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Retino-cortical computational model to study suppressive waves in fast motions



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Introduction

Ocular saccades are fast movements of 200 to 1500mm/s happening 3 times per second. This eyes motion isn't perceived by people due to a phenomenon called saccadic suppression.

Current hypothesis : Suppression is generated by an ocular motor command copy so-called corollary discharge transmitted into higher brain area where it generates the suppression [1].

Our hypothesis : Suppression is carried by retinal and cortical lateral connectivity that can lead to suppressive activity waves already observed in monkey primary visual cortex [2].

This new hypothesis has been elaborated following Mark Wexler experiments on human subjects. He managed to reproduce saccadic suppression **without eyes movements** by using a **1440Hz display** and stimuli with **static phases**.

Our goal is to use a retino-cortical computational model to investigate the role of frame rates and static phase stimuli on visual system

Psychophysical experiments with 60 and 1440Hz

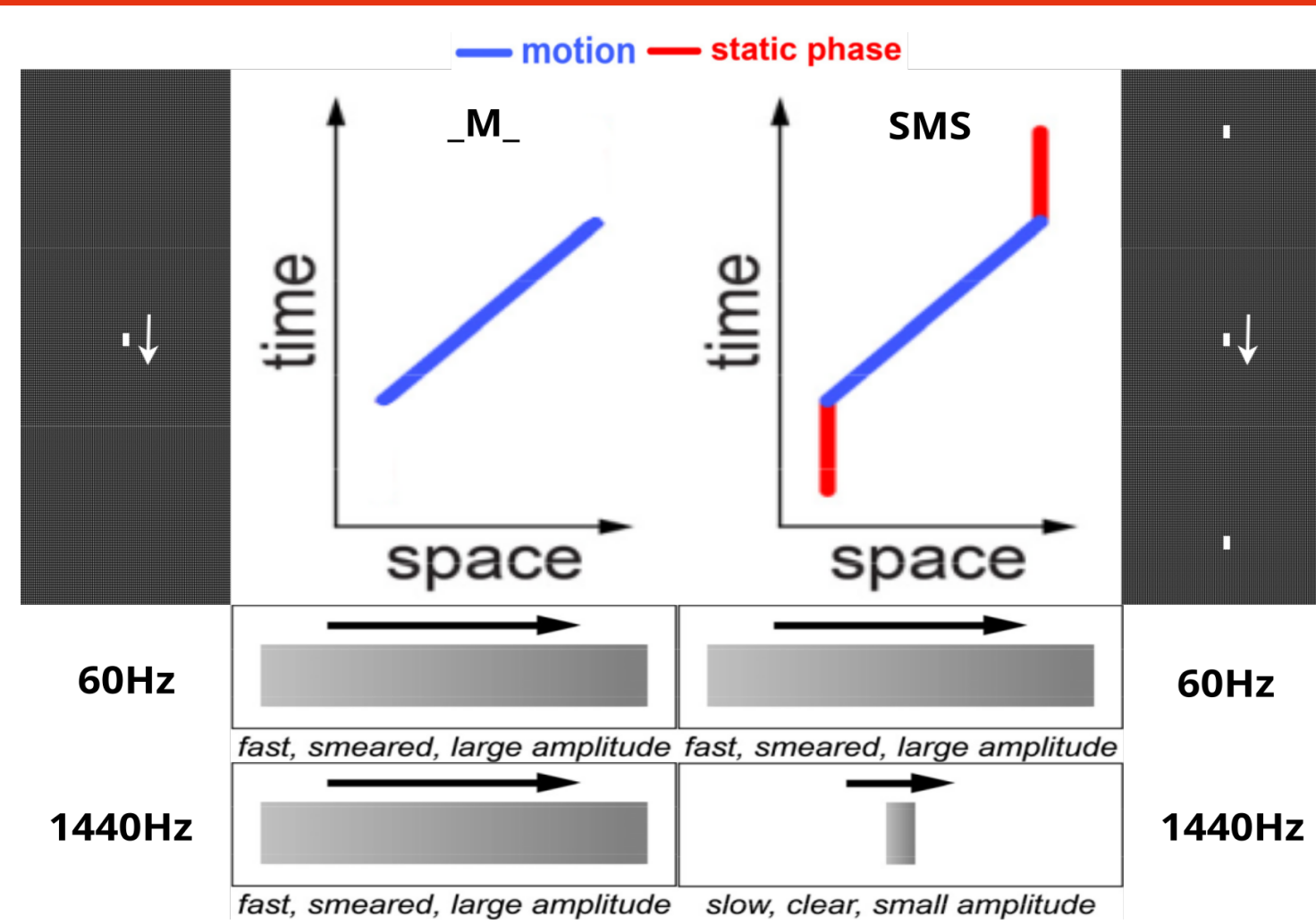


Fig 1 : Experiments are all done for human subjects with fixed eyes. Saccades are simulated thanks to stimuli with fast motion of 200 mm/s. Motion alone stimulus (left) exhibits fast, smeared and larger perception of the bar motion for both 60Hz and 1440Hz stimuli. Motion with static phase (right) allows slow, clear and smaller feeling of the bar motion at 1440Hz, not 60Hz.

Methods

Retinal model reproduces and simplifies the biological retina structure [3] :

- **Photoreceptors** function is reduced to convolution between stimulus and spatio-temporal kernel with center/surround architecture.
- **Bipolars cells** set synapses with amacrine cells of the same coordinates and have gain control to give them desensibilization.
- **Amacrine cells** then inhibit the closest bipolars cells. This lateral connectivity allows to get anticipation for specific parameter values.
- **Ganglions cells** have gain control and received input coming from multiple bipolar cells with a weight decreasing with distance.

Cortical model has been created to replicate **voltage sensitive dye imaging (VSDI)** by using cortical columns organization of the visual cortex [4]. The simulated cortical area is then summarized by a grid of **cortical columns**.

Each cortical column model contains 10 000 neurons split between excitatory and inhibitory population. Mean voltage of both populations is measured and used to compute VSDI intensity.

Lateral connectivity in this model allows to obtain **activity waves** as observed on Monkeys [2,5]

Fig 2 : Retinal model structure.

