NONLINEAR NEURONS IN THE EARLY VISUAL GANGLIA OF INSECTS: NEW RESULTS AND A COMPUTATIONAL MODEL

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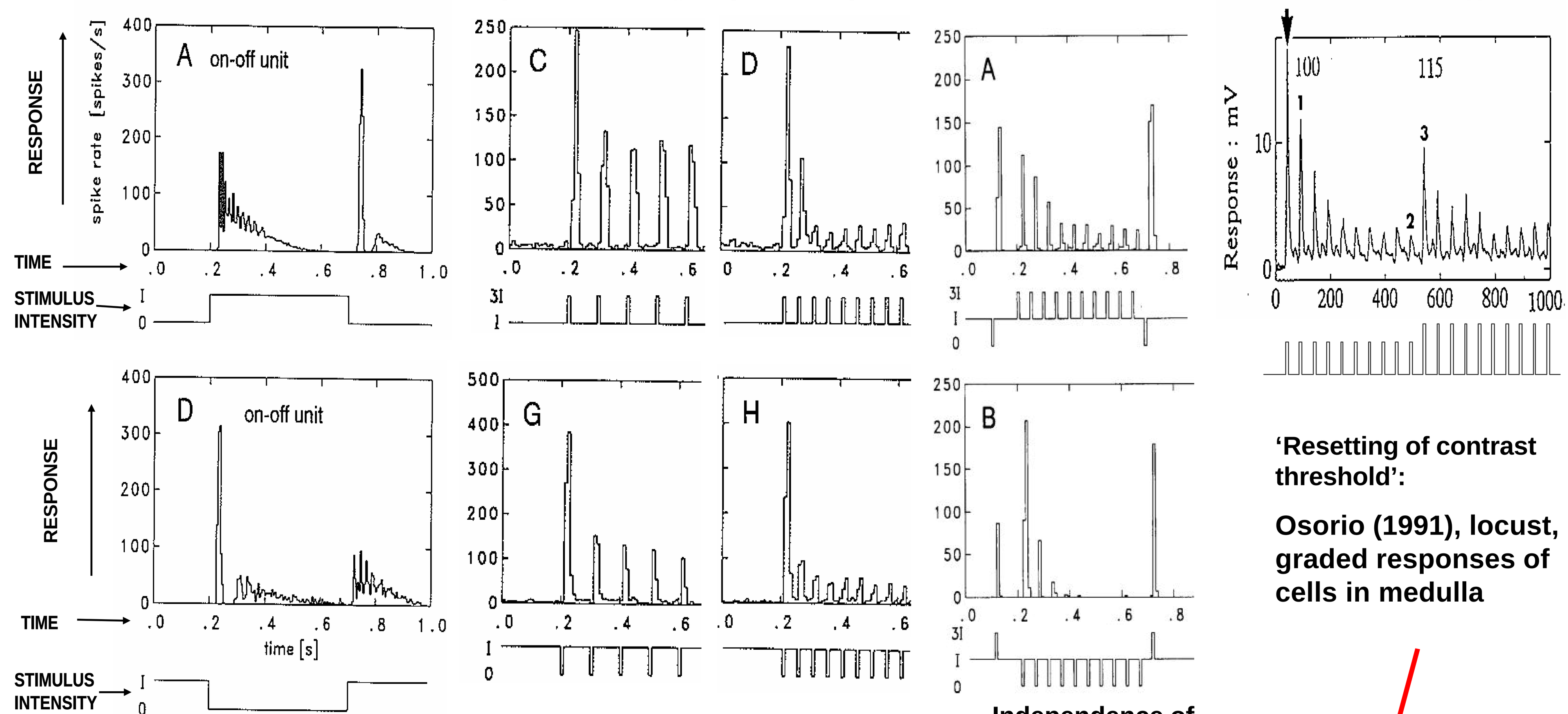
ABSTRACT. In the initial stages of the visual system of insects are found cells with strongly nonlinear (full-wave rectifying) and temporally transient response characteristics to changes in luminance. These include the so-called 'on-off' neurons thought to reside in the first optical ganglion (the lamina), and the 'transient' neurons in the second optical ganglion (the medulla). The 'on-off' cells as identified physiologically are one of only a limited number of cell types in the lamina and suggest a sophisticated level of spatial as well as temporal processing at this relatively early stage of vision. Both cell types show evidence of strong, rapid adaptation. Prior reports have suggested that the temporal acuity and contrast sensitivity of these neurons is lower than for the more nearly linear classes of neurons in the same ganglia, but we present experimental evidence that this is not the case, particularly for temporal response, and suggest that past results may be due to an interpretation of experimental results appropriate for linear systems analysis rather than the system under consideration. We propose a new computational model for on-off cells, with adaptation comprising a subtractive inhibition and occurring after rectifying nonlinearities that separate precursor signals into two distinct, 'ON' and 'OFF' pathways. We also suggest biophysically plausible mechanisms for these computations. This model leads to an interpretation of this class of neurons as detectors of *spatiotemporal novelty*, perhaps especially suited for role(s) in the processing of visual motion.

