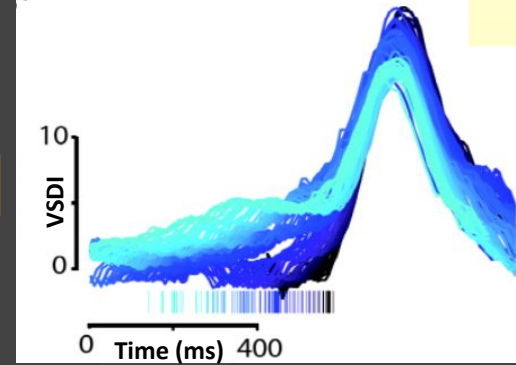
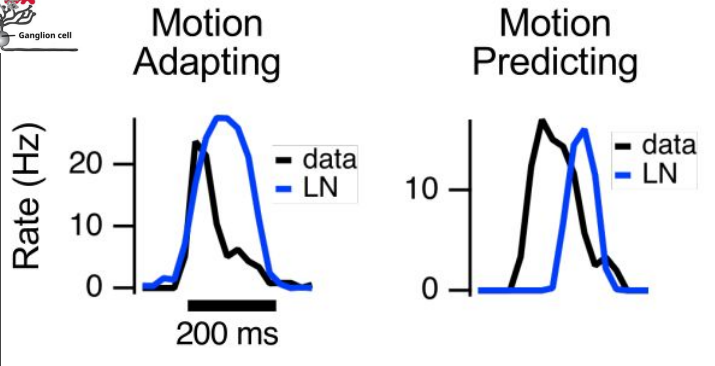
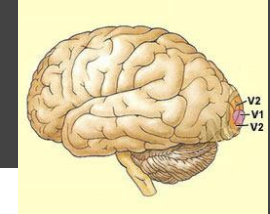
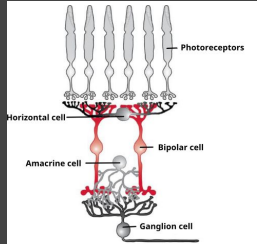
Visual anticipation



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Introduction

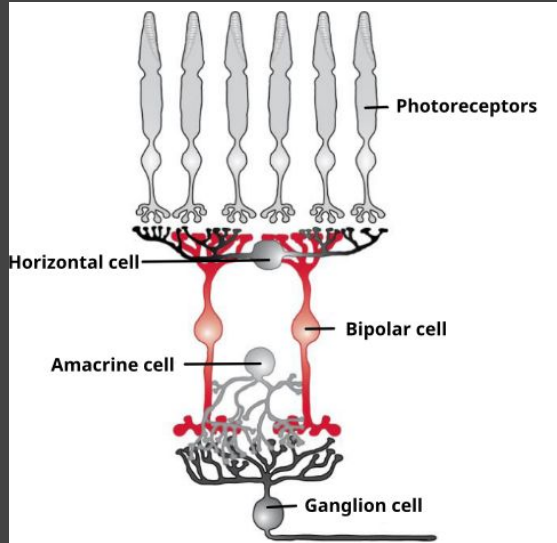
Visual anticipation



How do retinal and cortical anticipation interact?

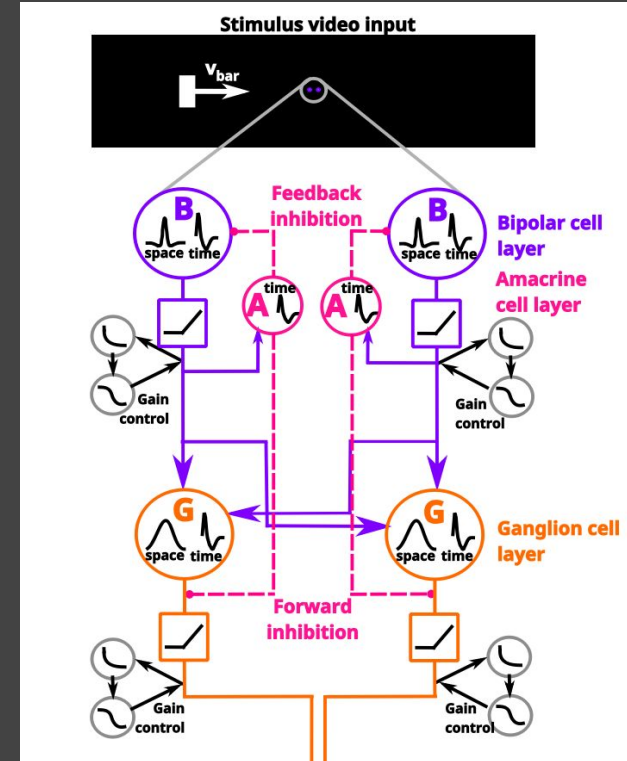
Modelling retina network

Biological retinal architecture



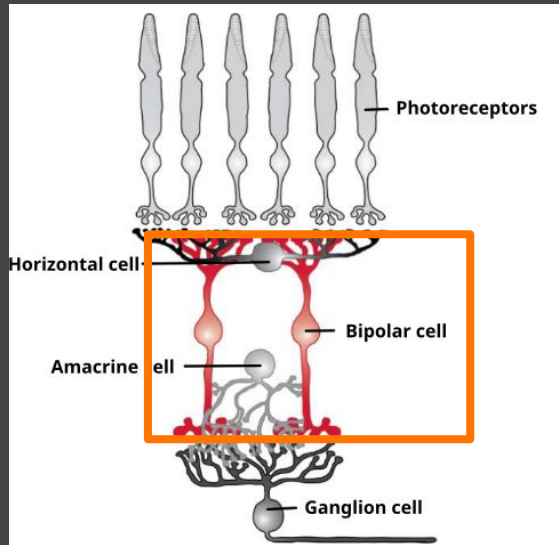
H.Shreyer, These (2018)

Retinal model architecture



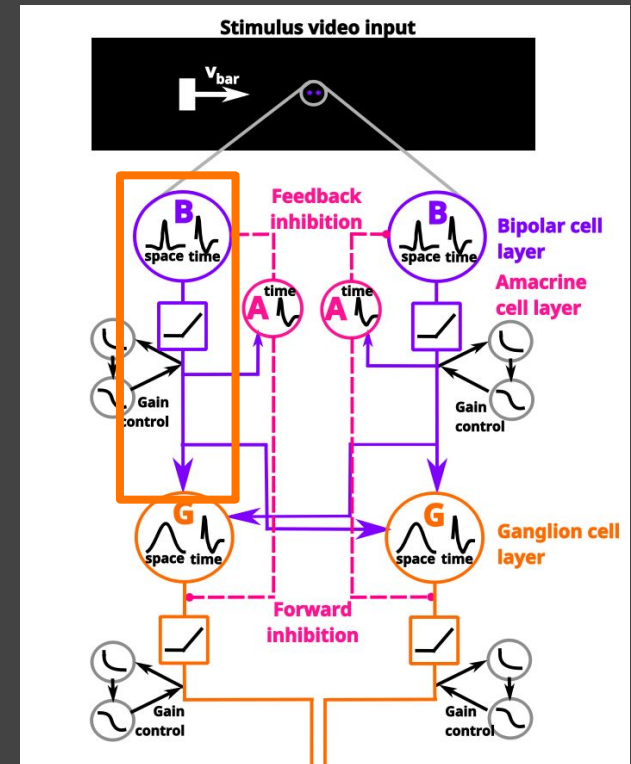
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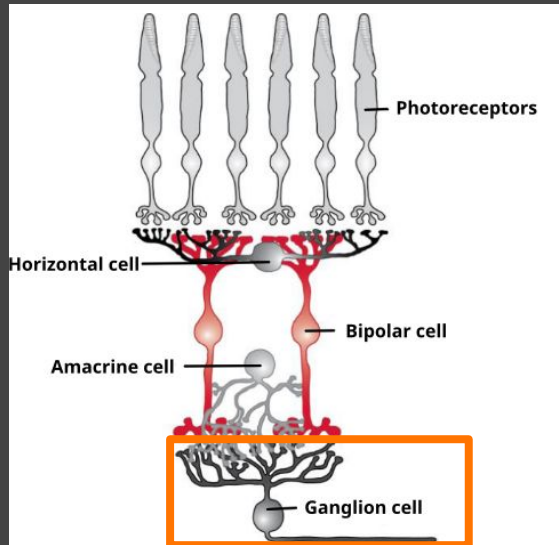
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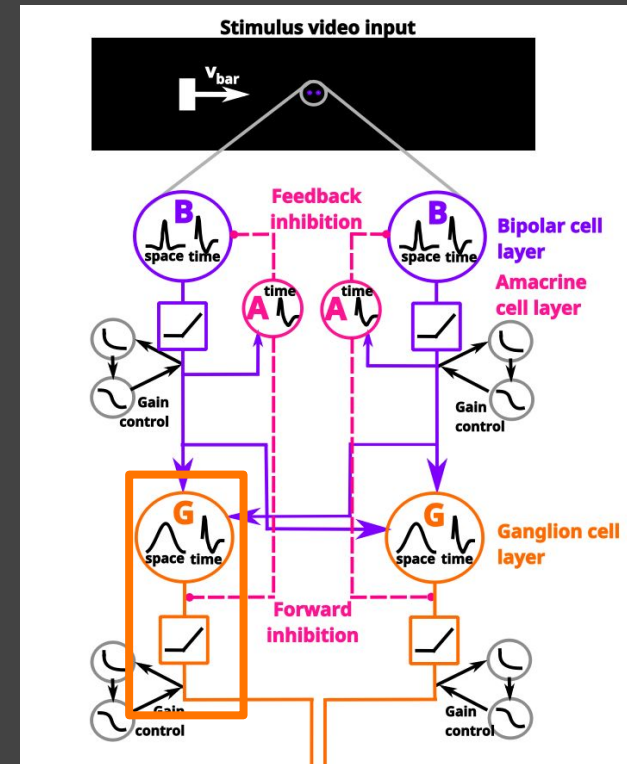
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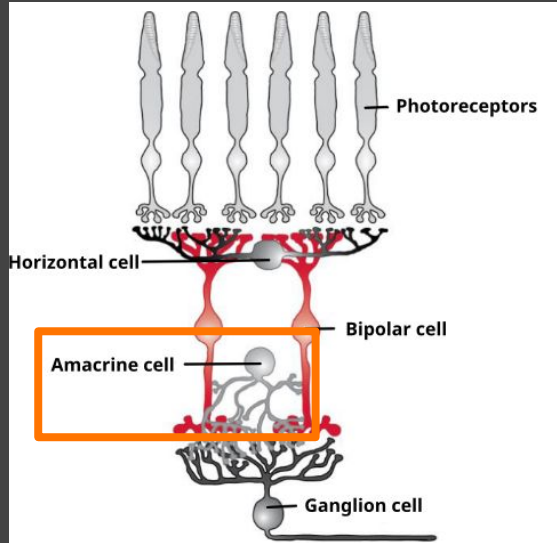
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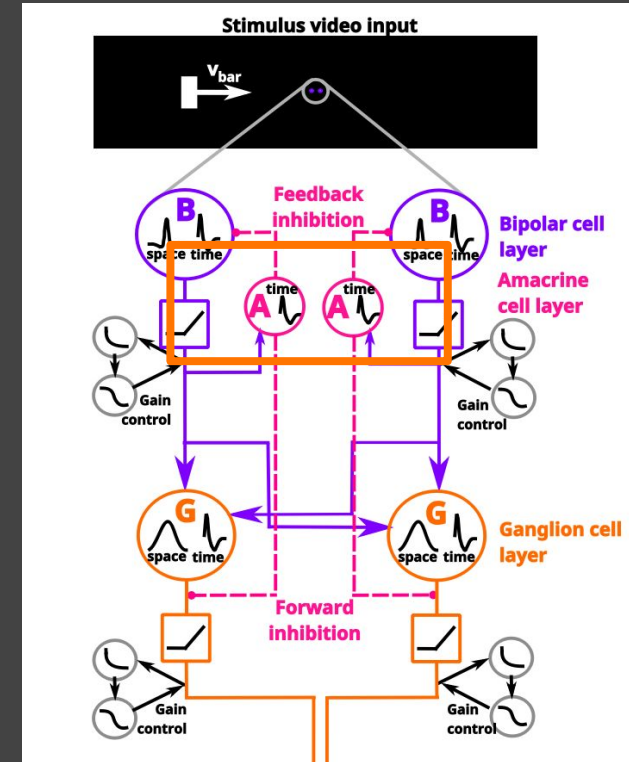
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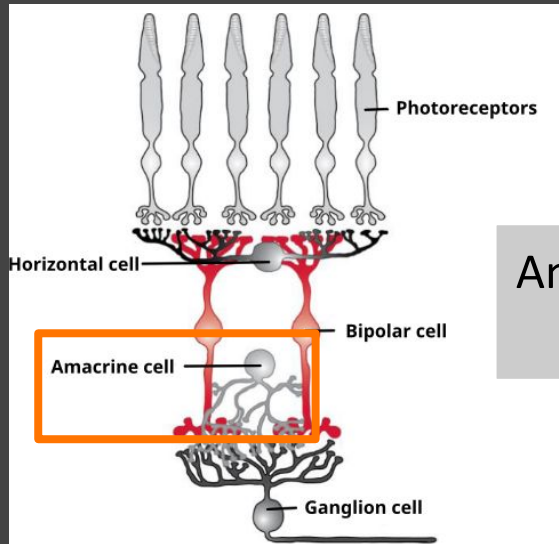
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Retinal model architecture



Modelling retina network

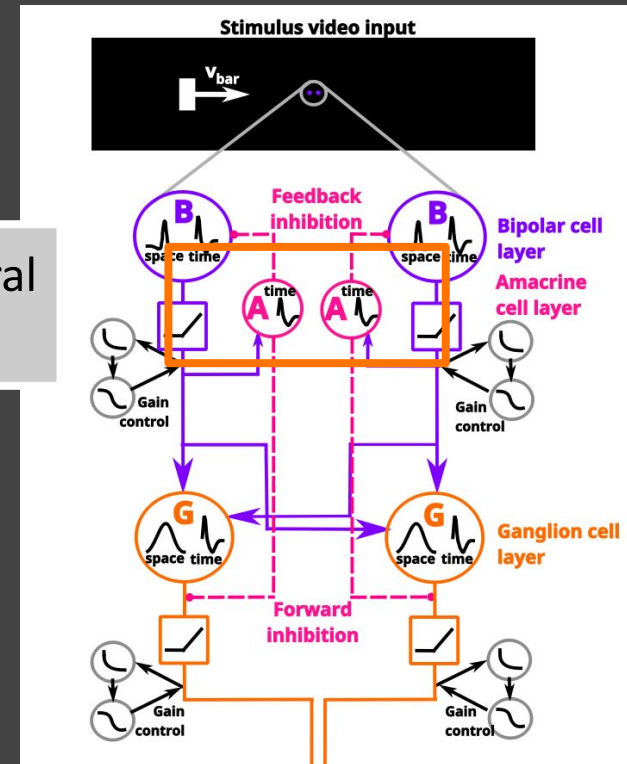
Biological retinal architecture



H.Shreyer, These (2018)

Amacrine lateral connectivity

Retinal model architecture



Modelling retina network

Bipolar equation

$$\frac{dV_{B_i}}{dt} = -\frac{1}{\tau_B} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}_A(V_{A_j}) + F_{B_i}(t),$$

Amacrine equation

$$\frac{dV_{A_j}}{dt} = -\frac{1}{\tau_A} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}_B(V_{B_i}),$$

