Characterization of synaptic transmission in the visual pathway of the blowfly using dual cell recording and laser ablation techniques

Julia Kalb, Ulrich Beckers, Martin Egelhaaf, and Rafael Kurtz
Dept. Neurobiology, Bielefeld University, Germany
julia.kalb@uni-bielefeld.de

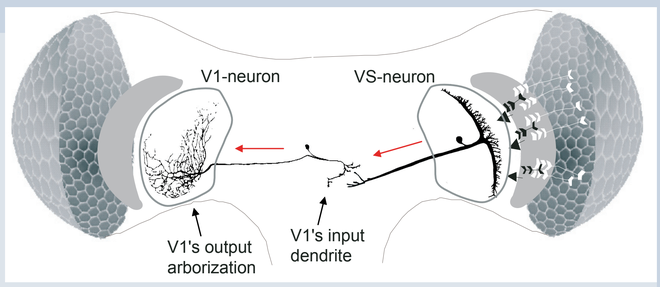
Introduction

For neuronal network analysis it is of particular interest how the interactions between individual neurons produces behavior. This critically depends on the biophysical properties of single nerve cells as well as on how signals are transferred within neuronal ensembles. Synapses thus represent key elements to understand the computational capabilities of the nervous system.
In the visual system of the blowfly, the cellular basis of neuronal computation can be studied *in vivo* and synaptic activity can be evoked by visual stimulation. Here we focus on a subset of identified motion sensitive neurons which consists of a small ensemble of presynaptic neurons and a single postsynaptic neuron. In previous studies these synaptic connections have been investigated with respect to the gain and the reliability of synaptic transmission during visual stimulation[1,2]. However, with this approach, it is difficult to isolate the influence of a single presynaptic element from that of its ensemble members because there is a considerable spatial overlap in their receptive fields. To analyse synaptic transfer characteristics in a more specific way we currently focus on the following approaches:

- Investigating potential adaptive properties during synaptic transmission
- Selective laser ablation of single presynaptic neurons

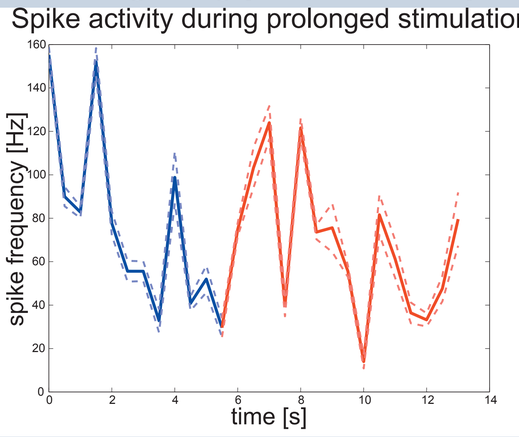
The recording site

- Each VS neuron gets direct retinotopic input
- Neighbouring VS cells have partially overlapping receptive fields and a weak electrical coupling is reported[3]
- VS neurons encode information by graded potential shifts with spike like depolarisations
- V1 receives input from VS1 to VS 3 (VS4) at excitatory synapses
- V1 transmits motion information to the contralateral brain hemisphere by spikes only

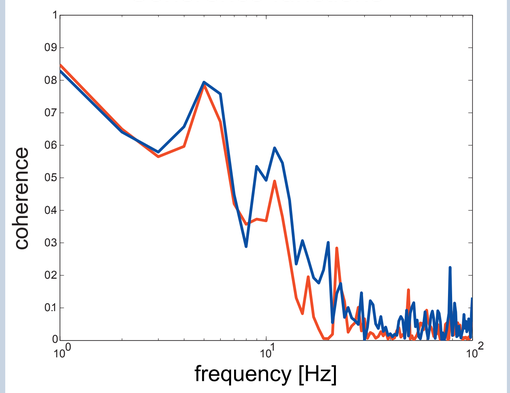


Investigating potential adaptive properties of synaptic transfer

Spike activity during prolonged stimulation



Coherence functions



During prolonged dynamic motion stimulation the V1 spike frequency decreases. To assess the impact of spike frequency adaptation on V1's performance in motion velocity encoding we compare the coherence functions during the non-adapted (left, blue line, first stimulus presentation) and the adapted state (left, red line, second stimulus presentation): Although the spike activity declines by 22,2 % (S.D. 4,4; 5 traces, left) there is only little change, if at all, in the coherence functions (right figure, same data).

Functional consideration & outlook

- In case of linear integration of motion signals and equal synaptic gain a reduction of less than a half might be expected. Further investigations are needed to show whether the reduction activity in V1 after VS1 ablation can be referred to a nonlinear integration mechanisms or/and different synaptic gain
- After ablation of VS1 V1 can still reliable and linear decode motion information from the remaining presynaptic activity
- Dual recordings of the presynaptic and postsynaptic neurons are done to investigate if the observed V1 spike frequency adaptation during prolonged motion stimulation can be attributed to an adaptive synaptic transfer mechanism
- Single electrode voltage clamp recordings of single presynaptic neurons while simultaneously recording V1 are performed to analyse the synaptic dynamics