PREVIOUS EXPERIMENTAL RESULTS

TEMPORAL RESPONSES (stimuli = light pulses (luminance increments and decrements))



Step responses

Rapid adaptation / 'de-adaptation'

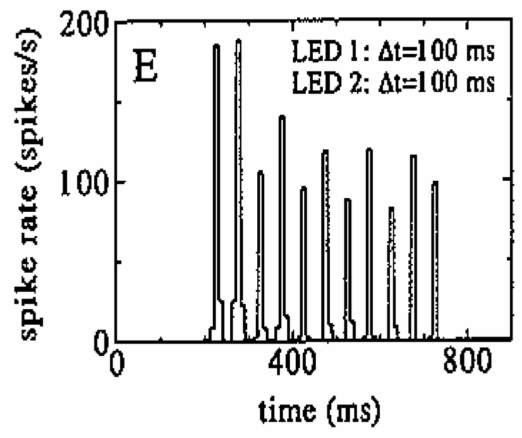
Independence of adaptation to luminance increases and decreases

'Resetting of contrast threshold':

Osorio (1991), locust, graded responses of cells in medulla

Jansonius and van Hateren (1991), blowfly, axons of spiking cells in first optic chiasm (lamina->medulla)

SPATIAL CHARACTERISTICS (stimuli = pulses (luminance increments or decrements) at two locations in receptive field)



Independence of adaptation at different spatial locations

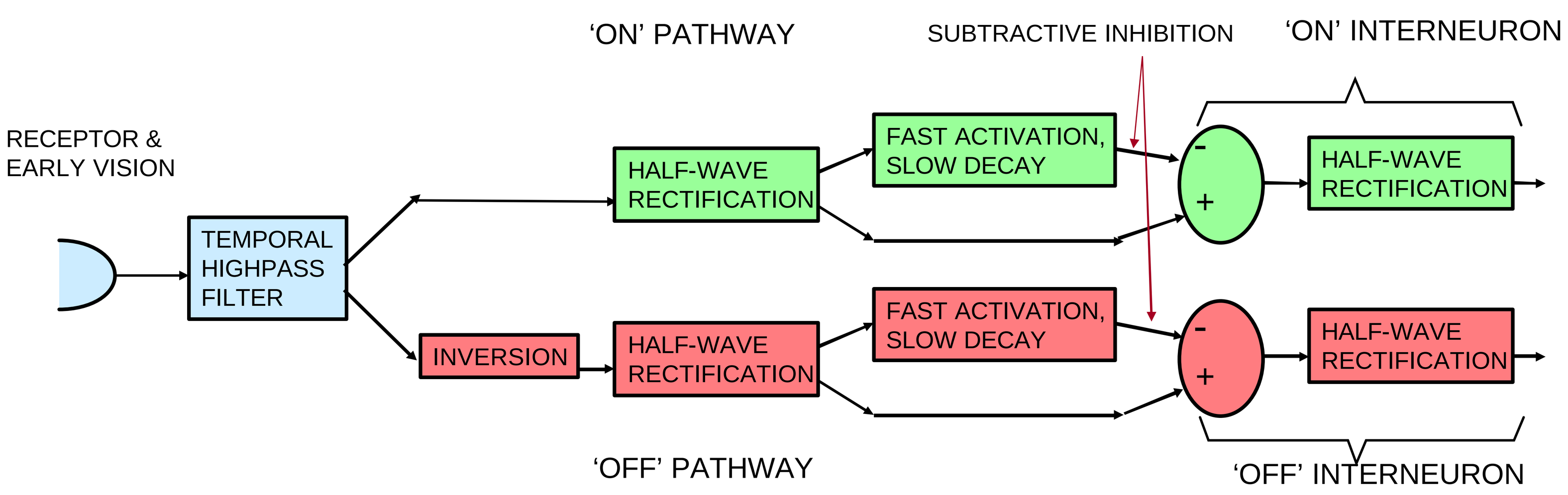
LED1	incr	--	decr	--	incr	incr	decr
LED2	--	incr	--	decr	incr	decr	incr
Relative Response	1	1.00 ±0.09	1.03 ±0.09	1.12 ±0.11	0.72 ±0.05	1.3 ±0.08	1.33 ±0.09