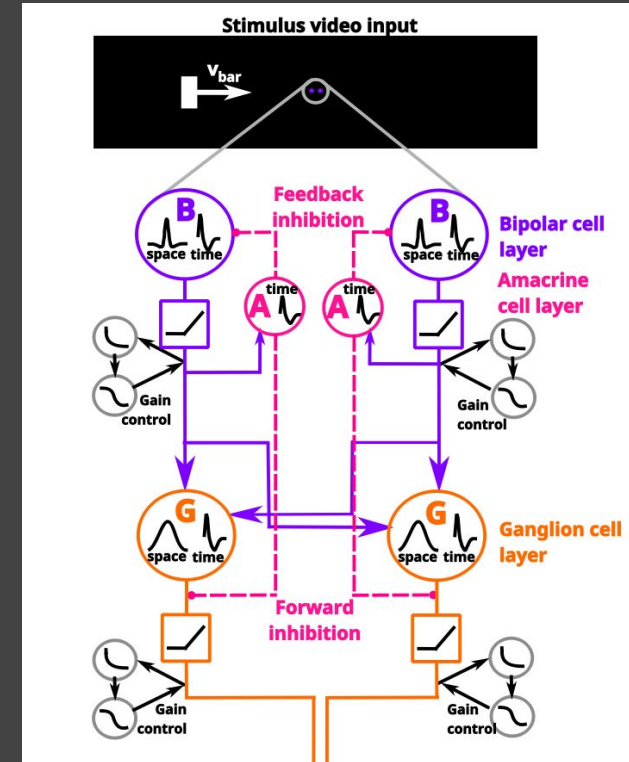
Ganglion cell equation

$$\frac{dV_{G_k}}{dt} = -\frac{1}{\tau_G} V_{G_k} + \sum_{i=1}^{N_B} W_{G_k}^{B_i} \mathcal{N}_B(V_{B_i})$$

$$R_{G_k} = N_G(V_{G_k}) G_G(A_{B_i})$$

S.Souihel, B.Cessac
Journal of Mathematical Neuroscience, (2020)

Retinal model architecture



Modelling retina network

Bipolar equation

$$\frac{dV_{B_i}}{dt} = -\frac{1}{\tau_B} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}_A(V_{A_j}) + F_{B_i}(t),$$

Amacrine equation

$$\frac{dV_{A_j}}{dt} = -\frac{1}{\tau_A} V_{A_j} + \sum_{i=1}^{N_B} W_{A_j}^{B_i} \mathcal{N}_B(V_{B_i}),$$

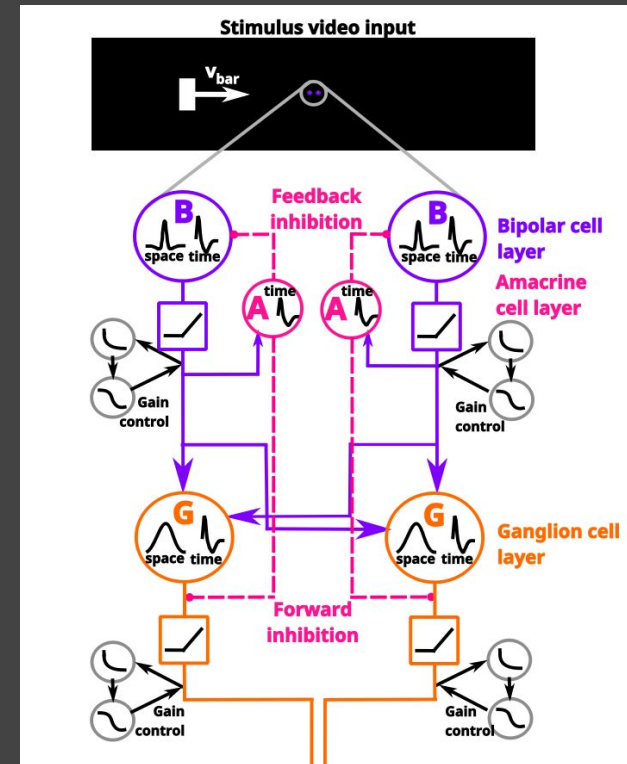
Ganglion cell equation

$$\frac{dV_{G_k}}{dt} = -\frac{1}{\tau_G} V_{G_k} + \sum_{i=1}^{N_B} W_{G_k}^{B_i} \mathcal{N}_B(V_{B_i})$$

$$R_{G_k} = N_G(V_{G_k}) G_G(A_{B_i})$$

S.Souihel, B.Cessac
Journal of Mathematical Neuroscience, (2020)

Retinal model architecture



Modelling retina network

Bipolar equation

$$\frac{dV_{B_i}}{dt} = -\frac{1}{\tau_B} V_{B_i} + \sum_{j=1}^{N_A} W_{B_i}^{A_j} \mathcal{N}_A(V_{A_j}) + F_{B_i}(t),$$

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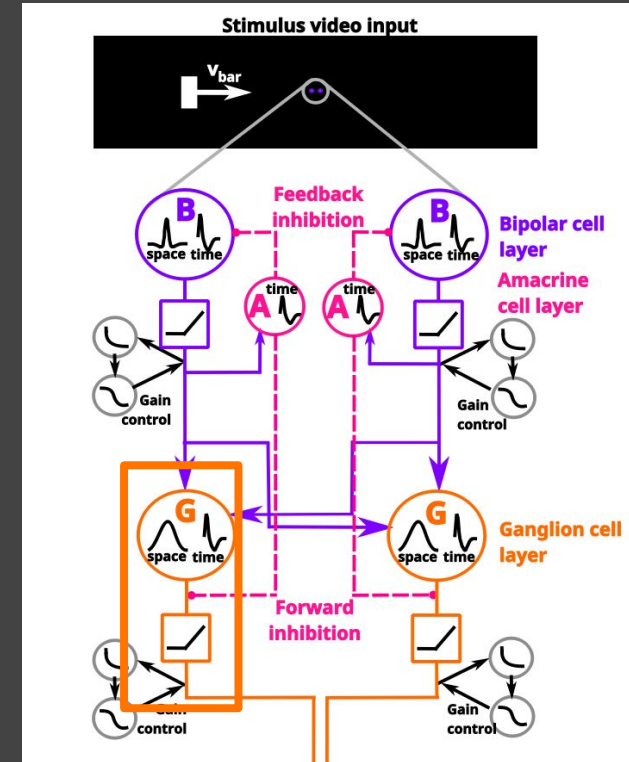
Ganglion cell equation

$$\frac{dV_{G_k}}{dt} = -\frac{1}{\tau_G} V_{G_k} + \sum_{i=1}^{N_B} W_{G_k}^{B_i} \mathcal{N}_B(V_{B_i})$$

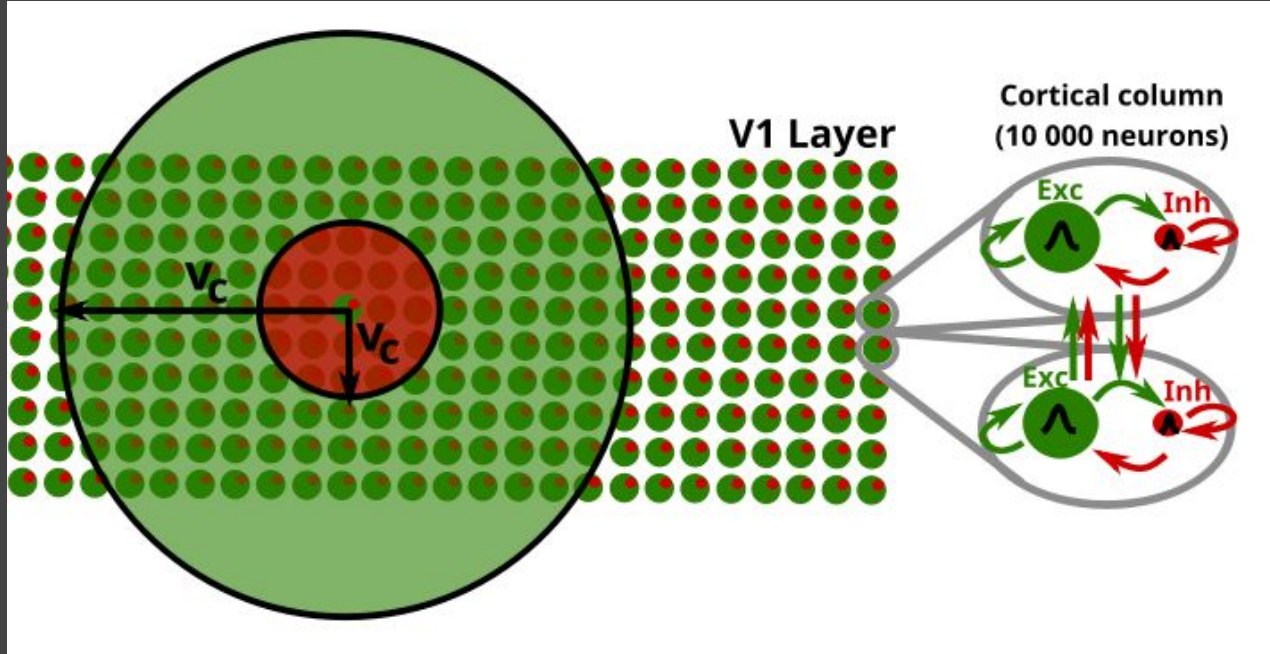
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S.Souihel, B.Cessac
Journal of Mathematical Neuroscience, (2020)

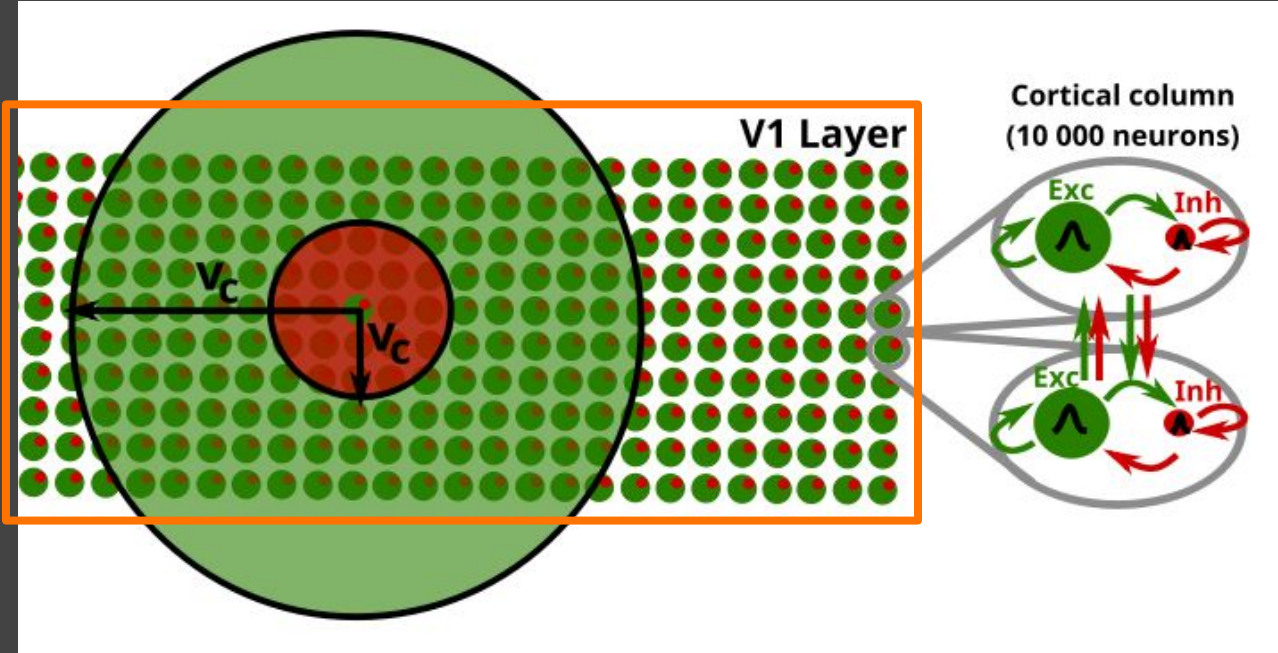
Retinal model architecture



Modelling primary cortex network

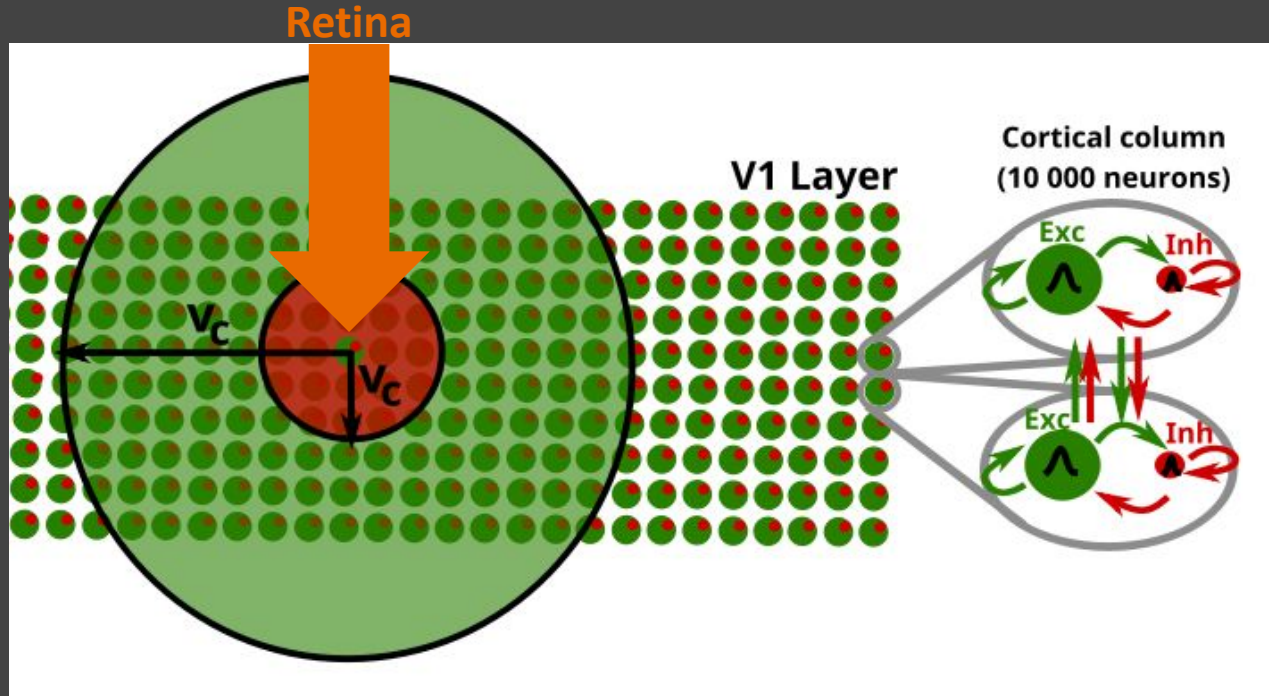


Modelling primary cortex network



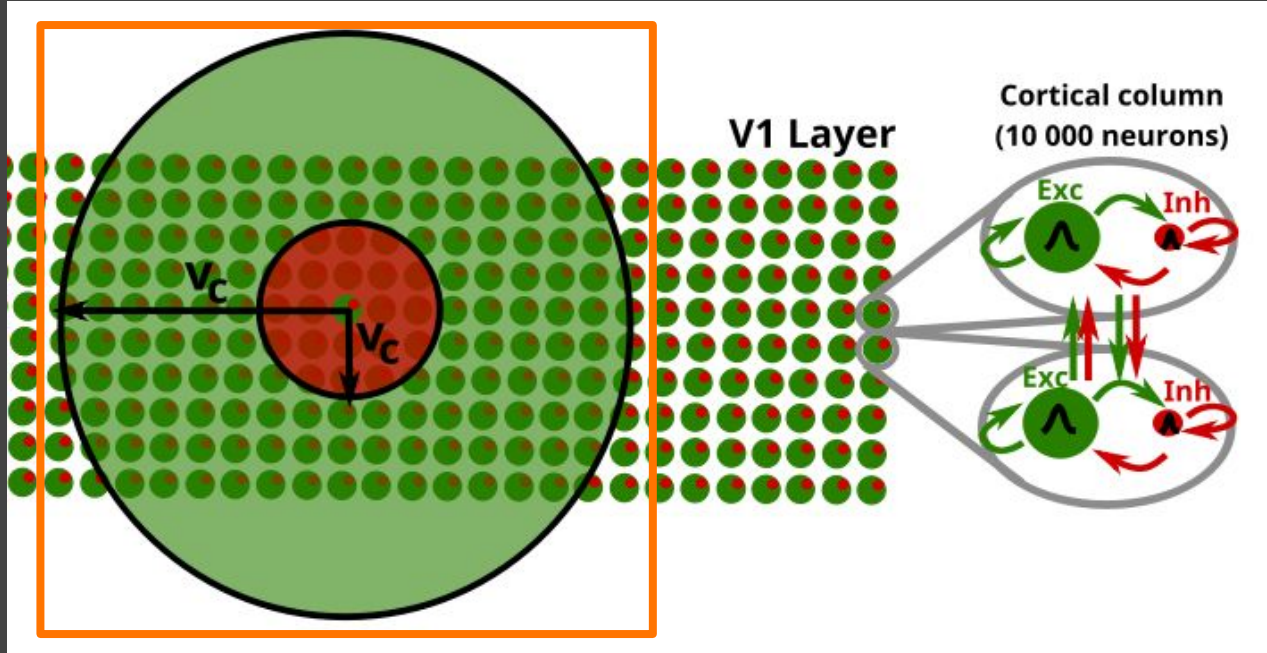
- Inspired from cortical column organisation.

