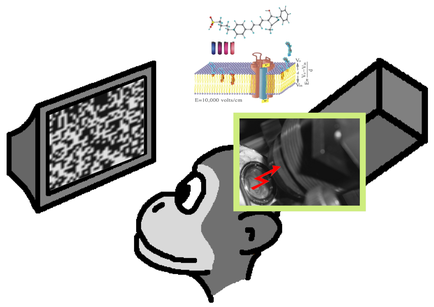
Interocular Normalization In Monkey Primary Visual Cortex

Alexandre Reynaud[1], Sébastien Roux[2], Sandrine Chemla[2], Frédéric Chavane[2] and Robert F. Hess[1]
[1]McGill University, Montréal, Canada; [2]INT-CNRS, Marseille, France alexandre.reynaud@mail.mcgill.ca

Introduction

The slight difference in the signals coming from the two eyes is used by our brain to compute a tridimensional representation of the visual world. The monocular inputs reach the cortex in layer 4 in segregated ocular dominance domains. Then they are first combined by binocular neurons in layer 2/3. Studying how the information coming from the two eyes is integrated in ocular dominance map's referential at the mesoscopic scale is however still unknown. For this purpose, we used voltage sensitive dye imaging (VSDI) in anesthetized and awake behaving monkeys to analyze how these signals are integrated and summed at the population level in V1.

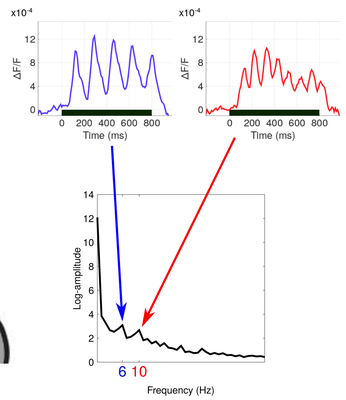
Voltage-Sensitive Dye Imaging (VSDI)



- Dalstar camera 512x512px 100Hz
- Voltage Sensitive Dye RH-1691 (Grinvald and Hildesheim, 2004)
- 3D monitor LG 32LB650V 32" 1920x1080px, 60Hz at 100cm

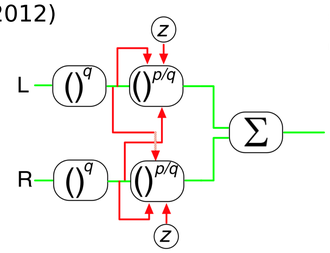
Steady-State Visual Evoked Response (SSVER)

- Steady-State Visual Evoked Response (SSVER frequency tagging paradigm)
- Dichoptic flickering checkerboard of 1° checks
- Target at 0, 25, 50 or 100%
- Dichoptic mask at 0 or 100% contrast

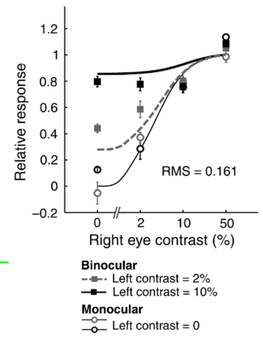


Interocular Normalization Model

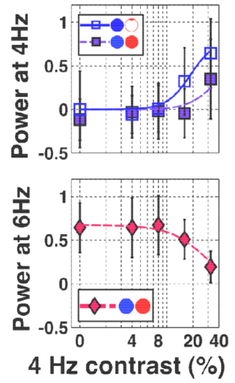
Normalization is a canonical suppressive mechanism in the brain (Heeger et al., 1996). It can be observed in VSDI in V1 (Reynaud et al., 2012)