Inhibition by two simultaneous luminance increments; Facilitation by simultaneous changes of opposite sign

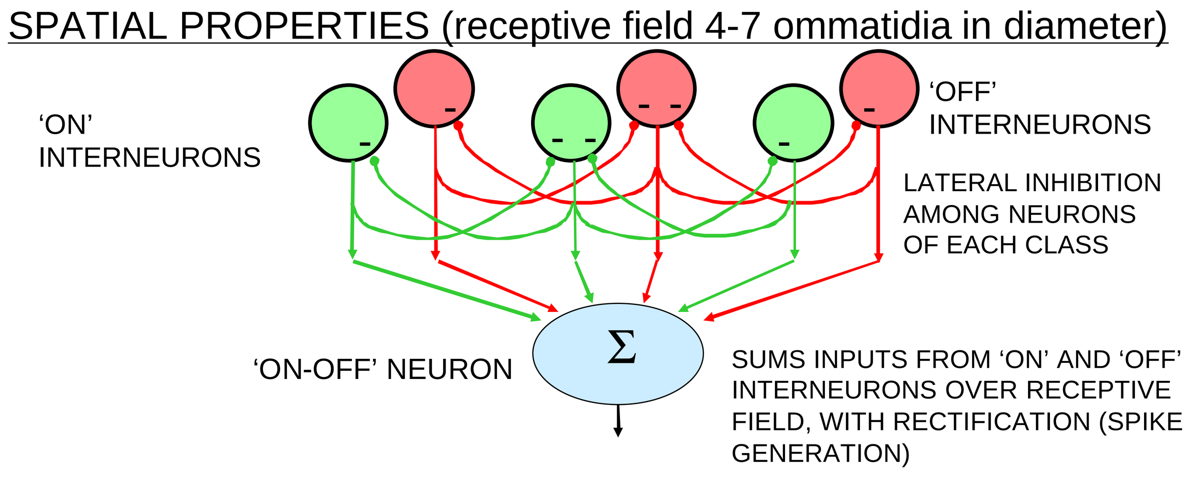
Jansonius and van Hateren (1993), blowfly, axons of spiking cells in first optic chiasm (lamina->medulla)

A MODEL:

TEMPORAL PROPERTIES (single cartridge)