Modelling primary cortex network



- Inspired from cortical column organisation.
- Fed by our retinal input

Modelling primary cortex network



- Inspired from cortical column organisation.
- Fed by our retinal input
- Lateral excitatory / inhibitory connectivity

Modelling primary cortex network

Spatio-temporal mean field equation + stationary input

$$\nu_e^{input}(x, t) = \nu_e^{drive} + \int_{\mathbb{R}} dy \mathcal{N}_e(x - y) \nu_e(y, t - \|y - x\|/v_c)$$

$$\nu_i^{input}(x, t) = \int_{\mathbb{R}} dy \mathcal{N}_i(x - y) \nu_i(y, t - \|y - x\|/v_c)$$

$$T \frac{\partial \nu_e(x, t)}{\partial t} = -\nu_e(x, t) + \mathcal{F}_e(\nu_e^{aff}(x, t) + \nu_e^{input}(x, t), \nu_i^{input}(x, t))$$

$$T \frac{\partial \nu_i(x, t)}{\partial t} = -\nu_i(x, t) + \mathcal{F}_i(\nu_e^{input}(x, t), \nu_i^{input}(x, t))$$

$$\mu_V(\nu_e, \nu_i) = \frac{\mu_{Ge} E_e + \mu_{Gi} E_i + g_L E_L}{\mu_G}$$

$$VSDI = \frac{\mu_V - \mu_{V0}}{\mu_{V0}}$$

Modelling primary cortex network

Spatio-temporal mean field equation + stationary input

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Modelling primary cortex network

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Modelling primary cortex network

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Modelling primary cortex network

Spatio-temporal mean field equation + stationary input

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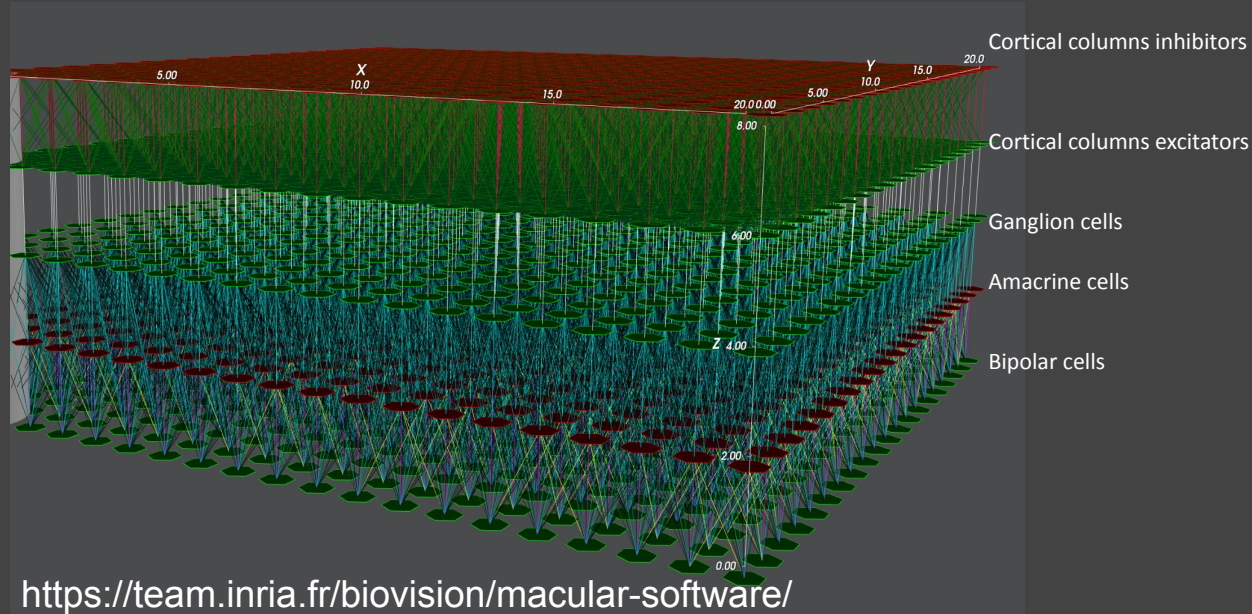
$$T \frac{\partial \nu_e(x, t)}{\partial t} = -\nu_e(x, t) + \mathcal{F}_e(\nu_e^{aff}(x, t) + \nu_e^{input}(x, t), \nu_i^{input}(x, t))$$

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Macular software



Implementation of the retino-cortical model in a network simulation software called Macular

Results

Results

Reproduction of the biological cortical latency experiment

Results

Reproduction of the biological cortical latency experiment

Effect of **adapting anticipation** on the cortical anticipation.

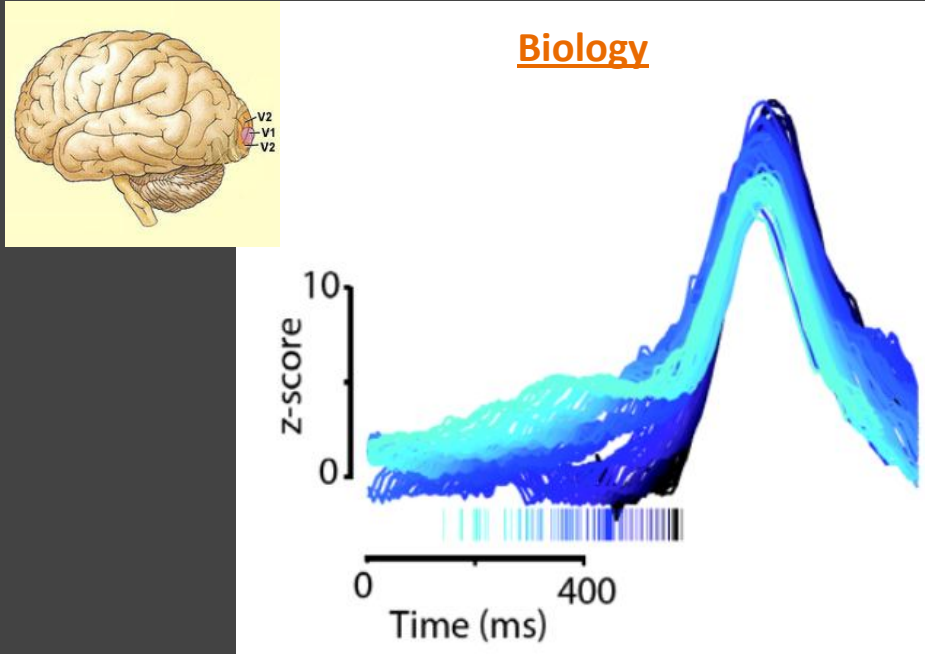
Results

Reproduction of the biological cortical latency experiment

Effect of **adapting anticipation** on the cortical anticipation.

Effect of **predicting anticipation** on the cortical anticipation.

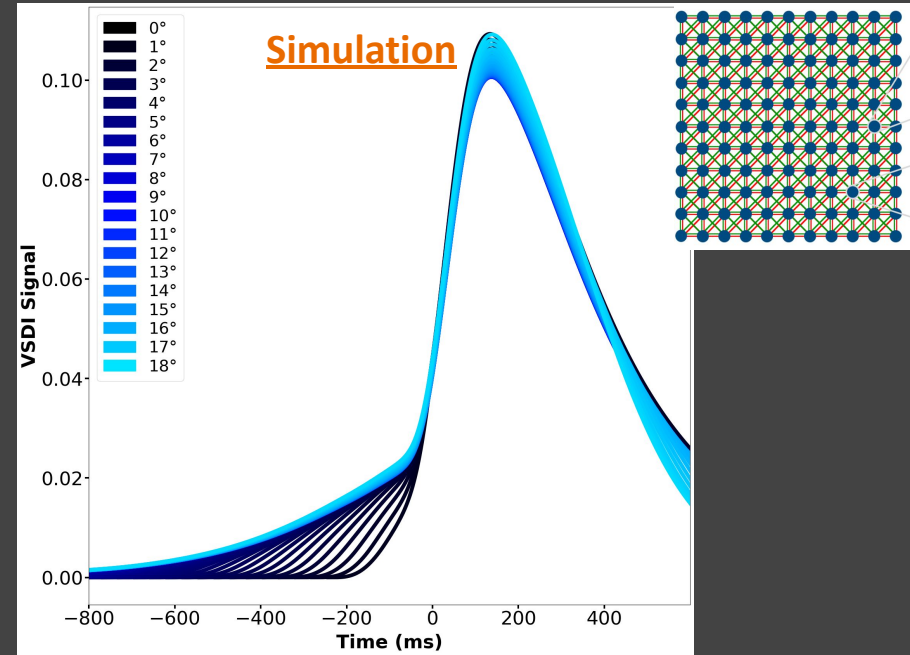
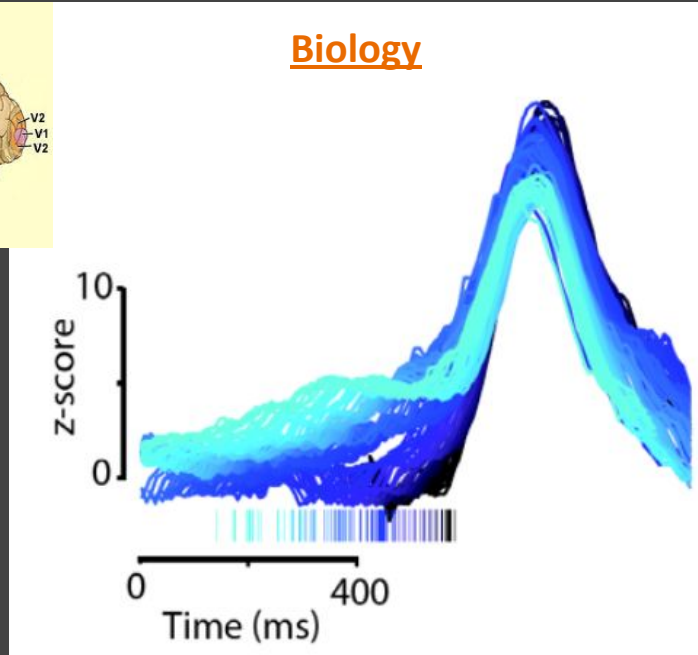
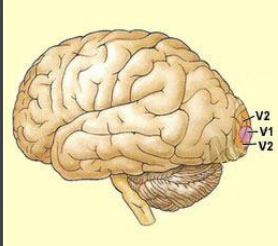
Can our retino-cortical model reproduce experimental data?



