# Investigation of synaptic signal transfer from graded potential presynaptic neurons to a spiking neuron in the fly visual pathway

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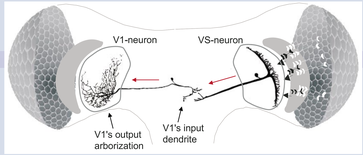
## Introduction

Synapses are generally supposed to operate efficiently only if their signalling range is matched well to the spectrum of prevailing presynaptic signals. To test this assumption, synaptic transmission was systematically characterized in vivo within the visual-motion pathway of the blowfly by simultaneous dual recordings from an identified synapse (VS-V1). The postsynaptic neuron (V1-cell) receives mixed signals consisting of graded potentials with superimposed spike-like depolarizations (spikelets) from a small number of presynaptic elements (VS-cells)[1]. Synaptic signal transmission has recently been shown to be almost linear for presynaptic voltage fluctuations up to about 10-20 Hz[2]. This corresponds with the frequency range of visual motion signals, which is limited due to the low-pass filters immanent to visual motion detection[3].

To assess the performance of single synapses and to control the presynaptic signals precisely we voltage-clamped one of the presynaptic neurons. We found, that single synapses can effectively convey signals over a much larger amplitude and frequency range than is normally utilized during graded transmission of visual signals. A reason for this discrepancy might lie in the transmission of spikelets, which reach larger amplitudes and contain higher frequency components than graded signals.

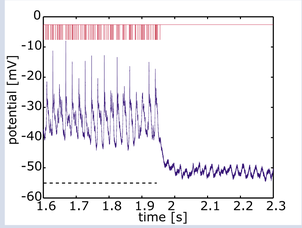


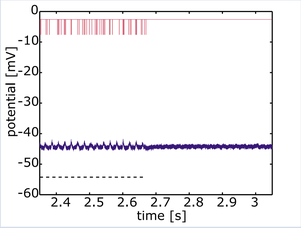

## The recording site

- VS-cells get direct retinotopic input and encode motion information by graded potentials with superimposed spikelets
- neigboring VS-cells have partially overlapping receptive fields and a weak electrical coupling is reported[4]
- V1 receives input from at least 4 VS-cells
- V1 transmits motion information by spikes to the contralateral brain hemisphere

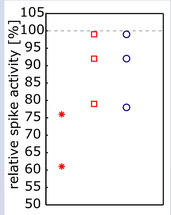
## Muting one presynaptic cell

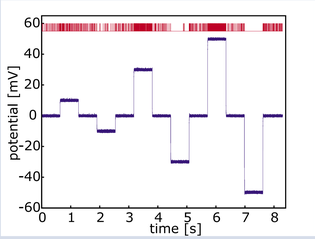
A functional inactivation of one presynaptic cell is achieved by voltage clamping to its resting potential. The figures below show recordings of neuronal responses during visual stimulation in preferred and null direction. The upper traces show registered postsynaptic spikes (V1-neuron), the lower traces the presynaptic potential (VS-neuron). Both figures show the same cell pair. Top, no voltage clamp applied. Bottom, with voltage-clamp of the presynaptic VS-cell to its resting potential.




The *right* figure shows the postsynaptic spike rate during preferred-direction motion in the voltage-clamp condition relative to the non-clamped condition. A reduction in the spike rate, variable in strength, was found in all tested cells.

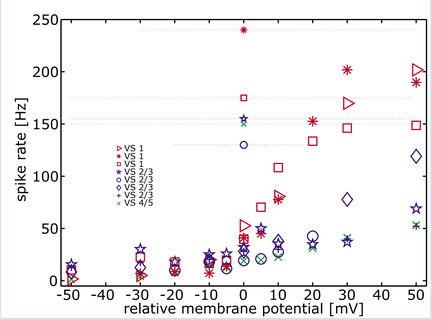



## Signalling range, gain and linearity

Signal transmission at individual synaptic connections was characterized by monitoring the postsynaptic response (V1-neuron) to precisely controlled membrane potential deflections of a single presynaptic VS-cell in the absence of visual stimulation (see left figure for example recording). With clamped presynaptic potential changes of up to ± 50 mV these values exceeded the range of graded potential changes during visual stimulation by far, which cover a range of about ± 10 - 15 mV.