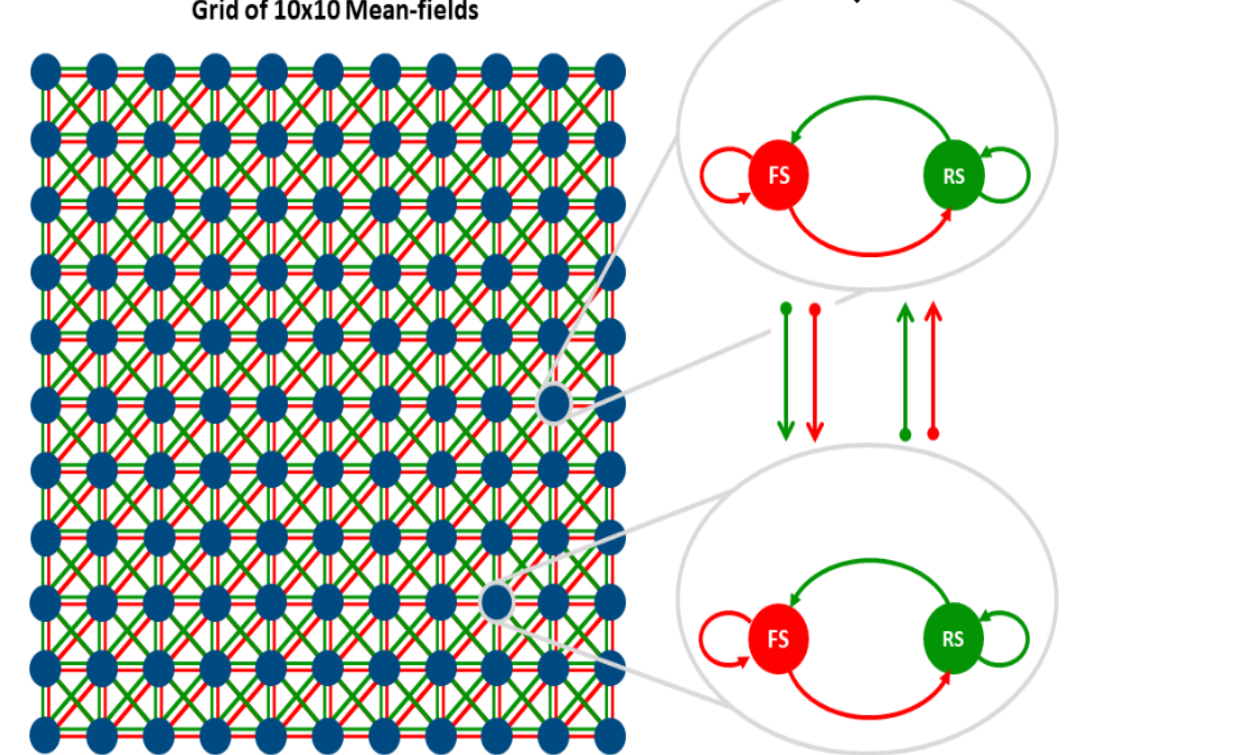
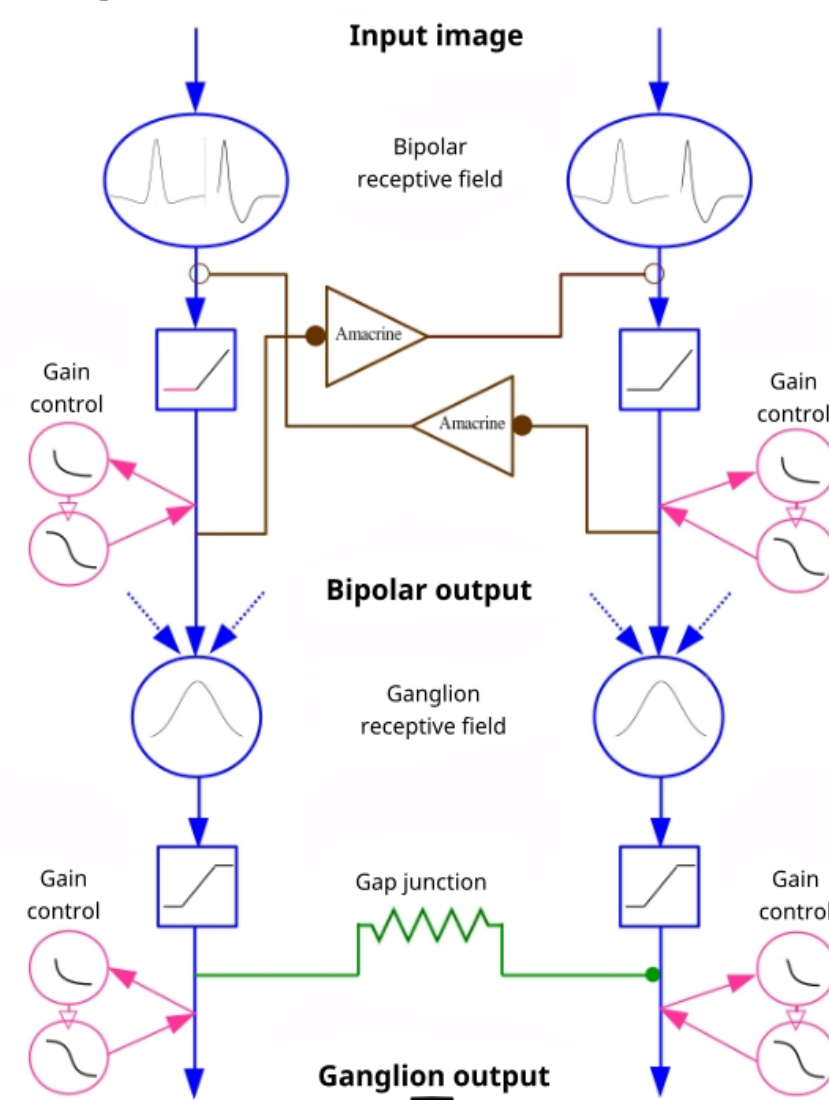


Fig 3 : Structure of one cortical column model (right) with inhibitory (red) and excitatory (green) population. Columns are connected together to create the simulated area (left).