G. Benvenuti et al.,
bioRxiv (2020)

Reproduction

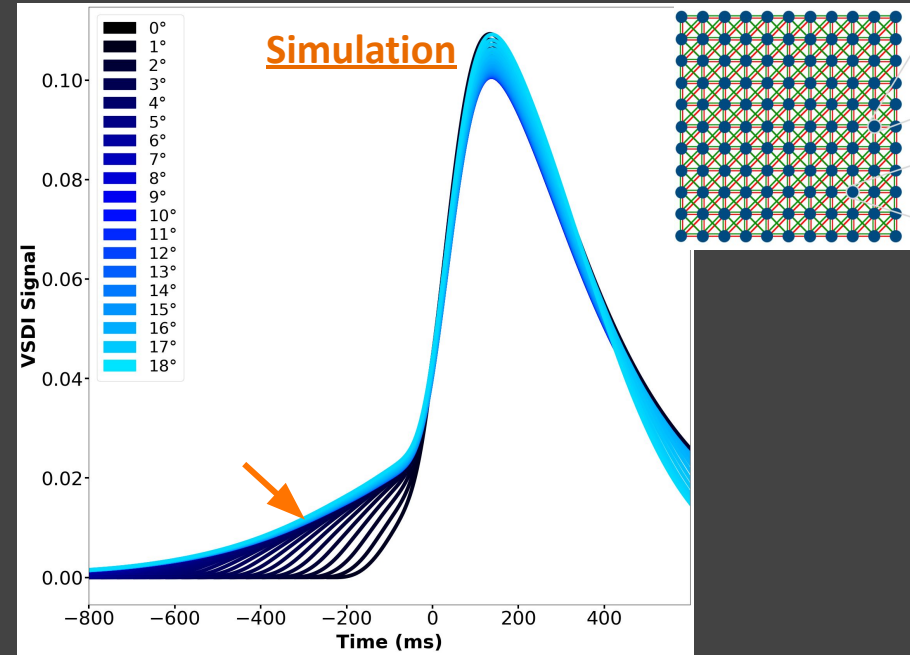
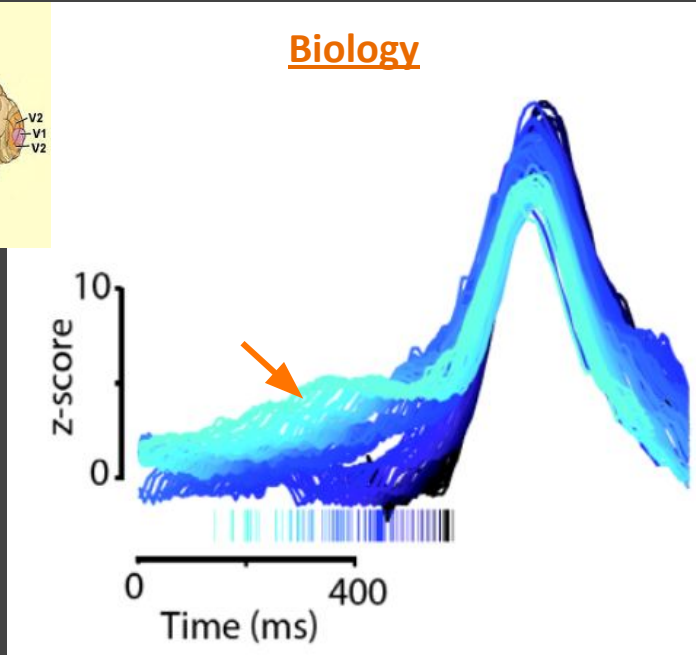
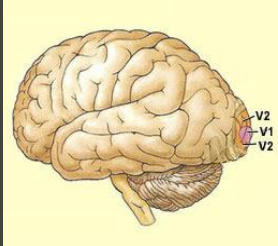
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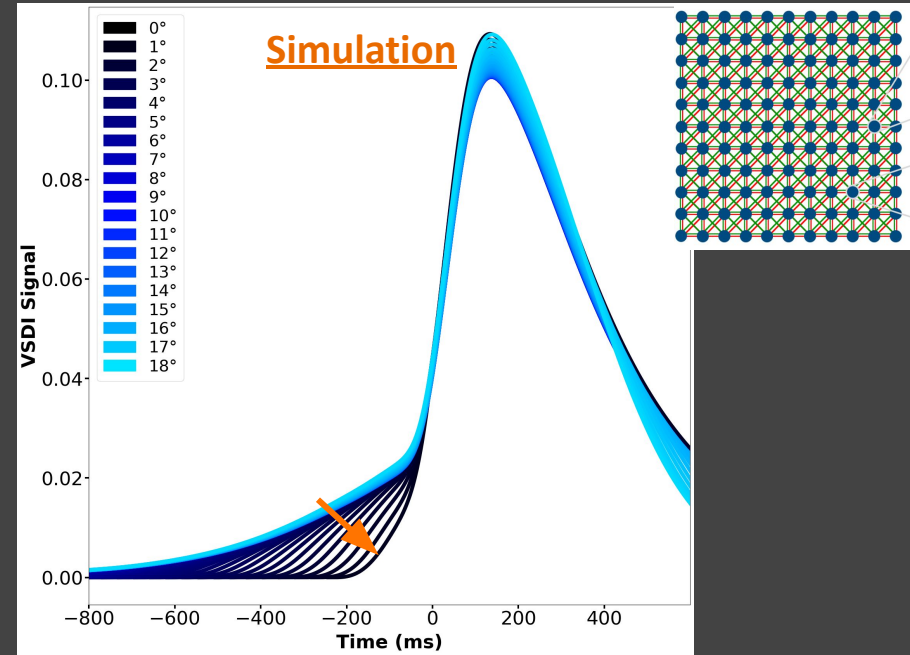
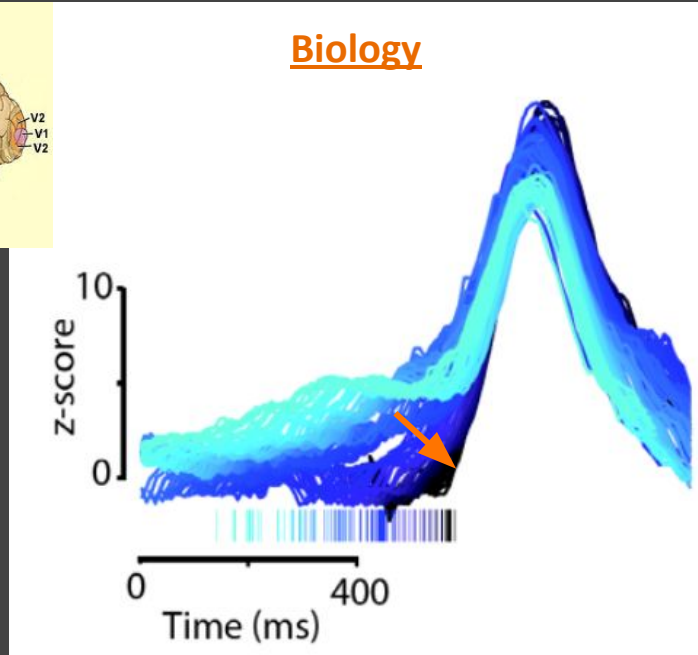
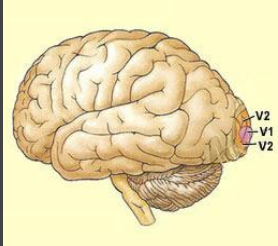
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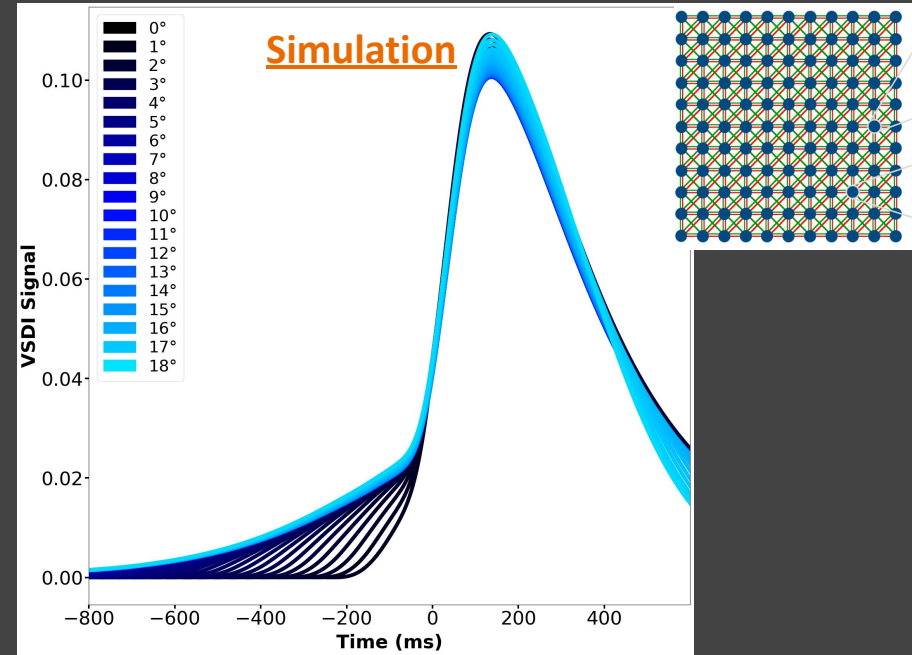
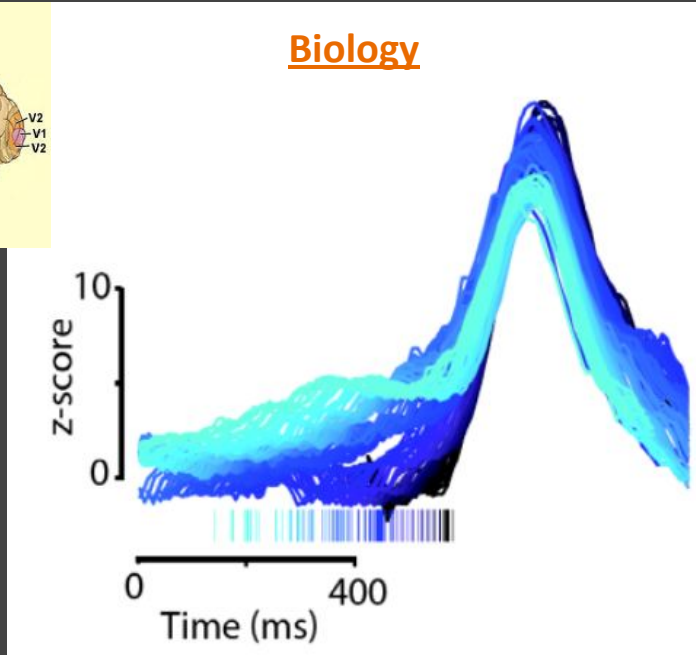
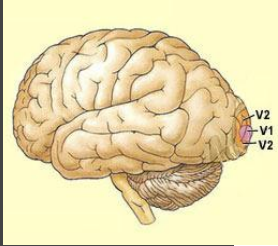
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Reproduction

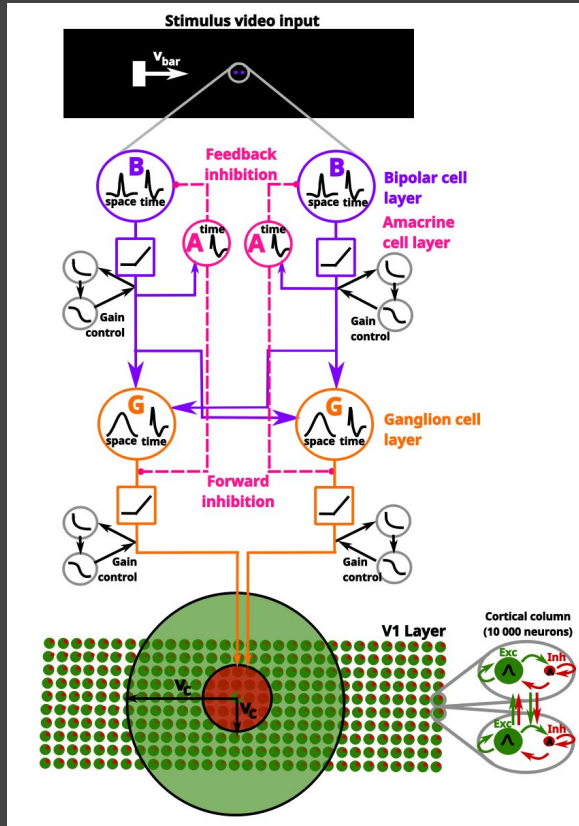
Can our retino-cortical model reproduce experimental data?



Our retino-cortical model reproduces biological cortical latency experiment

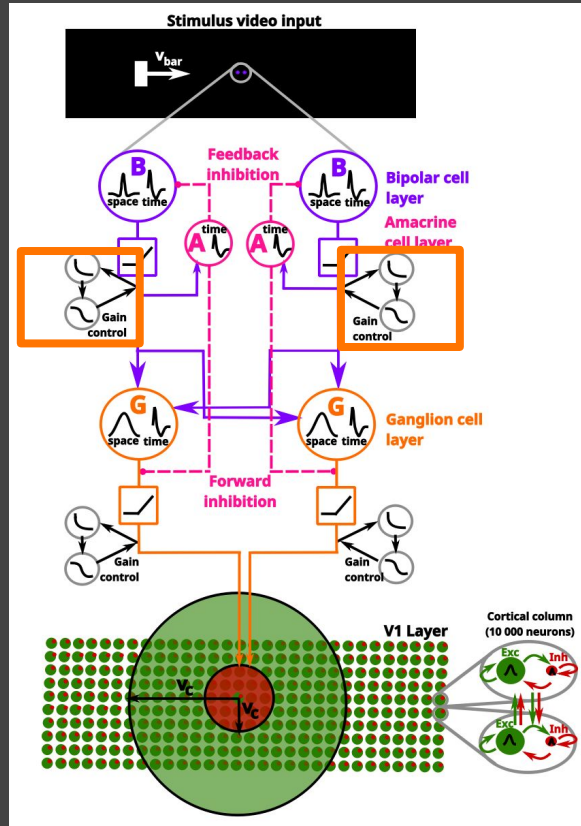
Adapting anticipation

How to model bipolar adapting anticipation?



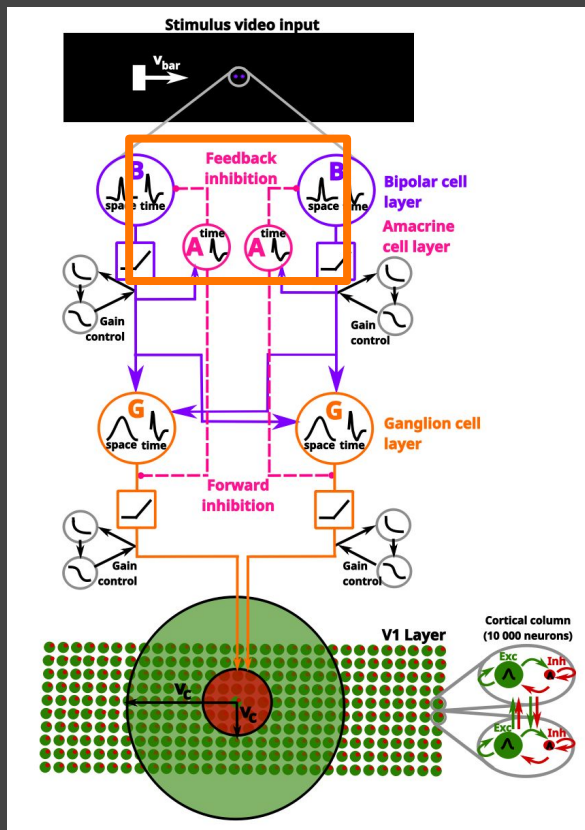
Adapting anticipation

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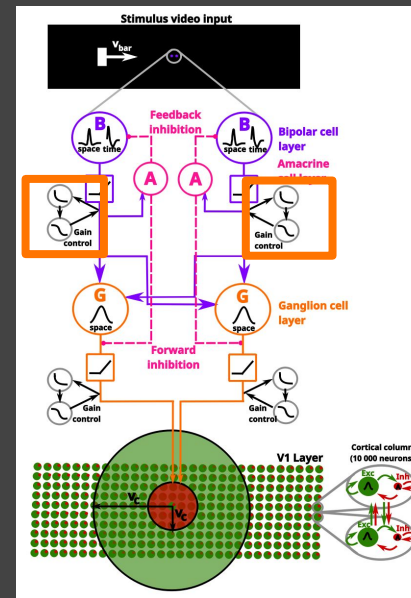
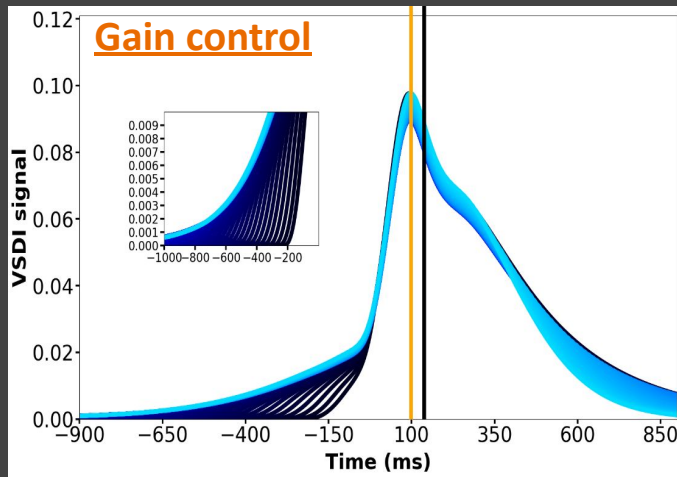
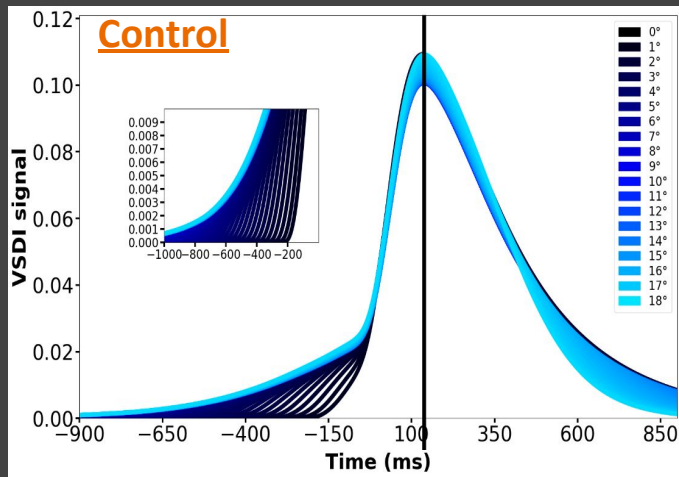
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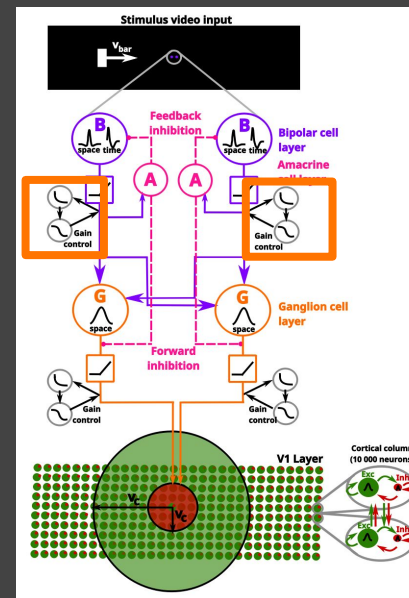
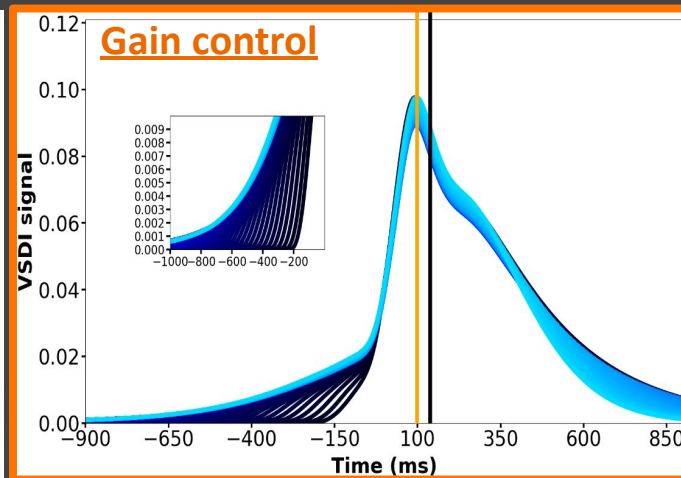
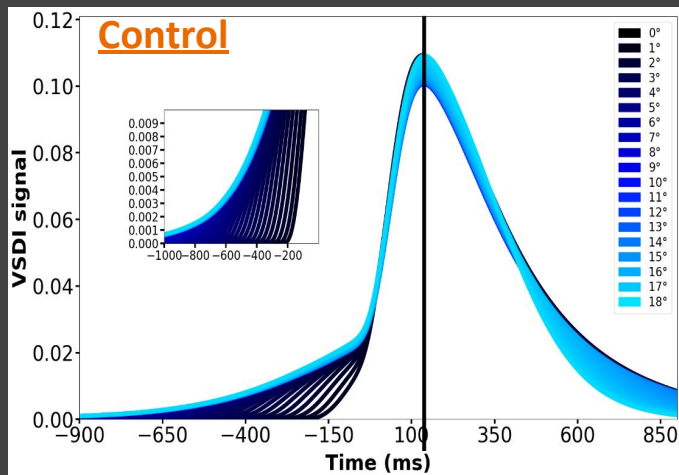
Adapting anticipation