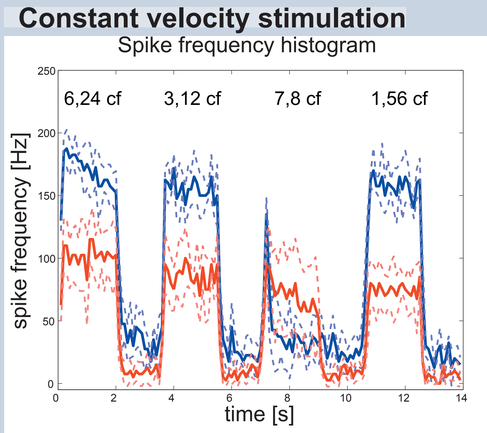
Selective laser ablation technique to analyse synaptic transfer properties

A popular method used for deleting individual neurons is the fluorescence laser-ablation technique[4]. Using this technique we want to analyse how the postsynaptic neuron reads out the ensemble activity. We compare the activity of the postsynaptic neuron before and after selective laser ablation of single presynaptic neurons. Here we use two types of stimulus conditions in order to assess different aspects of synaptic transfer properties:

- **Constant velocity stimulation** to analyse how synaptic integration of motion signals operates. Moreover, we want to find out if there is any difference in the synaptic gain between the individual synaptic connections
- **Dynamic velocity fluctuations** to estimate the impact of presynaptic elements on the posytsynaptic neuron's performance in reliable extraction of motion information

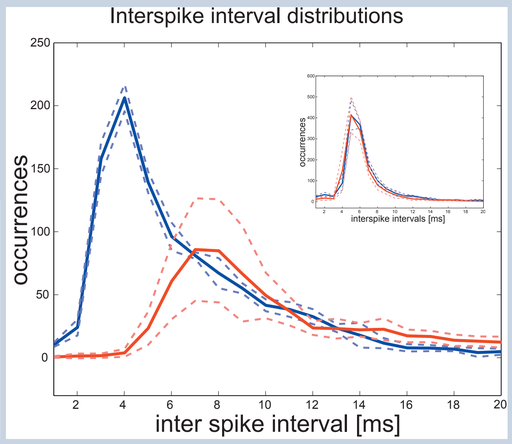
Constant velocity stimulation

Spike frequency histogram



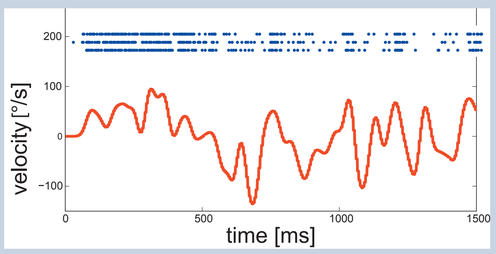
Moving square-wave gratings were used as motion stimuli. Between stimulus presentation the grating was stationary. The spike frequency histograms show the V1 mean spike response (n=4) to four different contrast frequencies before (solid blue lines, S.D. dashed lines) and after (solid red lines, S.D. dashed lines) deleting the VS1-neuron. The killing procedure strongly affected the V1 response amplitude: the activity declined to nearly to half of its previous value.

Interspike interval distributions



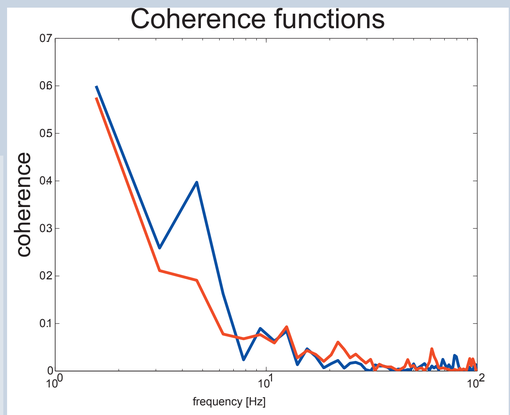
The mean interspike interval distributions (100ms bin width, same data as above) reflect the strong reduction in spike rate after eliminating the VS1 neuron. Control experiments during which we laser illuminated the lobula plate without killing a presynaptic neuron show no effect on the response amplitude and interspike interval distribution.

Dynamic velocity stimulation



To estimate the performance of V1 in encoding the motion velocity we determine coherence functions. The coherence function is a measure of linearity in the relationship between the stimulus traces and the spike activity and thus quantifies to what extend a dynamic stimulus is represented linearly and reliably in the spike activity.

Coherence functions



In a previous study V1 was found to encode motion velocity fluctuations up to approximately 5 - 10Hz in a fairly linear and reliable way. This is reflected in the coherence functions shown right. After eliminating the VS1 neuron no obvious change in the coherence function could be observed. This is surprising in the light of the strong reduction in spike rate, which the same V1 cell shows in response to ablation of VS1.

Literature

1. Kurtz R., Warzecha A-K., Egelhaaf M. (2001): Transfer of visual motion information via graded synapses operates linearly in the natural operating range. J Neurosci 21:6957-6966.
2. Warzecha A-K., Kurtz R., Egelhaaf M. (2003): Synaptic transfer of dynamic motion information between identified neurons in the visual system of the blowfly. Neuroscience 119:1103-1112
3. Haag J., Borst A. (2004): Neural mechanisms underlying complex receptive field properties of motion-sensitive interneurons. Nat Neurosci 7:628-634.
4. Farrow K., Haag J., Borst A. (2003): Input organization of multifunctional motion-sensitive neurons in the blowfly. J Neurosci 23:9805-9811