Macular is a modular simulation software made at INRIA where retinal and cortical models are implemented. It allows to see activity of cell layers or specific cells.

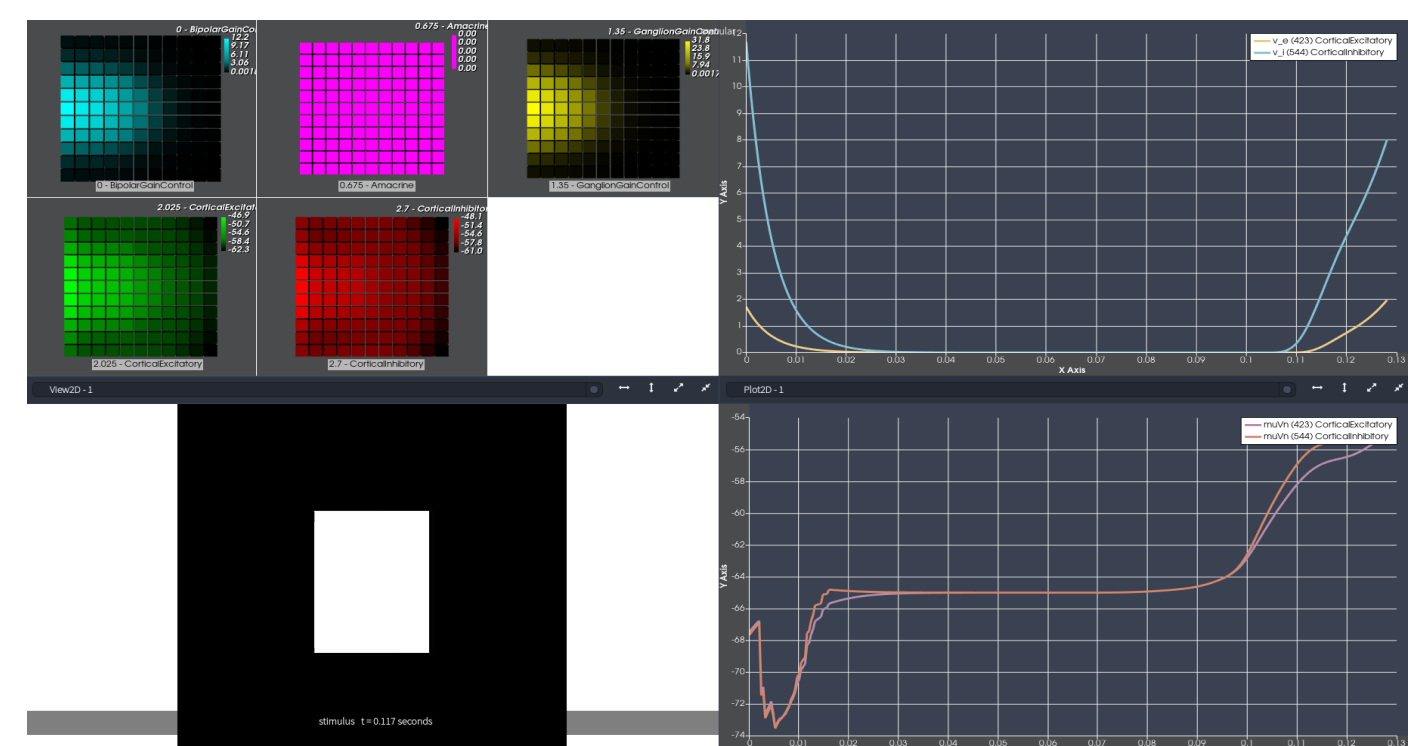


Fig 4 : Macular graphic interface. Top left are heatmaps of the five layers of our model : bipolar cells (cyan), amacrine cells (magenta), ganglion cells (yellow), excitatory cortical population (green) and inhibitory cortical population (red). Bottom left is displayed the stimulus of the current simulation. Right are graphs of specific cells. Stimulus, heatmaps and graphs are refreshed in real time with simulation progress.