Does bipolar gain control influence cortical anticipation?



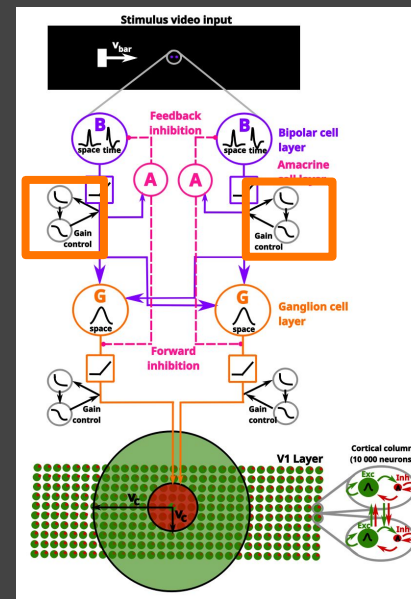
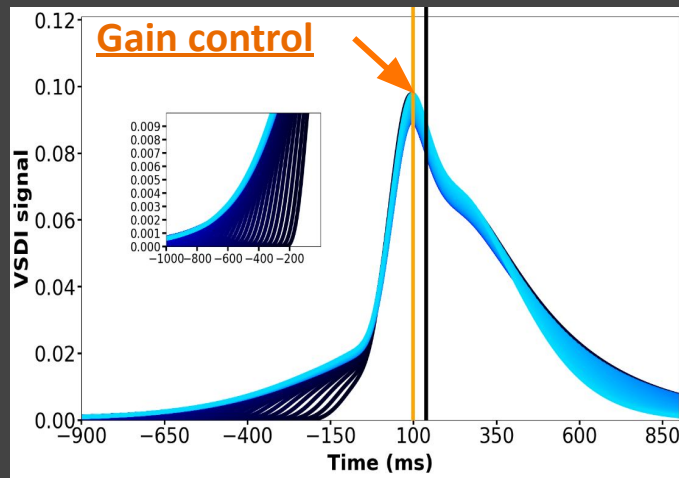
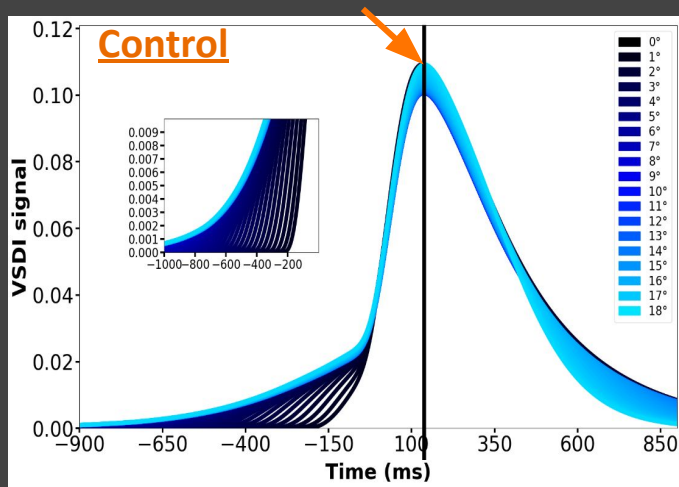
Adapting anticipation

Does bipolar gain control influence cortical anticipation?



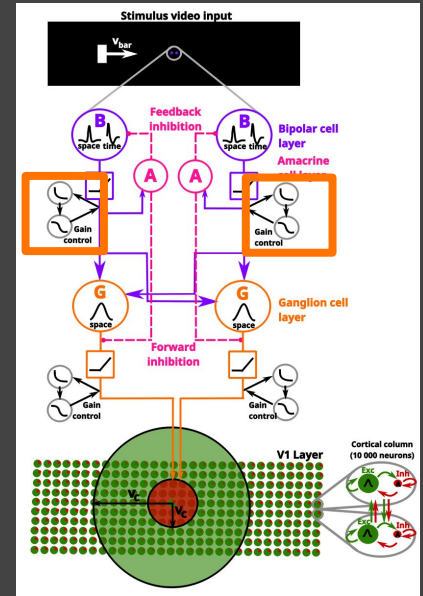
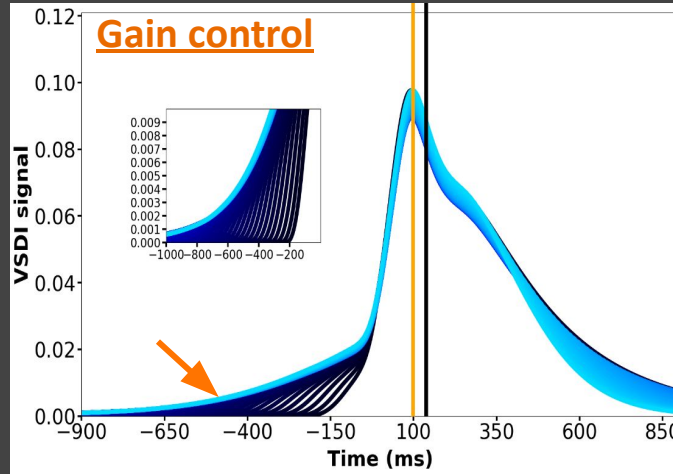
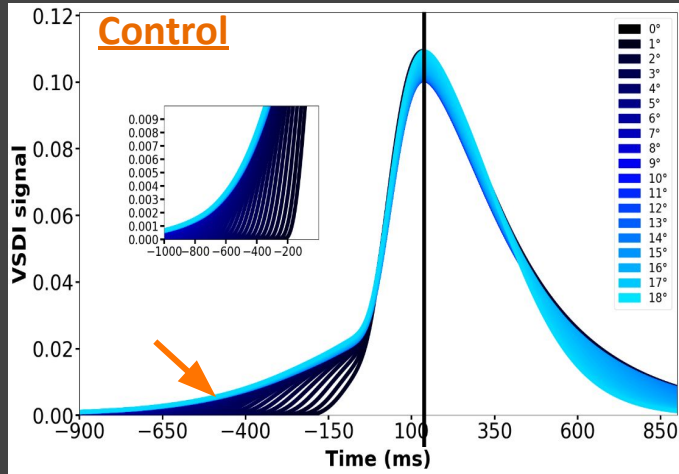
Adapting anticipation

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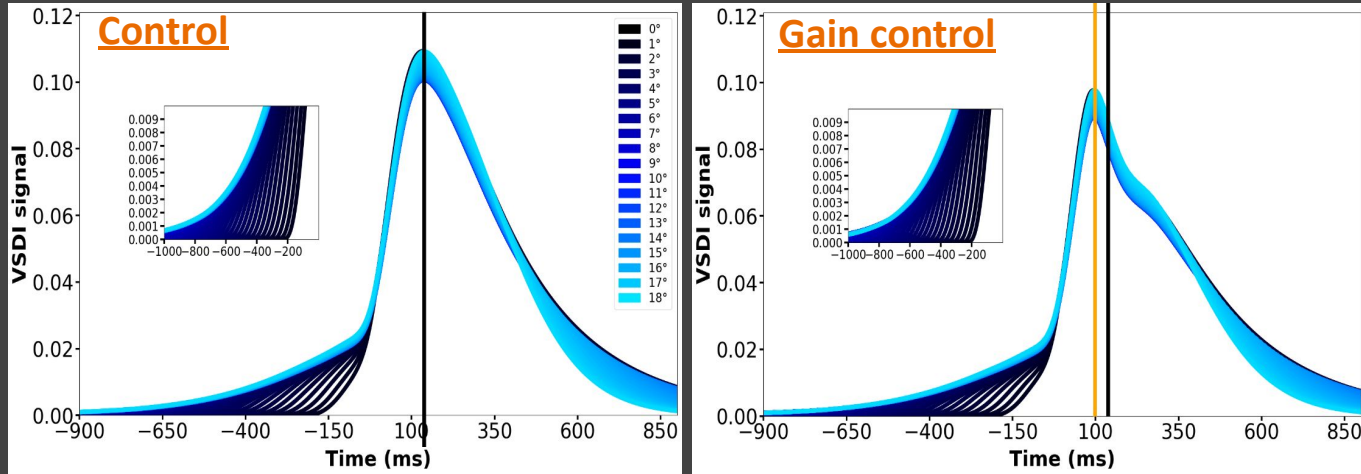
Adapting anticipation

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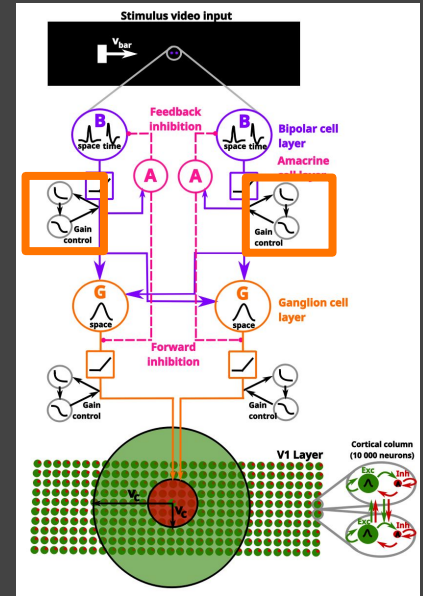


Adapting anticipation

Does bipolar gain control influence cortical anticipation?

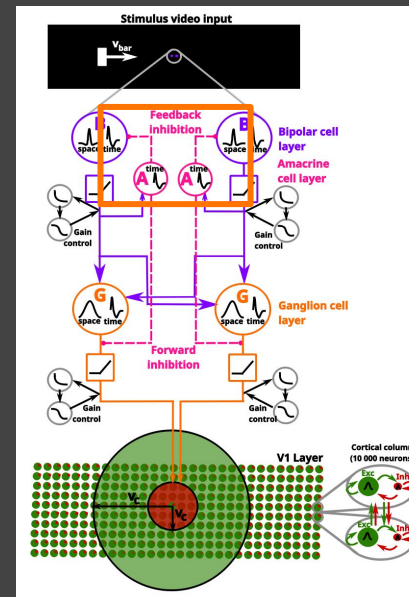
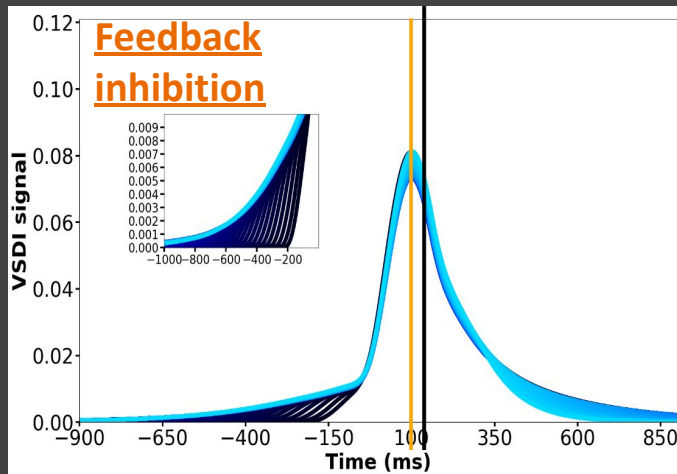
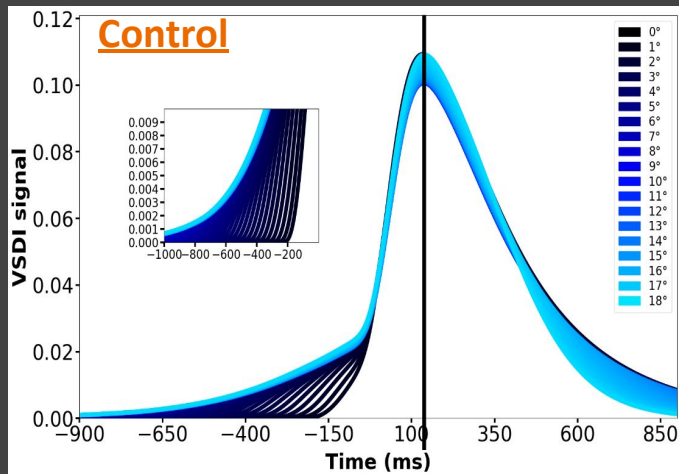


Bipolar gain control causes adapting anticipation in the cortex without affecting cortical anticipation.



