

# Dynamics of synaptic signaling from graded potential neurons to a spiking neuron in the fly motion-vision pathway

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## Introduction

Synapses are generally regarded to operate efficiently only if their signaling range is matched to the spectrum of prevailing presynaptic signals, in terms of both amplitudes and dynamics. The prerequisites to optimally match the signaling ranges may, however, differ between spike-mediated and graded synaptic transmission. This poses a problem on synapses which convey both graded and spike signals at the same time. To address this issue transmission was systematically characterized in vivo in the blowfly's visual-motion pathway by recording from single neurons which receive mixed signals consisting of graded potentials with superimposed and highly variable spikes from a small number of presynaptic elements<sup>1</sup>. Pre- as

well as postsynaptic neurons were previously shown to represent preferred-direction motion velocity reliably and linearly at low fluctuation frequencies<sup>2</sup>. To selectively assess the performance of individual synapses and to precisely control presynaptic signals, we voltage clamped single presynaptic neurons.

→ is synaptic filtering tailored to the demands of both graded and spike-mediated signaling?  
→ is the synaptic signaling range adjusted to the presynaptic amplitude and frequency spectra during visual stimulation?  
→ how does the postsynaptic neuron integrate individual synaptic input?

## The recording site

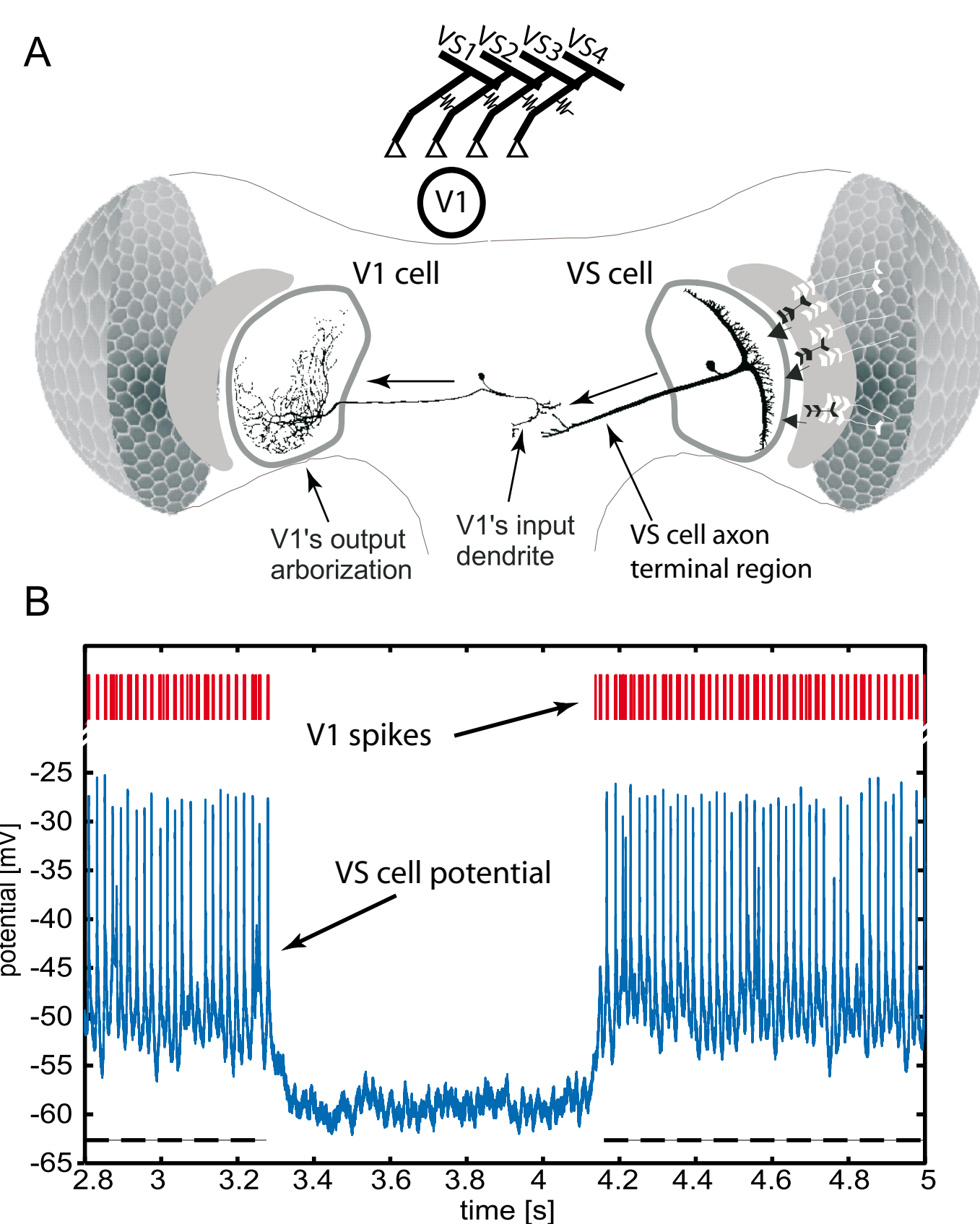
VS-cells get retinotopic input and encode motion information by graded potentials with superimposed spikes.

