Conduction of receptor current through the sensory dendrite of a spider mechanoreceptor neuron

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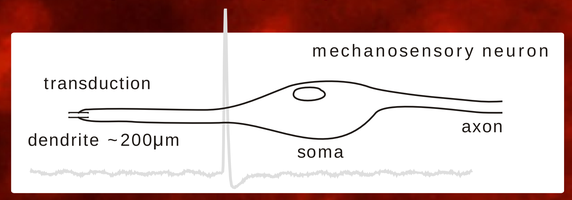
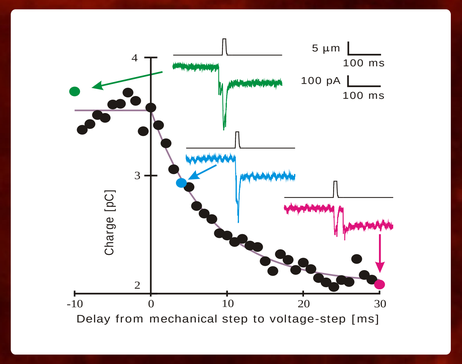
Where does the action potential start?
What are the passive properties of the dendrite?

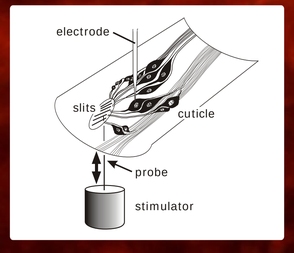




Sensory dendrite voltage jump experiment. A VS-3 neuron was clamped at its resting potential (-69 mV) and stimulated with a 5 µm step mechanical deflection of duration 10 ms. The membrane potential was stepped by -20 mV (hyperpolarizing) at varying times relative to the mechanical step. The main figure shows recovered charge in the soma caused by the mechanical step as a function of delay between the mechanical step and voltage jump.
Recovered charge, Q_0, was fitted by:

$$Q = Q_0 + \alpha^2 V_c g(-s)(1 - e^{-\sigma/\tau})$$

where: Q_0=recovered charge at the resting potential, α=attenuation of receptor potential by the dendrite, V_c=voltage jump, g=conductance change caused by mechanical stimulus (estimated from previous voltage clamp measurements), τ=dendrite membrane time constant and s=delay between mechanical step and voltage jump (Hausser and Roth, *J. Neurosci.* 17: 7606-25, 1997).
For this experiment, Q_0=3.53 pC, α=1.27, τ=7.97 ms.
Inset are shown the actual recordings of mechanical steps from the position transducer and resulting current records at delays of -10 ms (green), 4 ms (blue) and 30 ms (red) corresponding to the same colored points on the main figure.



Recording and stimulating VS-3 neurons. A concave piece of patellar cuticle containing the slits and associated neurons was dissected and mounted in a fixed holder. Slits were displaced by a glass probe driven by a piezoelectric stimulator.

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Introduction

Previous extracellular recordings from insect and spider mechanoreceptors have indicated that action potentials may start at the distal ends of the sensory dendrites in mechanoreceptor neurons. Immunohistochemistry has produced evidence for voltage activated sodium channels in the sensory dendrites of spider mechano-receptors and Pacinian corpuscles.

To test the previous hypothesis that receptor potentials are conducted passively to the somata of spider VS-3 mechanoreceptor neurons, we used three approaches to estimate the passive electrical properties of the sensory dendrites:

- Voltage jump measurements of voltage propagation outwards from the soma
- Frequency response measurements of receptor potential propagation inwards to the soma
- Comparison of receptor potential and action potential timing at the soma following mechanical steps

Methods

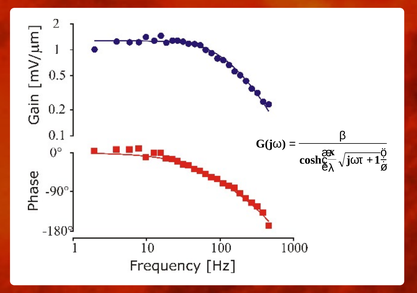
All measurements were made by the switching single electrode current-clamp and voltage-clamp techniques (SEC-05LX amplifier NPI Electronic) using sharp electrodes to penetrate the neuronal somata. Mechanical displacements were applied to the slits by a servo-controlled piezoelectric stimulator (LVPZT, Polytec Physik-Instrumente). All stimulation protocols and data analysis were performed by an IBM-compatible computer using 12-bit digital to analog and 16-bit analog-to-digital convertors (National Instruments) and custom written software.