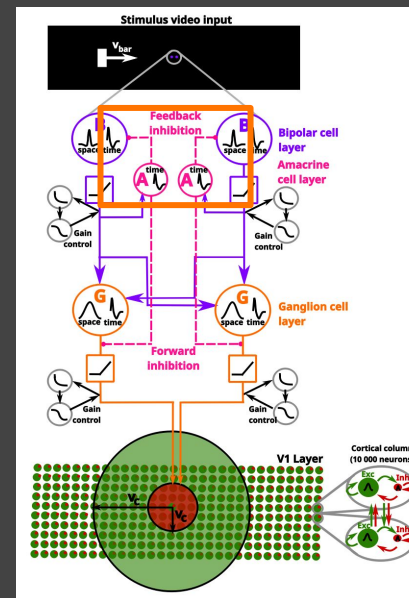
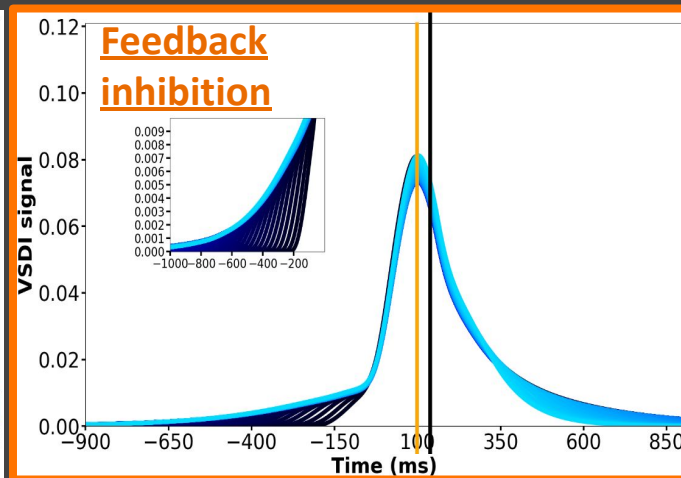
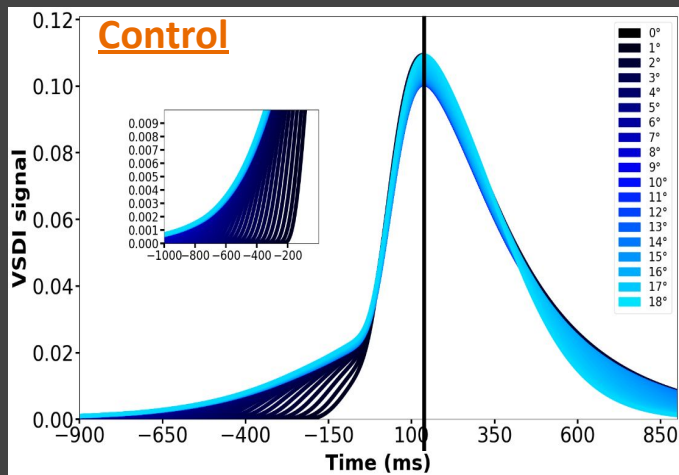
Adapting anticipation

Does feedback inhibition influence cortical anticipation?



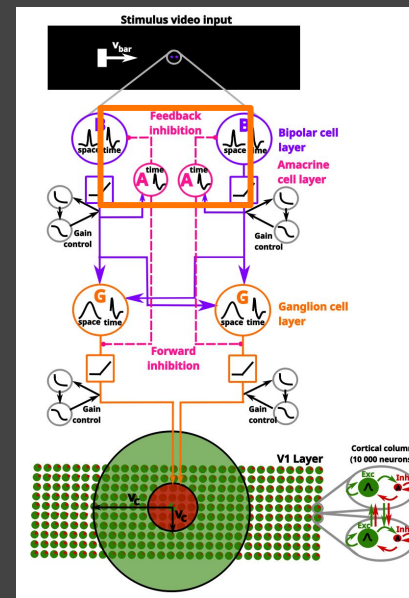
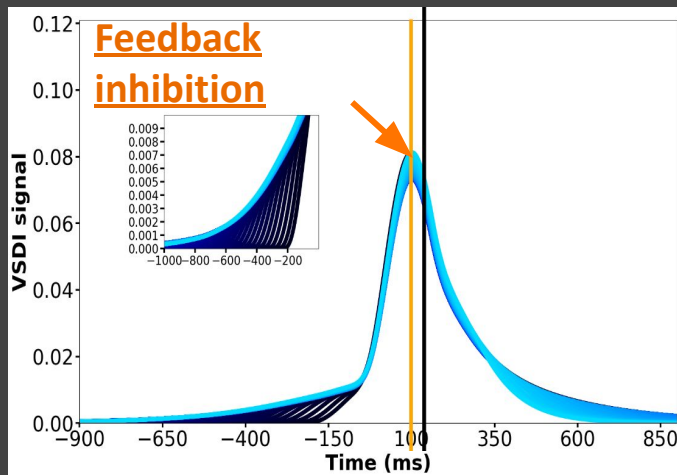
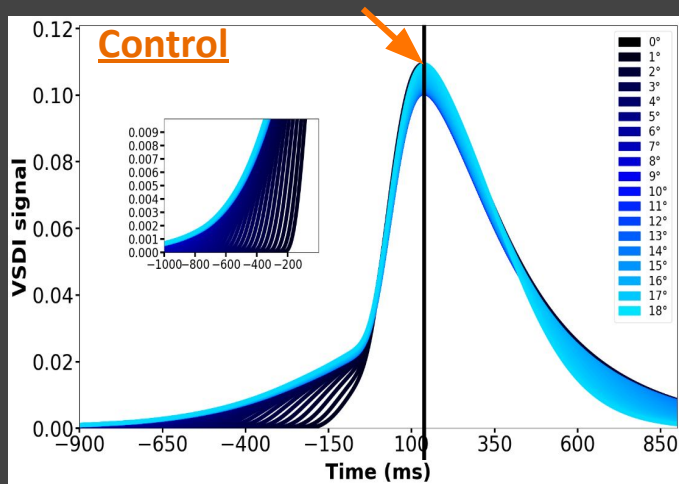
Adapting anticipation

Does feedback inhibition influence cortical anticipation?



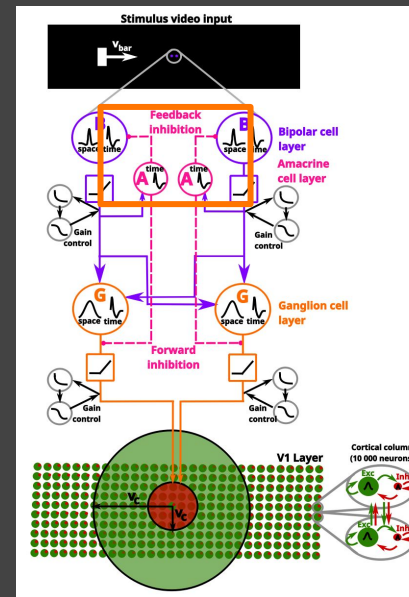
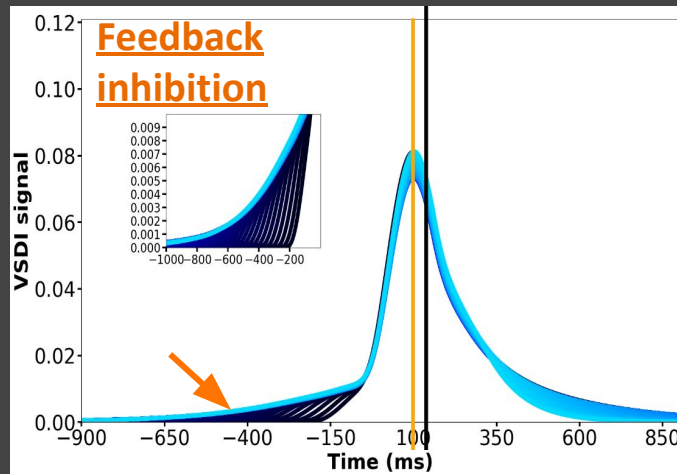
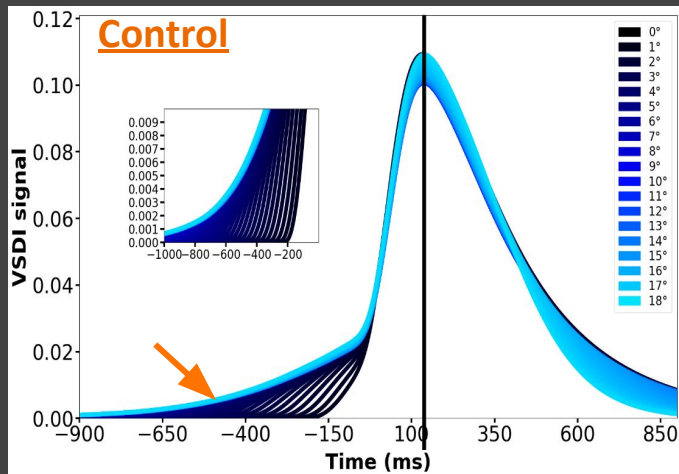
Adapting anticipation

Does feedback inhibition influence cortical anticipation?



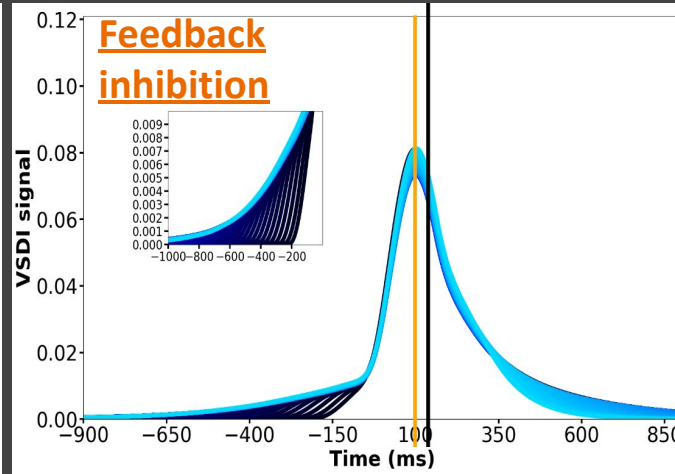
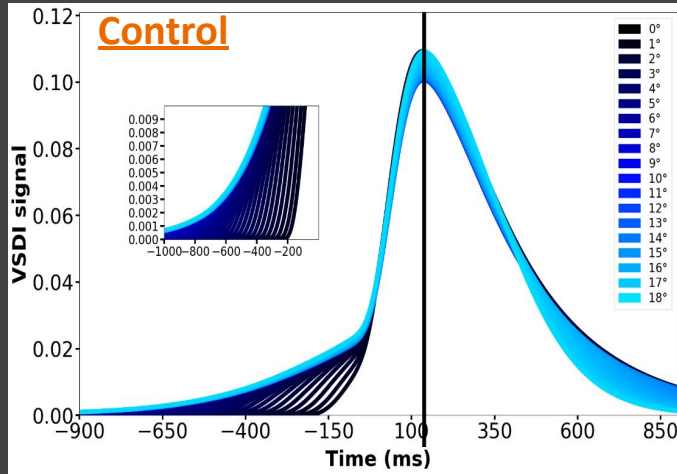
Adapting anticipation


Does feedback inhibition influence cortical anticipation?

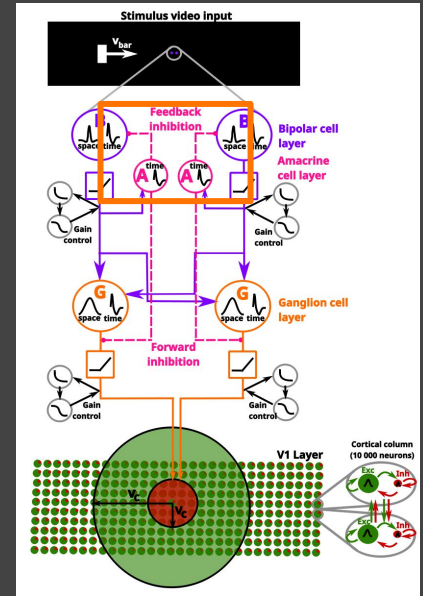


Adapting anticipation

Does feedback inhibition influence cortical anticipation?

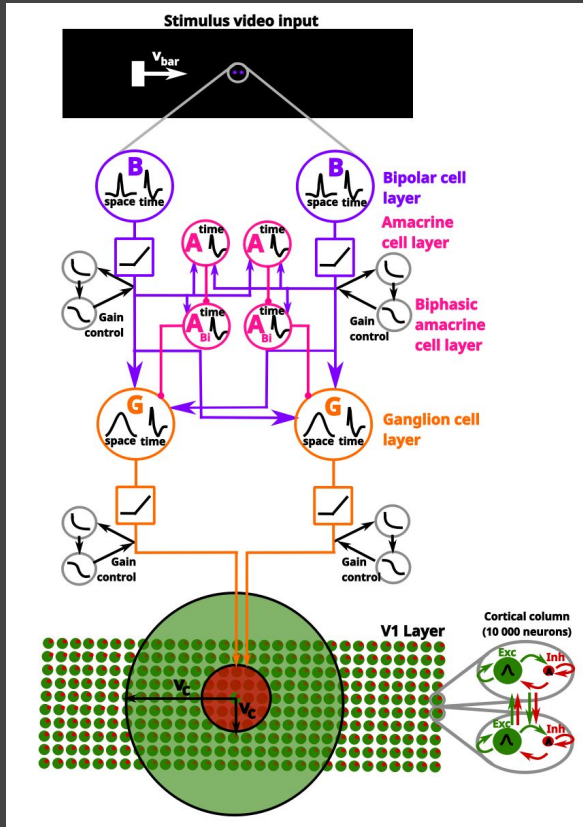


 Amacrine feedback inhibition generates adapting anticipation in the cortex but disturb cortical anticipation



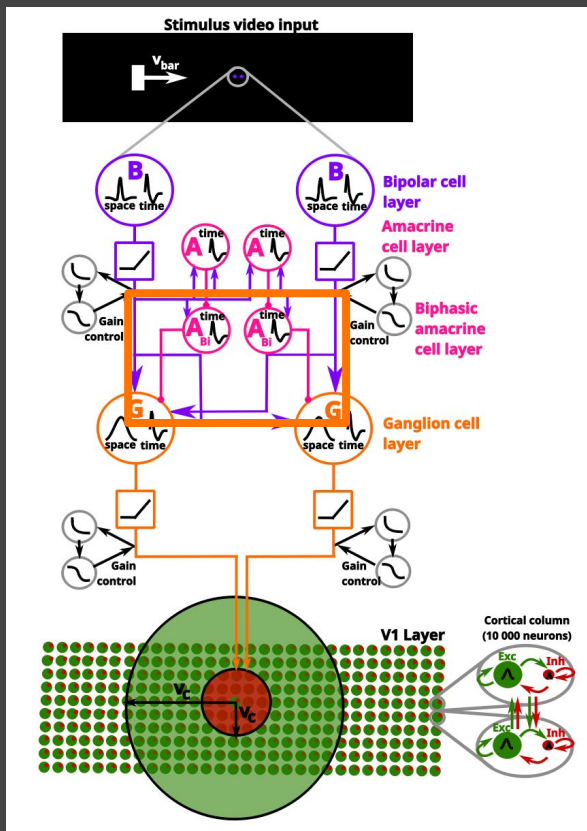
Predicting anticipation

How to model retinal predicting anticipation?

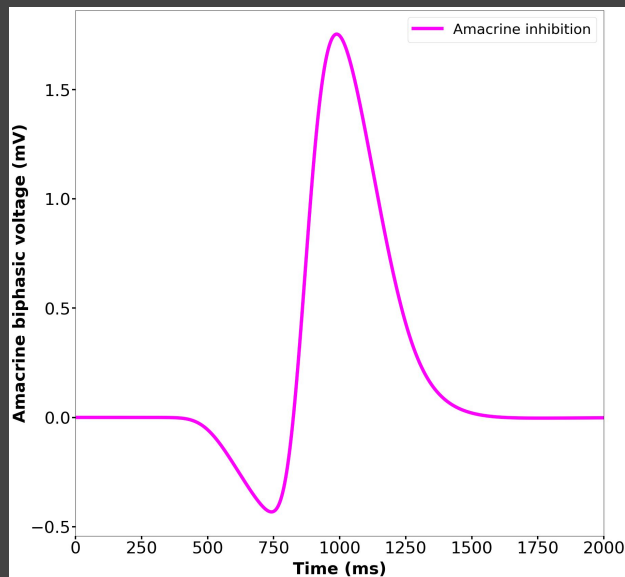


Predicting anticipation

How to model retinal predicting anticipation?