Neighboring VS-cells have partially overlapping receptive fields and a weak electrical coupling is reported<sup>3</sup>.

V1 receives input from at least 4 VS-cells<sup>4</sup>.

V1 transmits motion information by spikes to the contralateral brain hemisphere.

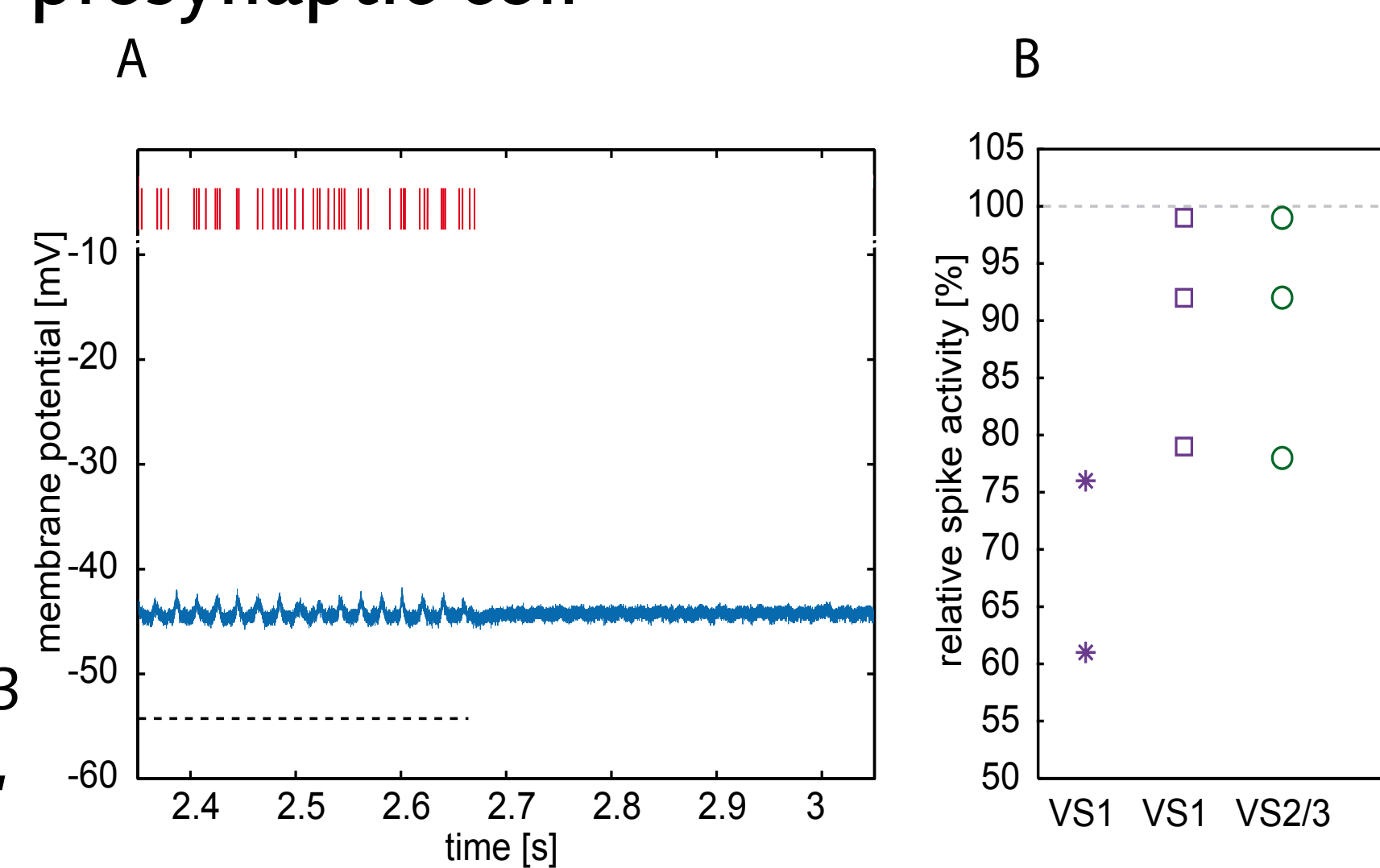
Figure B shows an example recording of neuronal responses during visual stimulation in preferred and null direction. Top traces show registered postsynaptic spikes (V1-neuron), bottom traces the presynaptic potential (VS-neuron).