References

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Results

Cortical suppressive wave :

Frédéric Chavane's team have recently shown existence of a suppressive wave in Monkey primary visual cortex (V1) with apparent motion stimulus. Two dots are flashed at two spatial and temporal positions. Single flashed dot causes a gaussian spreading activity (Fig. 5A and B). Difference between apparent motion and sum of both flashed dots alone shows suppression appearing from the second stimulus onset and going to the first stimulus. This wave has the same spatial extent and speed than lateral cortical connectivity.

Suppressive wave in Monkey cortex V1

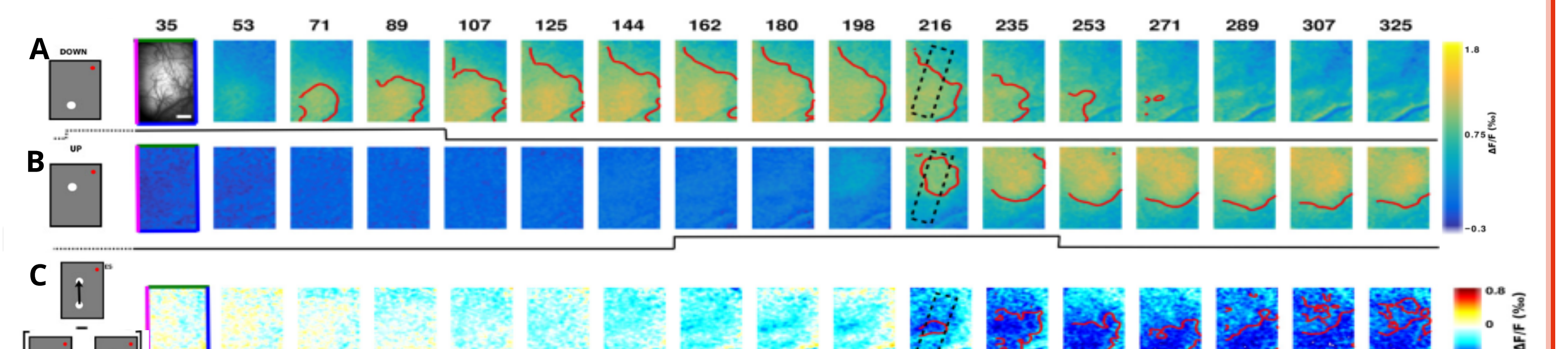


Fig 5 : Cortical response of monkeys to down (A) or up (B) stimulus alone. Panel C is the difference between apparent motion stimulus of 6,6°/s and sum of down and up stimulus.

Flashed dots stimuli in macular show the same spreading activity than in Monkey. Difference between apparent motion and summed flashed dots reveals a replicate suppression wave beginning in stimulus 2 and propagating to stimulus 1.