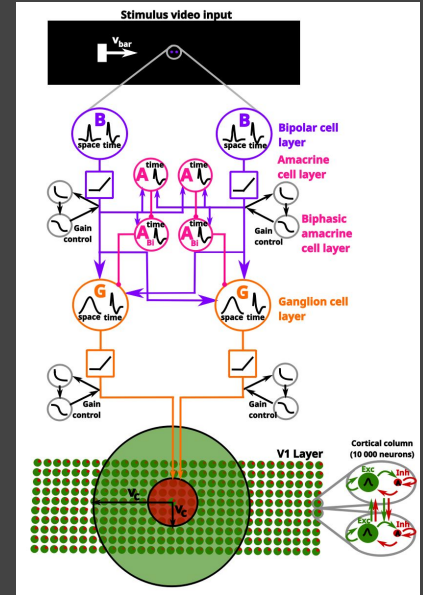
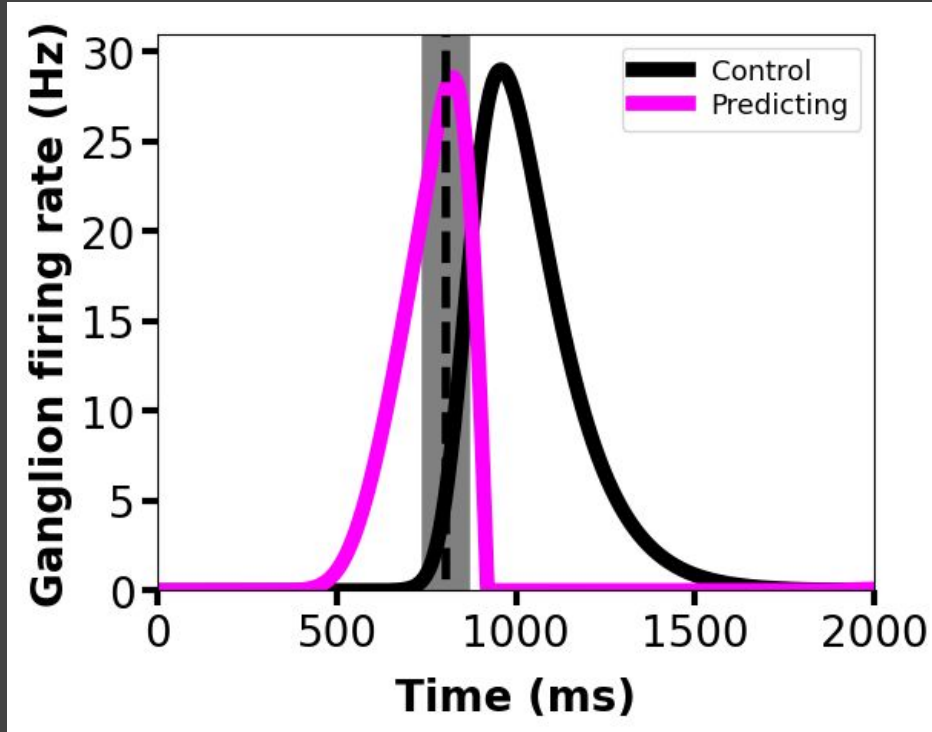


Amacrine bipolar voltage



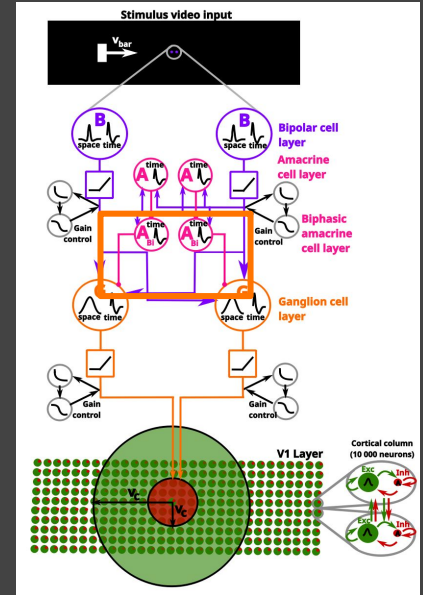
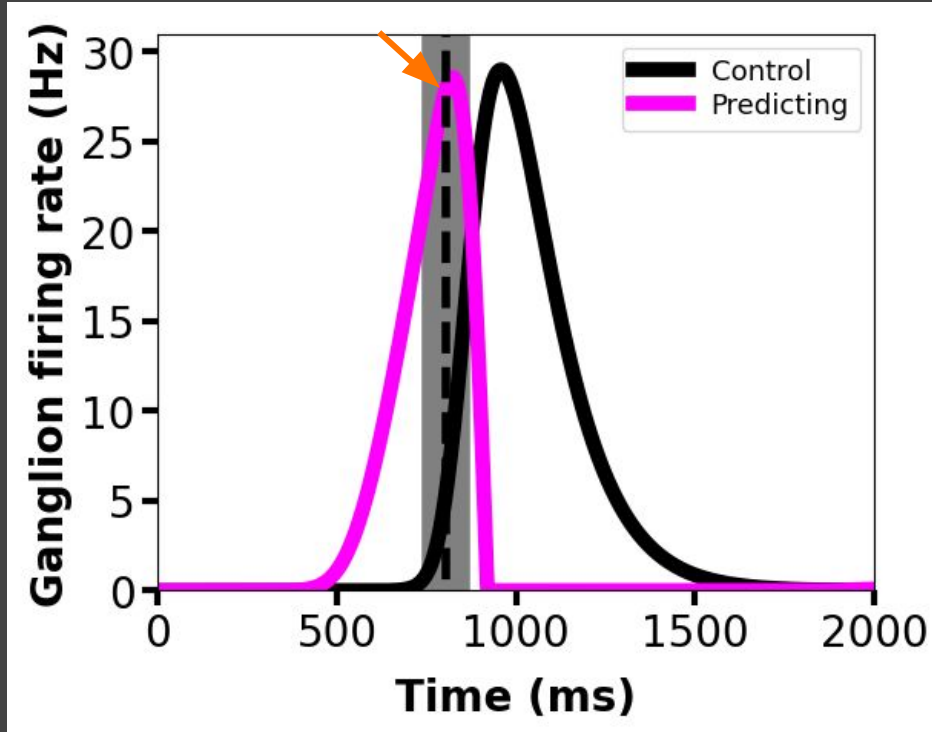
Predicting anticipation

Does amacrine biphasic connectivity create predicting anticipation?



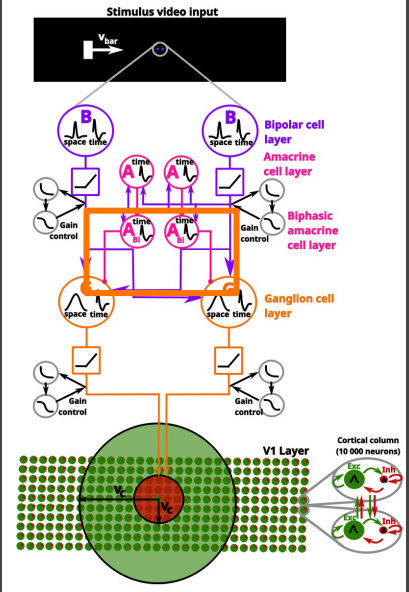
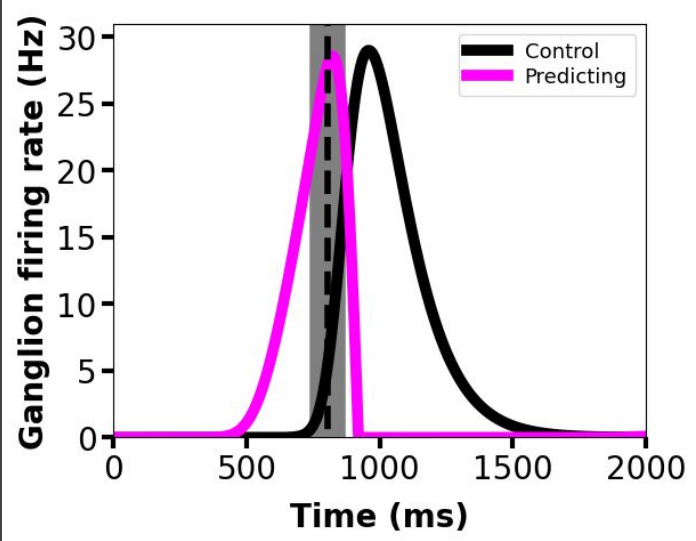
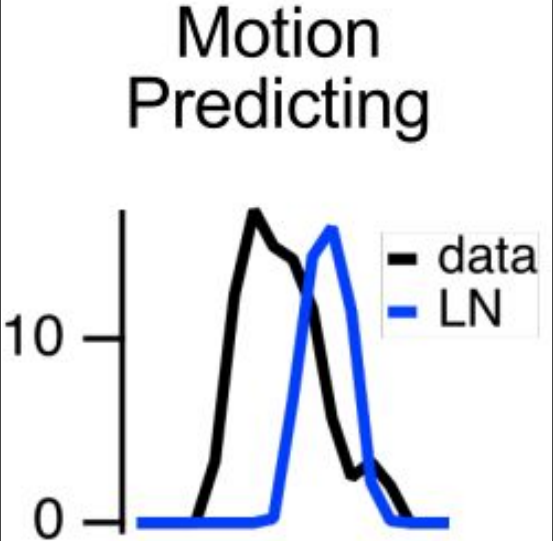
Predicting anticipation

Does amacrine biphasic connectivity create predicting anticipation?



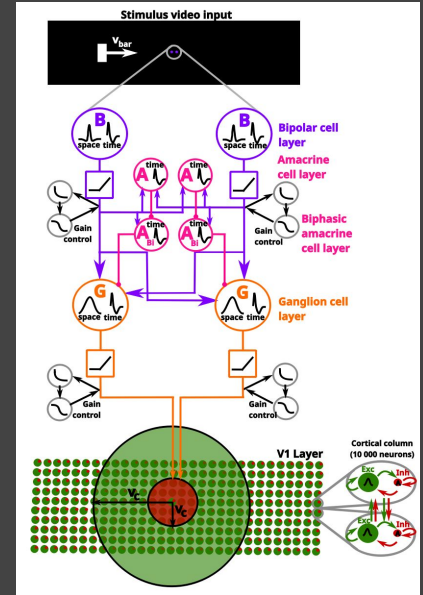
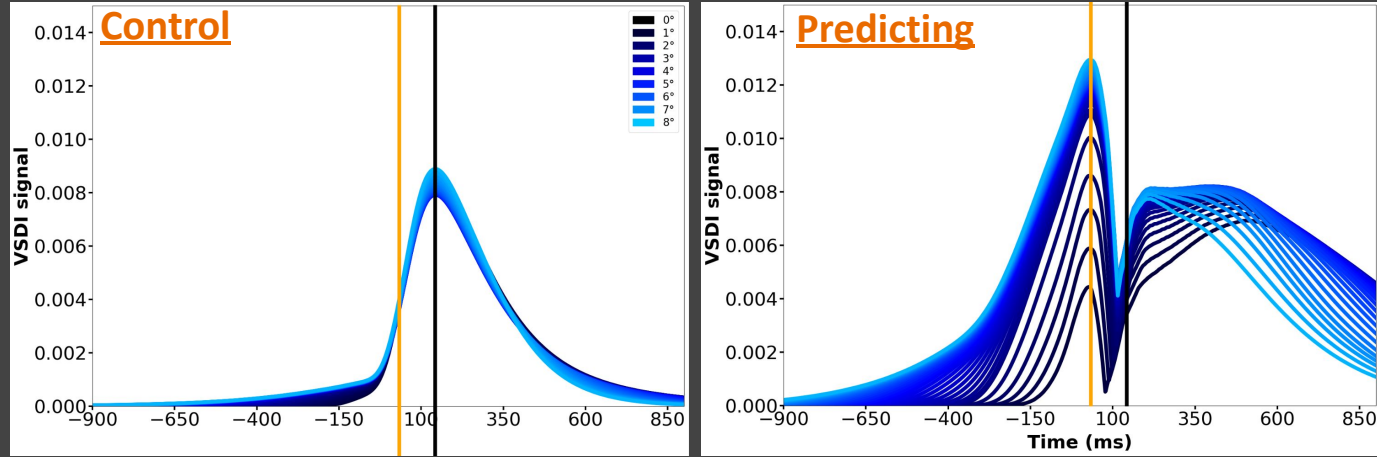
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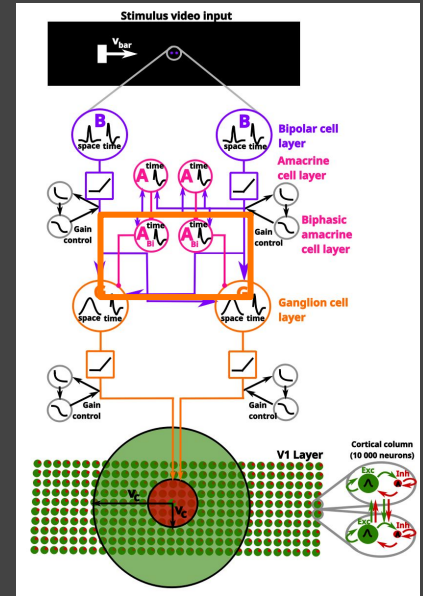
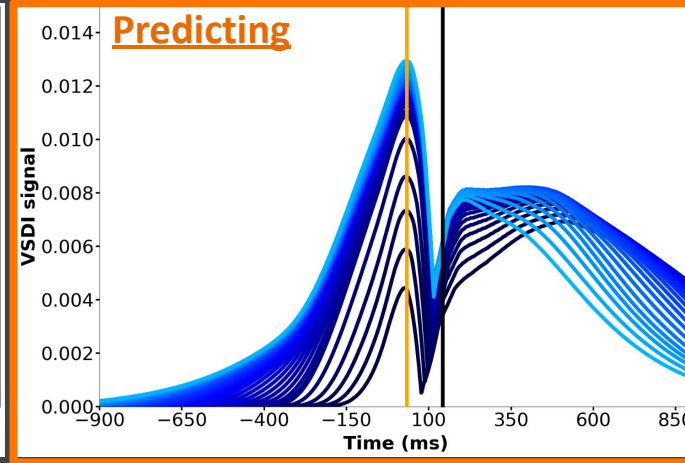
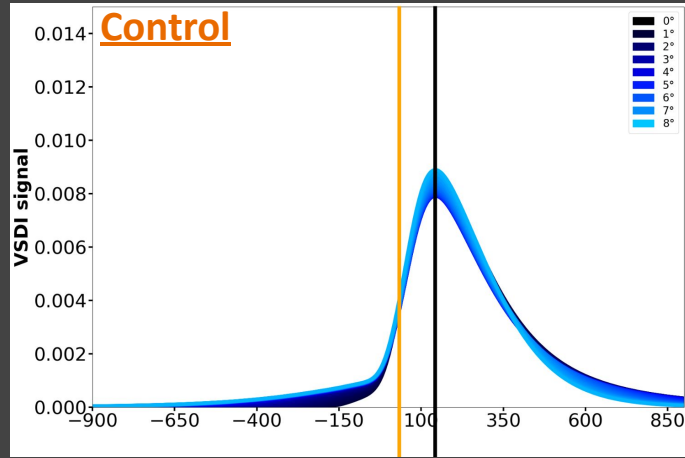
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Does retinal predicting anticipation influence cortical anticipation?