Right, mean postsynaptic spike responses for eight tested cell pairs versus presynaptic clamp potential. For comparison the postsynaptic spike rate during a strong visual response is plotted (thin dotted vertical lines). The input-output functions keep linear until the postsynaptic spike rate reaches its intrinsic maximum firing rate. The gain of the input-output function differs considerably between cells. The working range of the synapse (i.e. the range over which a change in presynaptic potential induces a change in postsynaptic response) exceeds the naturally occurring presynaptic potentials considerably.




## Literature

1) Kurtz, R. et al. (2001): Transfer of visual information via graded synapses operates linearly in the natural activity range. J. Neurosci. 21:6957-6966.
2) Warzecha, A. K. et al. (2003): Synaptic transfer of dynamic motion information between identified neurons in the visual system of the blowfly. Neuroscience 119:1103-1112.
3) Haag,J. et al. (1999): The intrinsic electrophysiological characteristics of fly lobula plate tangential cells: III. visual response properties. J. Comp. Neurosci.213-234.
4) Haag, J., Borst, A. (2004): Neural mechanisms underlying complex receptive field properties of motion sensitive interneurons. Nat. Neurosci. 7:628-634.

Contribution for the 5th FENS Forum, Vienna 2006 (July, the 12th 2006).

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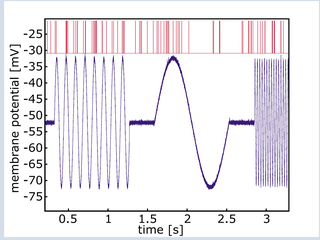
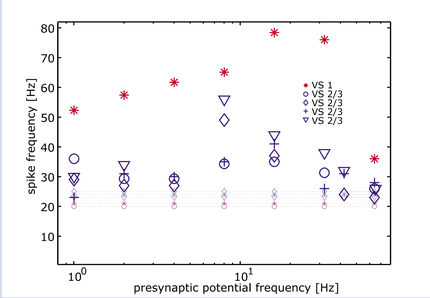
## Dynamic properties of synaptic transmission




Filter properties of the synapse were analyzed by presynaptic application of sine-wave potentials covering a frequency range from 1 - 64 Hz. All frequencies were applied for 1 s. A detail of a recording is shown on the *left*.

The right figure shows the mean spike rates of all tested cells at different presynaptic potential frequencies. Only spikes occurring during the positive halve wave (0-π) were factored in. For comparison, the spontaneous spike rates were also plotted (thin vertical lines). In general, first the spike rate increases slightly with increasing frequency. It peaks at 8 or 16 Hz and falls off at higher frequency. Thus, synaptic transfer can be characterized as slightly band-passed.




## Conclusions

In summary, our results are in agreement with linear summation of several differently weighted presynaptic inputs by V1 with a saturation limit set by V1's maximum spike rate. Two aspects are surprising:

- Single VS-cells can drive V1 to near-maximum spike rates, although V1 normally combines input from several VS-cells
- Single VS-V1 synapses cover a larger working range both in terms of steady-state and dynamic presynaptic depolarizations than expected from naturally occurring graded presynaptic visual motion signals.

These findings seem to contradict the hypothesis that the working range of synapses is matched to the prevailing presynaptic signals. The functional consequence of the large synaptic working range might be the ability to handle the special properties of the presynaptic signals from VS-cells. These consist of signals with distinctly different amplitude and frequency content, i.e. small graded potentials with most of their power during visual stimulation below 10Hz and large spike-like signals which contain much higher frequencies.