Summery of Results

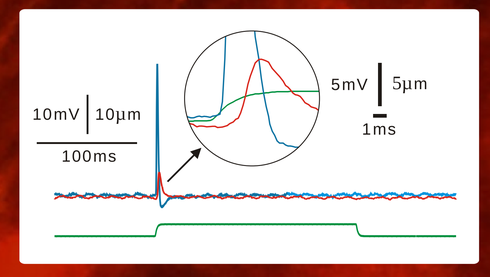
- The sharp transition at zero time delay in the voltage jump experiments indicates that mechanical steps causes a fast, transient (impulse) increase in conductance.
- The mean dendrite membrane time constant of 6.25 ms agrees with previous estimates of ~7 ms in the somata of these neurons.
- The mean dendrite space constant was ~200 µm (significantly less than previous estimates).
- Voltage jump experiments gave a mean value of α=1.11 for dendrite voltage attenuation, which cannot be correct. Frequency response measurements gave α=0.37. The discrepancy means that previous estimates of mechanically induced conductance at the dendrite tips were too low. Mechanically induced conductance must be at least 15 nS for a maximal stimulus.
- The mean transduction parameter α=2.68 mV/µm combined with the action potential threshold in the soma of ~30 mV would give a slit movement threshold of ~10 µm, but the actual threshold is 2 µm. This indicates that action potentials start in the dendrite.
- Action potentials arrived in the soma at least 1 ms before the passively conducted receptor potential. This also indicates that action potentials start in the dendrite.

Conclusions

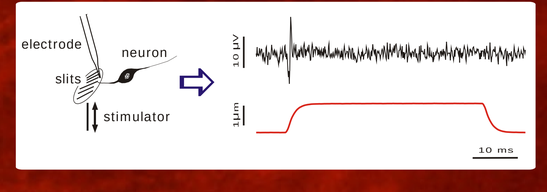
- Sensory dendrites of VS-3 neurons would significantly attenuate and retard a passively conducted receptor potential.
- Action potentials normally arise at a low threshold region in the dendrite tips and propagate actively along the dendrites to the somata.
- Dendritic action potentials would provide the most rapid detection of mechanical events, and facilitate the perception of rapidly changing mechanical signals such as vibrations.
- This situation may be common to other arthropod mechanoreceptors and possibly to arthropod thermoreceptors and chemoreceptors that have similar morphology.



Sensory dendrite frequency response. Gain and phase components of the complex frequency response, $G(j\omega)$, obtained by stimulating a VS-3 neuron with pseudorandom white noise displacement of the slit (0.397 µm RMS amplitude) while recording the resultant receptor potential in the soma under current clamp.
Solid lines are the fitted cable equation shown in the figure; where: β=mechanotransduction voltage sensitivity, x=dendrite length, λ=dendrite space constant and τ=dendrite membrane time constant (fixed at 6.25 ms).
For this experiment, x/λ=1.03, β=1.92 mV/µm



Current clamp response timing. Membrane potential responses in the soma of a VS-3 neuron to a 3 µm step displacement of the slit. The main figure shows superimposed current clamp recordings of membrane potential before (blue) and after (red) application of TTX during the first 25 ms after the mechanical step. The complete recordings, together with the position transducer output (green) are shown inset on a longer time scale. No change in membrane potential occurred after application of TTX, but the action potential was suppressed, leaving a receptor potential of about 5 mV amplitude. Note that the action potential commenced during the rising phase of the movement, whereas the receptor potential rose more than 1 ms later.



Extracellular recording from the dendrite of a VS-3 neuron during mechanical stimulation. Action potentials (upper black trace) were observed by a blunt glass microelectrode placed close to the dendrite (left) following a mechanical step (lower red trace).