## Functional inactivation of one presynaptic cell

A functional inactivation of one presynaptic cell is achieved by voltage clamping to its resting potential. Fig. A: postsynaptic (top) and presynaptic (bottom) response to motion in preferred (dashed line) and null direction (no marker).

Fig. B: postsynaptic spike rate relative to condition without voltage clamp in 3 dual recordings. A spike rate reduction, variable in strength, was found in all tested cells.



## Literature

1) Kurtz, R. et al. (2001): Transfer of visual information via graded synapses operate linearly in the natural activity range. *J. Neurosci.* 21:6957-6966

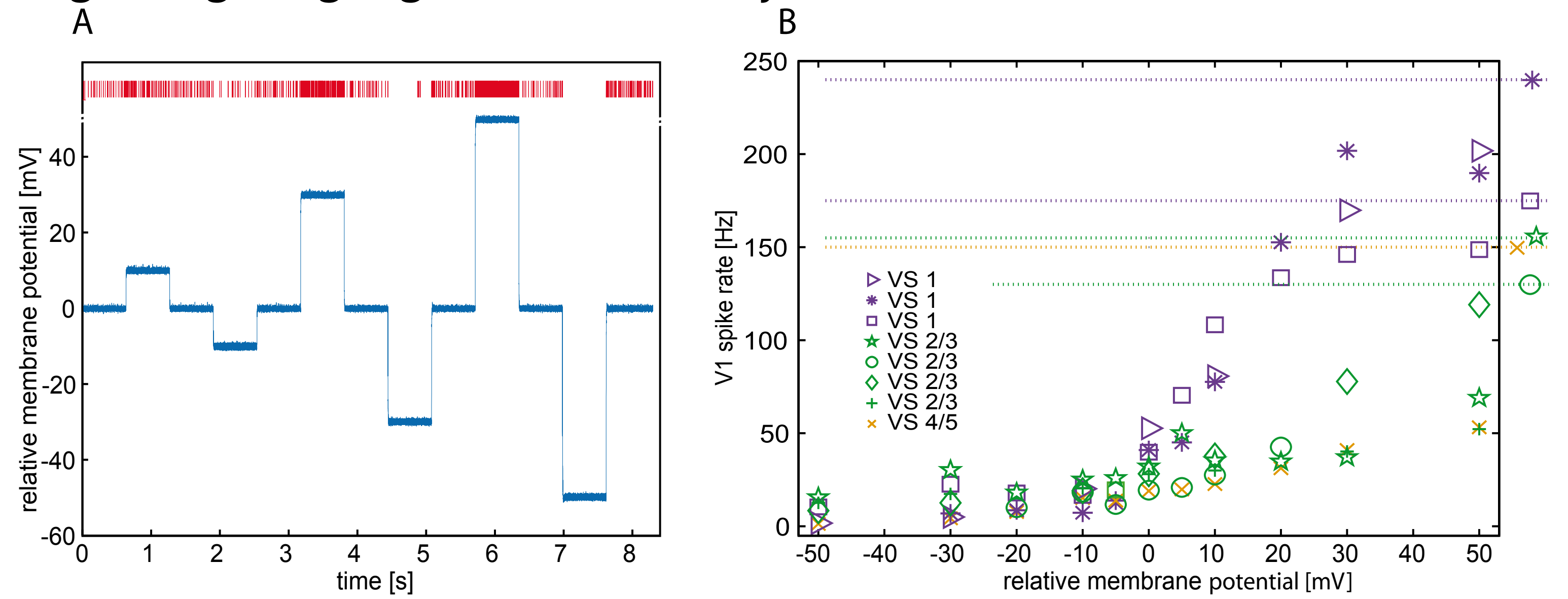
2) Warzecha, A. K. et al. (2003): Synaptic transfer of dynamic motion information between identified neurons in the visual system of the blowfly. *Neuroscience* 119:1103-1112

3) Haag, J., Borst, A. (2004): Neural mechanisms underlying complex receptive field properties of motion sensitive interneurons. *Nat. Neurosci.* 7:628-634

4) Kalb, J. et al (2006): Robust integration of motion information in the fly visual system revealed by single cell photoablation. *J. Neurosci.* 26: 7898-79006