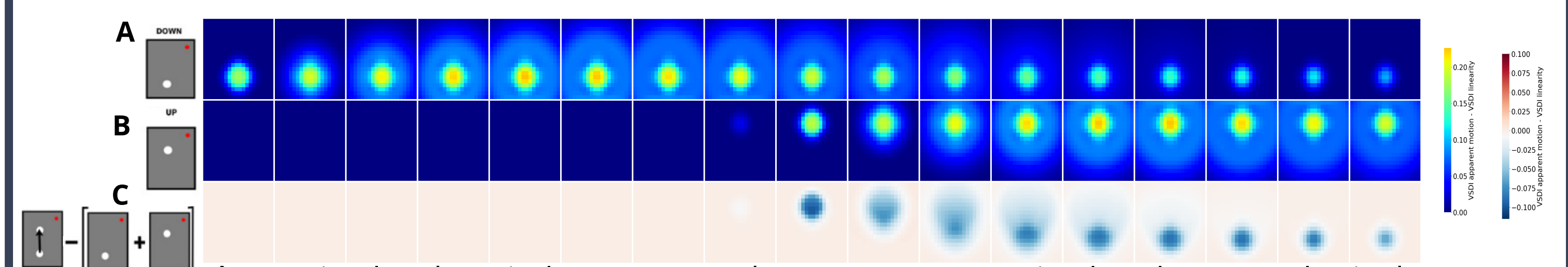


Fig 6 : Simulated cortical response to down (A) or up (B) stimulus alone. Panel C is the difference between apparent motion stimulus of 6,6°/s and sum of down and up stimulus.

Frame rate effect on retino-cortical response :

Simulations with increasing frame rates generate lower bipolar and ganglion response. Moreover, this response happens earlier (Fig 5). This activity decreases more with higher bar speed. Stronger activity for 60Hz can also be seen in cortical response by subtracting activity at 60 Hz to activity at 1440Hz (Fig 8).

