Local and Global Neural Mechanisms Underlying the Robust Velocity Coding of Natural Images

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Thesis Abstract

Interpreting motion in the natural world presents a major challenge for visual systems. Natural scenes vary enormously in structure, luminance and contrast, all parameters known to modulate the response of biological motion detectors. Nevertheless, many animals overcome this challenge and adopt visually guided behaviour for which the accurate estimation of self-motion and image velocity is required.

It is generally accepted that Reichardt correlator-like computations underlie local motion detection in insects. Reichardt correlators, however, generate ambiguous estimates of velocity, because they are sensitive to several additional image parameters, such as those mentioned above. How does the visual system generate accurate estimates of apparent image velocity when the elements underlying local motion detection produce ambiguous velocity signals?

This thesis investigates the neural processing of image velocity. I performed sharp electrode intracellular recordings from identified motion sensitive neurons in the lobula plate of the hoverfly, *Eristalis tenax*. A series of natural and artificial images were used to investigate the processing of a vast range of scenes.

I show that the horizontal system (HS) neurons have a remarkable capacity to estimate image velocity reliably for vastly different natural scenes. This property is at odds with the HS neurons' responses to experimenter-defined stimuli. I reveal several activity dependent features of the neural response that may reconcile the ability to accurately encode the velocity of natural images with the mechanisms underlying motion processing. Images that were initially weak neural drivers have long latencies, with responses continuing to increase in magnitude over several hundred milliseconds. Images that were initially strong neural drivers, reached peak responses more rapidly followed by significant reductions in response over longer time scales. Despite being different in sign and time course, these two activity dependent changes in response act as near-ideal normalisers for images that would otherwise produce highly variable response magnitudes.

By analysing the time course of neural response and manipulating image contrast, I show that this property is likely to emerge from a combination of static and dynamic non-linarities. When image contrast is reduced, thus reducing the range of input signals to local motion detectors, the essential non-linearity of the Reichardt correlator model provides a good prediction of global responses. Thus, suggesting an important role for non-linear mechanisms being recruited by high contrast local features in the robust encoding of natural scenes.

Finally, I use an experimental paradigm that reduces the influence of spatial integration and thus enables the analysis of responses equivalent to the outputs of individual local motion sensitive elements presynaptic to the HS neuron. I show evidence for an adaptive gain reduction that affects the sensitivity of individual motion detector responses to subsequent features. This gain reduction is facilitated by local neighbouring motion stimulation and is thus, well suited to take advantage of the predictable nature of natural scenes.

Declaration

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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1. Nordström, K. Barnett, PD., Moyer de Miguel, IM., Brinkworth, RSA. and O'Carroll, DC. (2008) Sexual dimorphism in the hoverfly motion vision pathway. Current Biology 18: 661–667. DOI 10.1016 DOI 10.1016/j.cub.2008.03.061

2. Barnett, PD., Nordström, K. and O'Carroll, DC. (2009). Motion adaptation and the velocity coding of natural scenes, Submitted to Current Biology, MS Current-Biology-D-09-00354

3. Barnett, PD. and O'Carroll, DC. (2009) Receptive fields of fly motion detecting neurons integrate local features within natural scenes unpredictably.

4. Barnett, PD., Nordström, K. and O'Carroll, DC. (2009) Local motion detection: temporal and spatial modulation of gain and transient responses to features

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Statement of Contributions to Jointly Authored Works

The following states the contribution of the authors to the following published works

1. Nordström, K., Barnett, PD., Moyer de Miguel, IM., Brinkworth, RSA. and O'Carroll, DC. (2008) Sexual dimorphism in the hoverfly motion vision pathway. Current Biology 18: 661–667. DOI 10.1016/j.cub.2008.03.061

Conceptualization: Receptive field mapping and analysis techniques were developed by David O'Carroll. The primary observation resulted from collection of various receptive fields from motion sensitive neurons collected during electrophysiological experiments (see below). The interpretation of these results was shared amongst all the coauthors.

Realization: Electrophysiological recordings were conducted by Karin Nordström, Paul Barnett, and Irene Moyer de Miguel. Anatomy was done by Paul Barnett. Stimulus movies were collected and modified by Russell Brinkworth. Data collection and analysis was primarily done by Karin Nordström.

Documentation: Karin Nordström and David O'Carroll were primary writers of the paper, with contributions from Paul Barnett and Russell Brinkworth. Figures were made by Karin Nordström, except for the anatomy where Paul Barnett developed the images and movies.

2. Barnett, PD., Nordström, K. and O'Carroll, DC. (2009) Motion adaptation and the velocity coding of natural scenes. Submitted to Current Biology, MS Current-Biology-D-09-00354

Conceptualization: All the coauthors were involved in the conceptualization and development of ideas included throughout the paper.

Realization: Electrophysiological recordings were conducted by Paul Barnett and Karin Nordström. Data analysis was done by Paul Barnett.

Documentation: Paul Barnett, Karin Nordström and David O'Carroll were all involved in writing the paper. Figures were made by Paul Barnett.

3. Barnett, PD. and O'Carroll, DC. (2009) Receptive fields of fly motion detecting neurons integrate local features within natural scenes unpredictably.

Conceptualization: Both authors were involved in the conceptualization and development of ideas included throughout the paper.

Realization: Electrophysiological recordings were conducted by Paul Barnett. Analysis was done by Paul Barnett.

Documentation: Paul Barnett and David O'Carroll wrote the paper. Paul Barnett made the figures.

4. Barnett, PD., Nordström, K. and O'Carroll, DC. (2009) Local detector analysis reveals a locally mediated mechanism of motion adaptation.

Conceptualization: Paul Barnett and David O'Carroll conceived the experiments. Paul Barnett, Karin Nordström and David O'Carroll all contributed to the development of ideas.

Realization: Electrophysiological recordings were conducted by Paul Barnett. Analysis was done by Paul Barnett.

Documentation: Paul Barnett primarily wrote the paper. Karin Nordström and David O'Carroll provided significant written contributions and editing. Paul Barnett made the figures.

I agree with the above statements of contributions and give permission for the papers to be included in this thesis.

Paul Barnett:

Karin Nordström:

Irene Moyer de Miguel:

Russell Brinkworth:

David O'Carroll:

Author's Comments

All publications within this thesis are in the exact form of the original articles as published or as submitted in cases where the article are not yet in press, with the following exceptions:

Typesetting has been altered so that there is a consistent format throughout the entire thesis.

The figures have been inserted into the text at appropriate places, which may differ from the final published version of the papers.

Figures are referenced throughout the text as they are in the published or submitted versions of the papers, but are captioned based on their chapter and figure number, e.g. Figure 1 in Chapter 2 is captioned as Figure 2.1.

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