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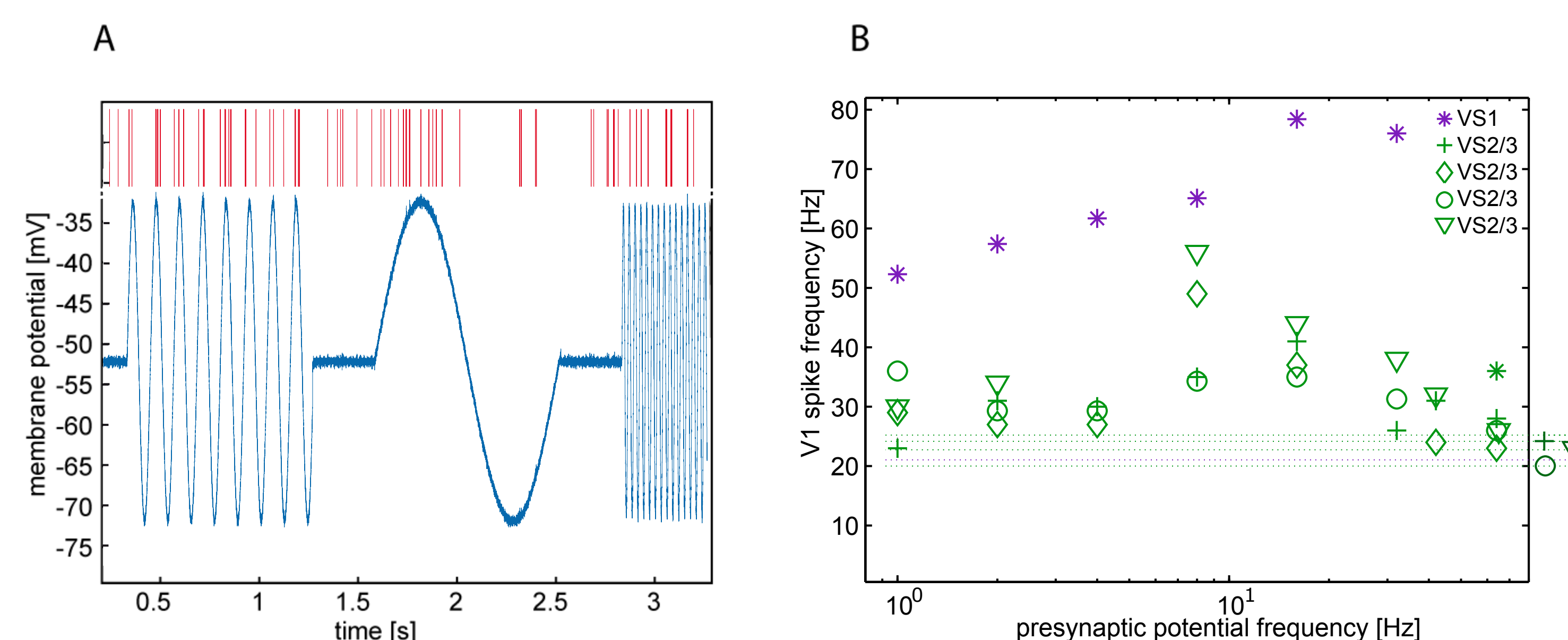
## Signaling range, gain and linearity



Signal transmission at individual synaptic connections was characterized by monitoring the postsynaptic response (V1) to precisely controlled membrane potential deflections of single presynaptic VS-cells in the absence of visual stimulation (example given in Fig. A). Presynaptic potentials were clamped to  $\pm 50$  mV relative to rest, thus exceeded the range of graded potential changes during visual stimulation by far ( $\pm 10$  -15 mV). Fig. B shows the mean postsynaptic

spike responses versus presynaptic clamp potential for 8 cell pairs. For comparison the postsynaptic spike rate during strong visual stimulation is plotted (thin dotted vertical lines). The input-output functions keep linear until the postsynaptic spike rate gets close to its intrinsic maximum firing rate. The gain of the input-output function differs considerably between cells. The working range of the synapse exceeds the naturally occurring presynaptic potentials considerably.

## Dynamic properties of synaptic transmission



Filter properties of the synapses were analyzed by presynaptic application of sine-wave modulated potentials covering a frequency range of 1 - 64 Hz. Fig. A shows a detail of a recording. Fig. B shows the mean spike rates of all tested cells at different presynaptic modulation frequencies. Only spikes occurring during the positive half wave

(0- $\pi$ ) were counted. 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

Our results are in agreement with linear summation of several differently weighted presynaptic inputs by V1, only limited by V1's intrinsic maximum spike rate. Two aspects are surprising:

→ Even 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 transmit spike-mediated signals in addition to the graded presynaptic signals.