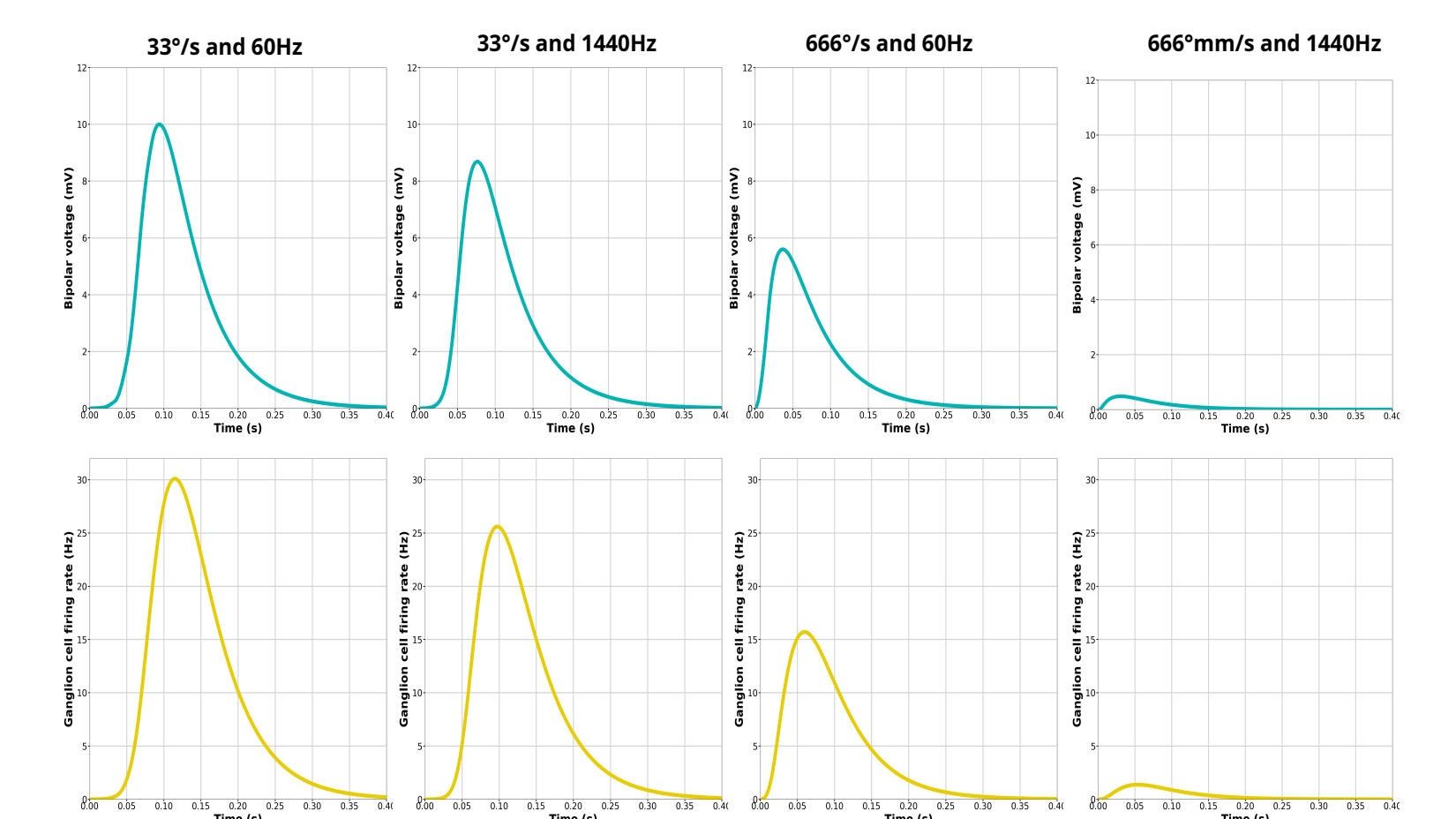


Fig 7 : Retinal response to white bar in motion with a bar speed of 33°/s or 66°/s and frame rates at 60Hz or 1440Hz. Blue graphs correspond to bipolar cells and yellow graphs to ganglion cells.

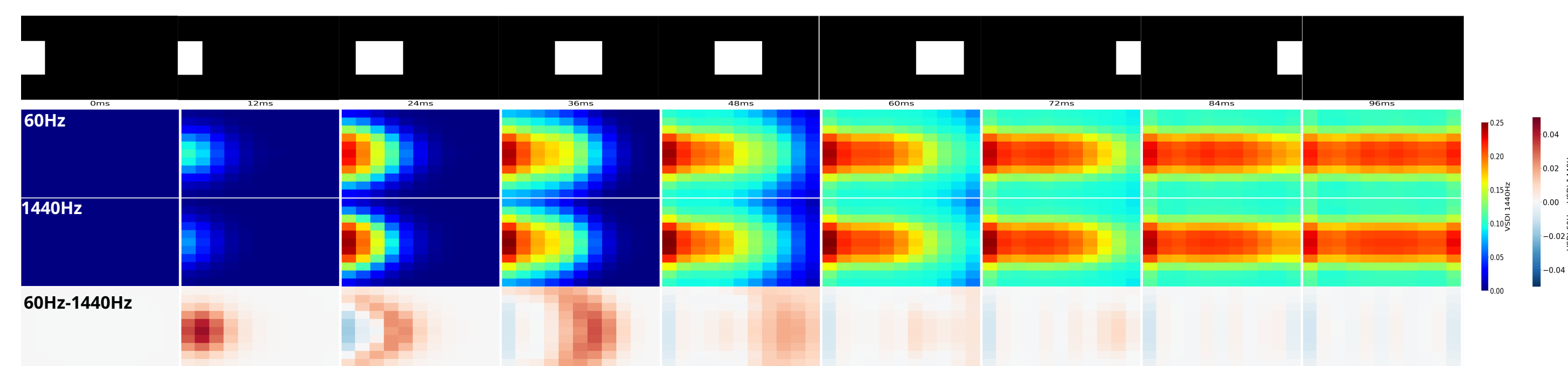


Fig 8 : Effect of frame rates on cortical activity. Top and middle panels are respectively 60 and 1440Hz stimuli. Bottom panel is the difference of VSDI activity between 60 and 1440Hz simulation for a speed of 33°/s.

Conclusions & Perspectives

In this poster, we have proposed a retino-cortical model able to act both on retina and cortical parameters with very simple stimuli.

This retino-cortical model have been well calibrated in order to reproduce Chavane's optical imaging results. In particular, we managed to replicate suppressive waves caused by apparent motion in primary visual cortex.

Preliminary results have highlighted a difference in retinal and cortical activities between 60 and 1440Hz frame rates. This difference seems to be stronger with high speed. Thus, refresh rates are fundamental to shape response to visual stimuli and can't be ignored.

Now, we want to continue our frame rates experiments by using Mark stimuli with static phasis and compare it to motion alone. We will simulate with 60 and 1440 frame rates and saccadic speed.

Acknowledgements

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