Meese et al., 2006

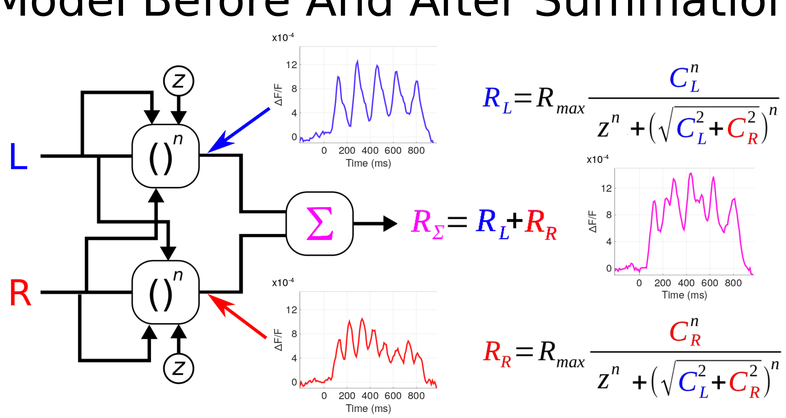


Moradi and Heeger, 2009



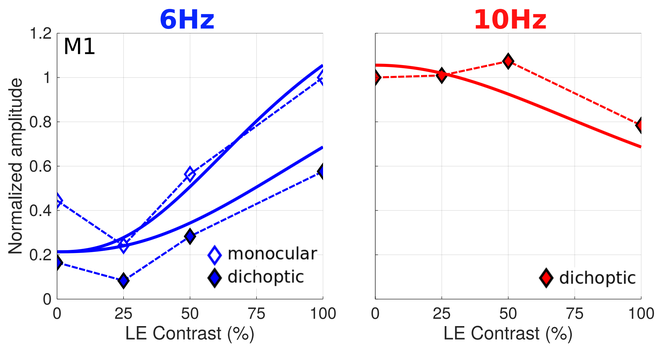
Chadnova et al., 2018

Model Before And After Summation



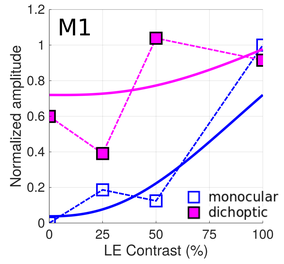
VSD imaging is able to describe each eye independent response by frequency analysis but also the binocular response by amplitude analysis with a SSVER paradigm

Frequency Analysis



- The SSVER increases with contrast
- The response is suppressed by a dichoptic mask
- The suppression strength depends on mask contrast

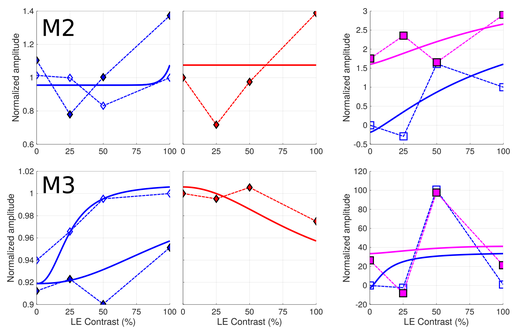
Amplitude Analysis



- The signal amplitude increases with contrast
- The response to the dichoptic mask adds to the signal amplitude

Other Monkeys

- For M2, the responses seem to add in the frequency domain
- For M3, one data point is very strange in the amplitude domain



Conclusions

- The contribution elicited by the stimulation of one eye to the population activity in V1 is suppressed by the dichoptic stimulation of the other eye.
- At the summation site, the global population activity elicited by the stimulation of the 2 eyes sum in a non-linear way
- This signal integration is accurately accounted for by an interocular normalization model both at the dichoptic and summation sites
- These approach and model confirm an implication of V1 population in the combination of the two eyes signals. Whether this normalization originates locally, or from feedback, feedforward or long range connectivity remains to be investigated

Acknowledgements

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References

- Chadnova, E.; Reynaud, A.; Clavagnier, S.; Baker, D. H.; Baillet, S. & Hess, R. F. (2018), Interocular interaction of contrast and luminance signals in human primary visual cortex, NeuroImage 167, 23-30.
- Grinvald, A. & Hildesheim, R. (2004), VSDI: a new era in functional imaging of cortical dynamics, Nat Rev Neurosci 5(11), 874--885.
- Heeger, D. J.; Simoncelli, E. P. & Movshon, J. A. (1996), Computational models of cortical visual processing, Proceedings of the National Academy of Sciences of the United States of America 93, 623--627.
- Meese, T. S.; Georgeson, M. A. & Baker, D. H. (2006), Binocular contrast vision at and above threshold, J Vis 6(11), 1224--1243.
- Moradi, F. & Heeger, D. J. (2009), Inter-ocular contrast normalization in human visual cortex, J Vis 9(3), 13.1--1322.
- Reynaud, A.; Masson, G. S. & Chavane, F. (2012), Dynamics of local input normalization result from balanced short- and long-range intracortical interactions in area v1, J Neurosci 32(36), 12558--12569.