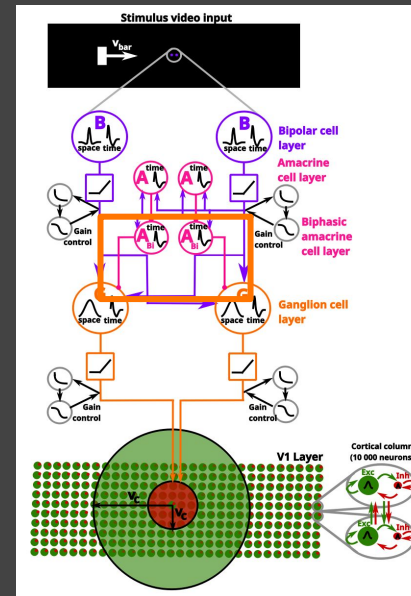
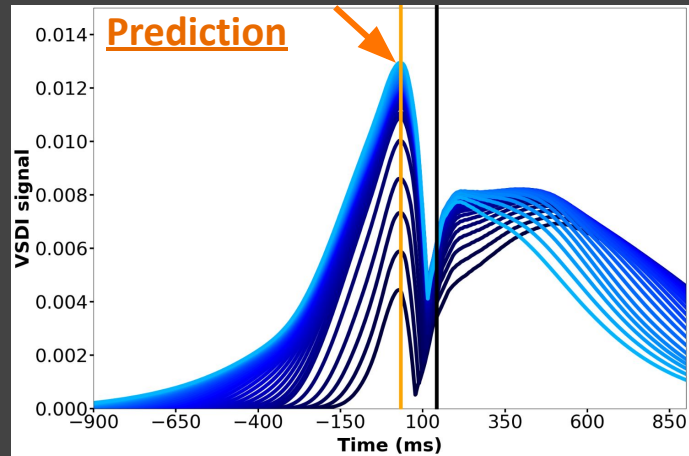
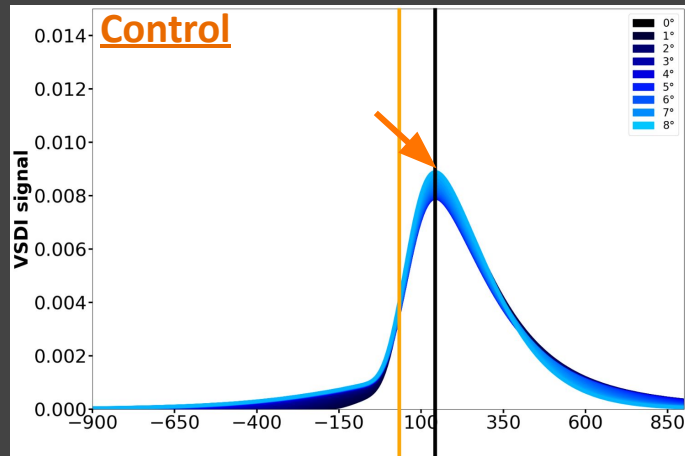
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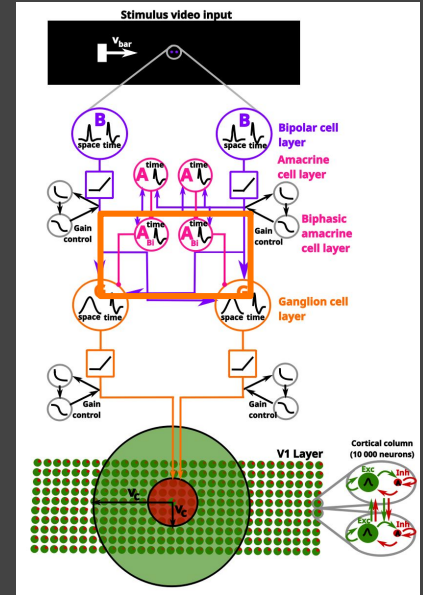
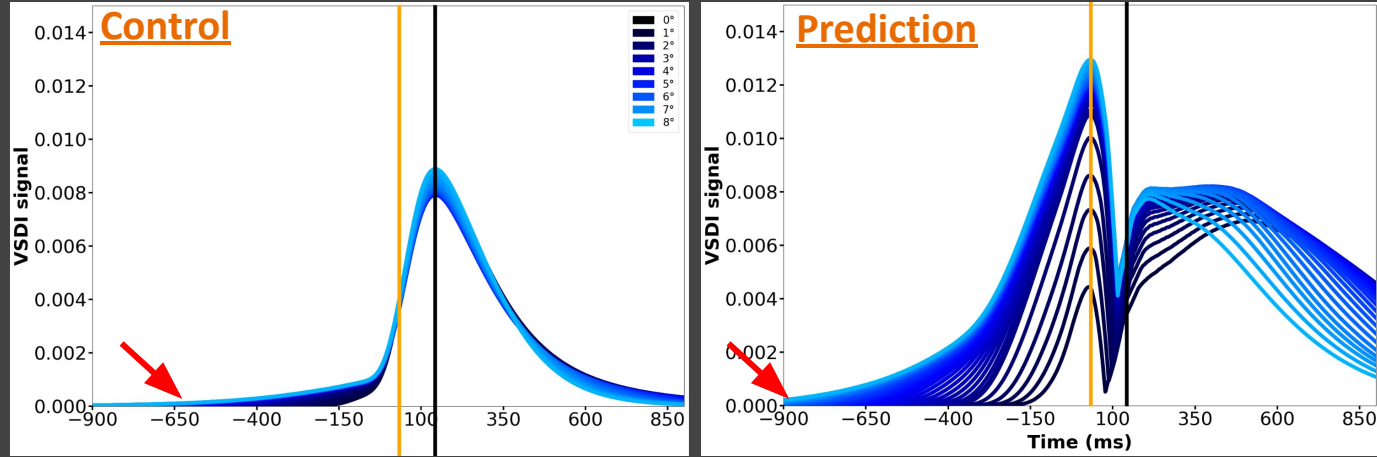
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Does retinal anticipation by adaptation influence cortical anticipation?



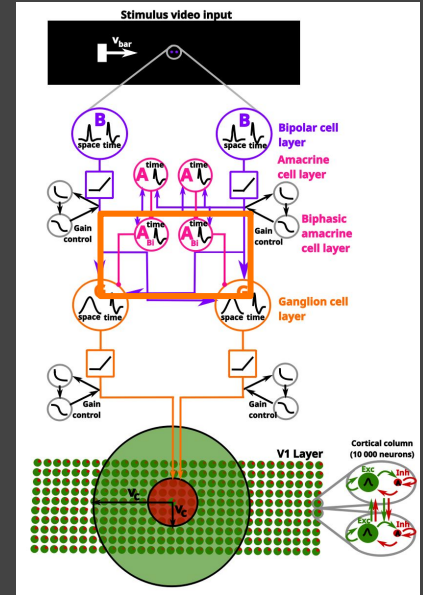
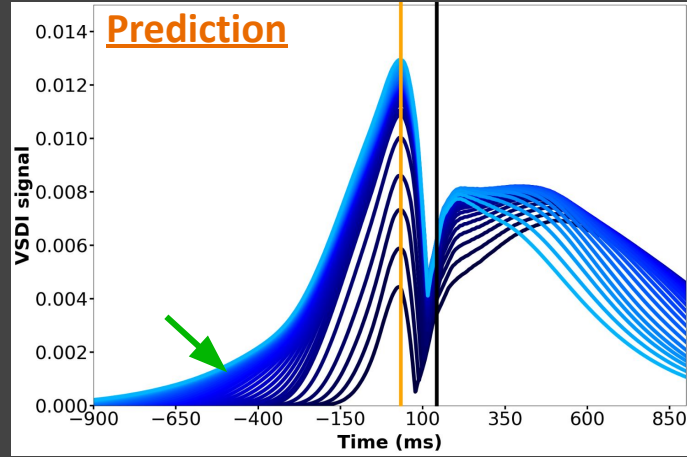
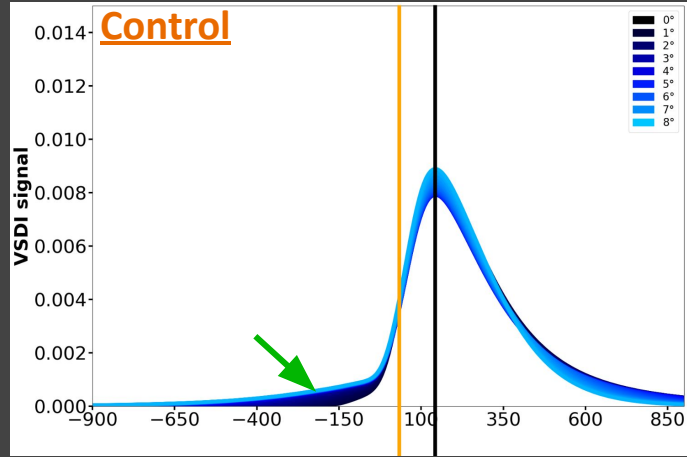
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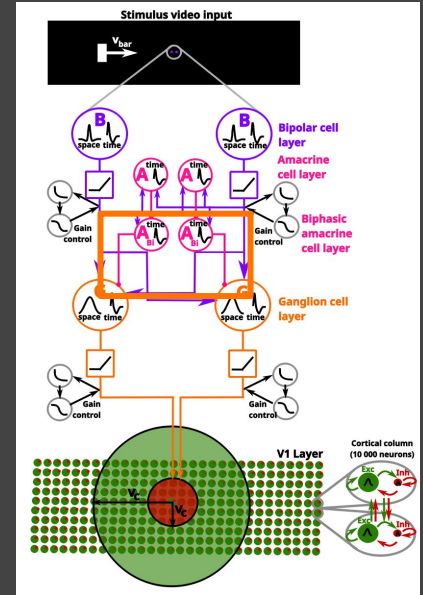
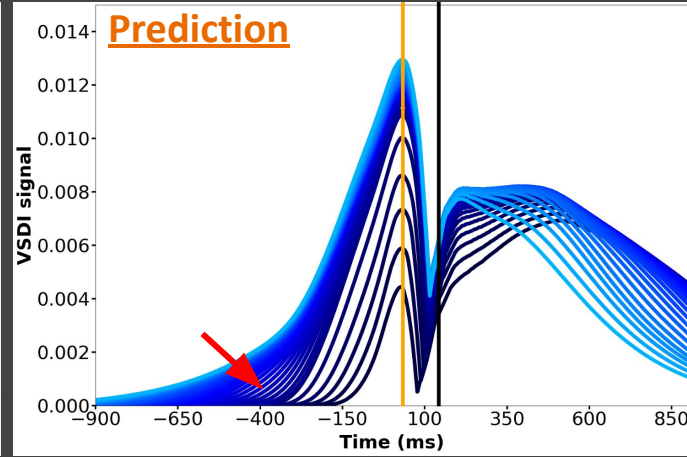
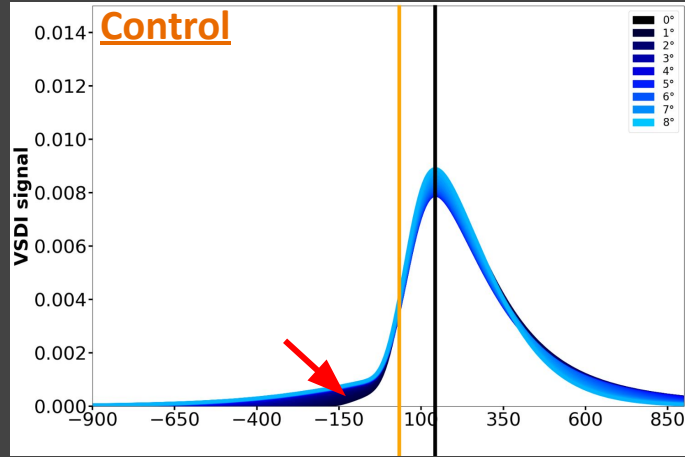
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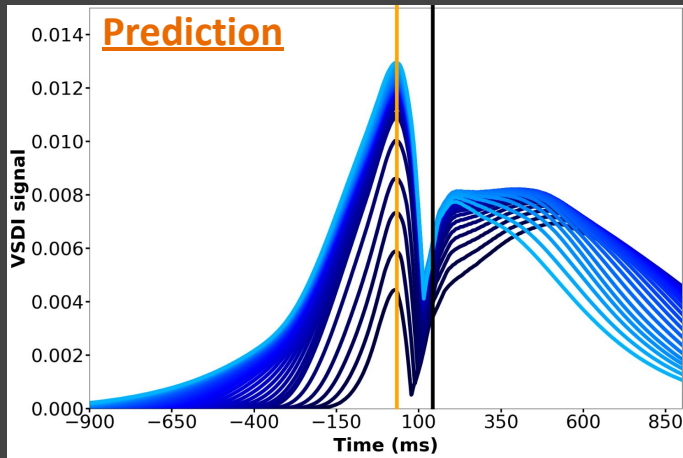
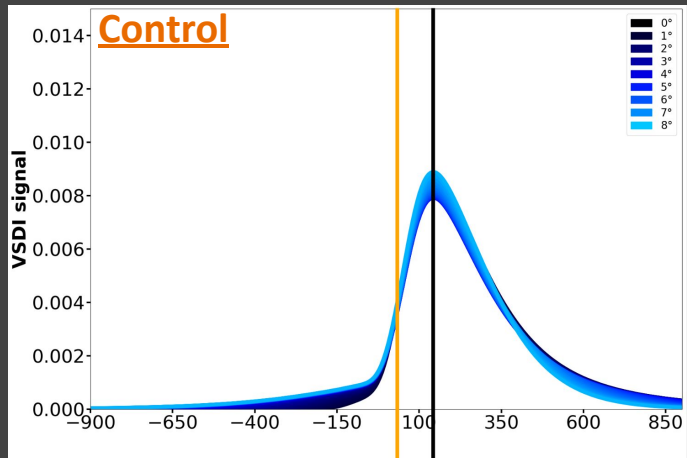
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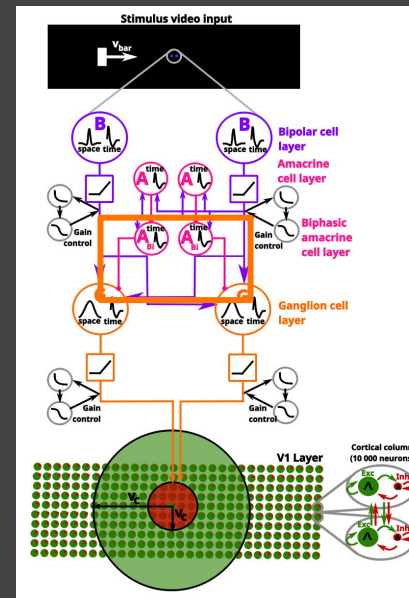


Prediction

Does retinal anticipation by adaptation influence cortical anticipation?



Retinal predicting anticipation causes an earlier peak in the cortex and enhances cortical anticipation



How to study **visual anticipation** in a retino
cortical pathway model?

Conclusion

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Implementation :

- The retino-cortical model is **implemented** in a network simulation software.

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- The retino-cortical model is **implemented** in a network simulation software.

Reproduction :

- The retino-cortical model **reproduces** biological cortical latency experiment

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- **Complementary effect** between adaptive and predictive anticipation ?

Perspectives

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- Exploring retinal and cortical anticipation in the retino-cortical pathway.
- Extending it to the understand of other visual phenomena (saccades...).

Thank you for your attention !

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