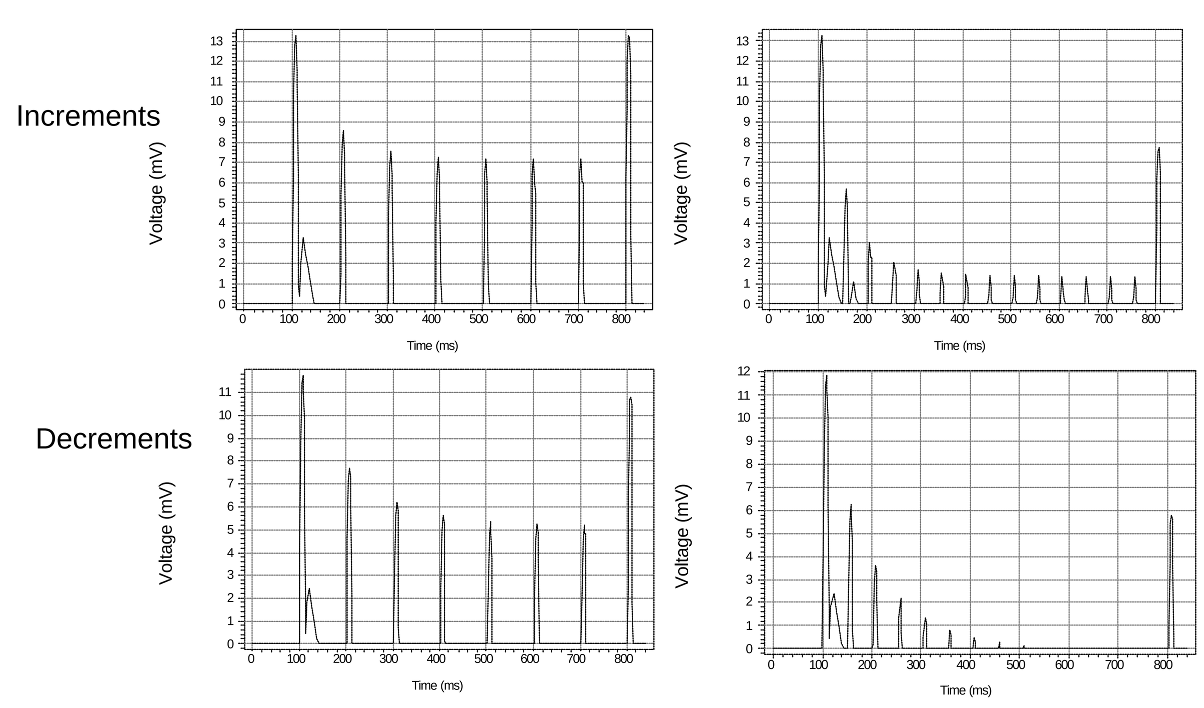
SPATIAL PROPERTIES (receptive field 4-7 ommatidia in diameter)



SOME SELECTED SIMULATIONS RESULTS:

Stimuli comparable to those in Figures C,D and G,H above, except amplitude of final pulse is increased to show 'resetting of contrast threshold'.

Model also displays independence of adaptation for increments and decrements.



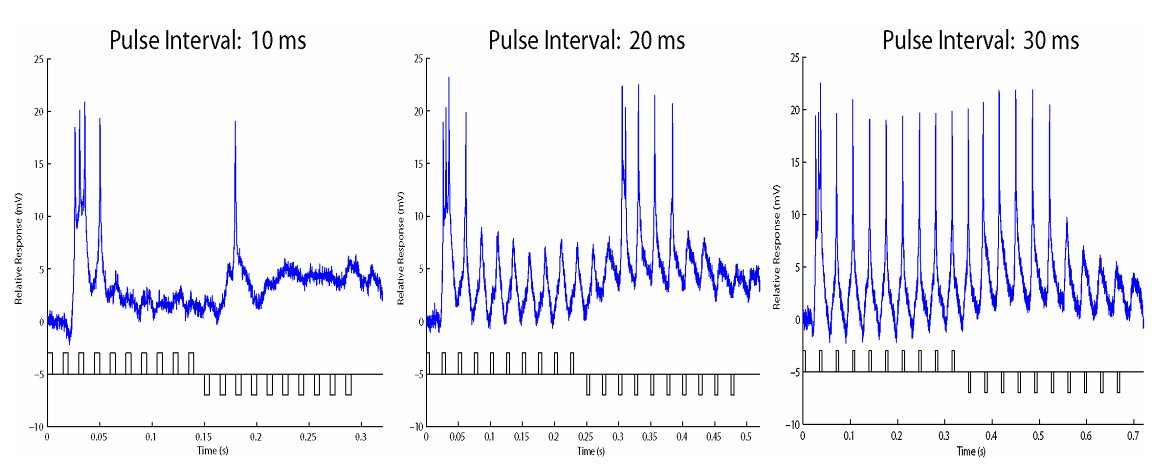
CONCLUSIONS AND PREDICTIONS:

Earlier models differ in placing rectification later in the pathway; a critical test of this model will be response to simultaneous luminance decrements at 2 locations in receptive field (prediction: inhibited response relative to single increment or decrement)

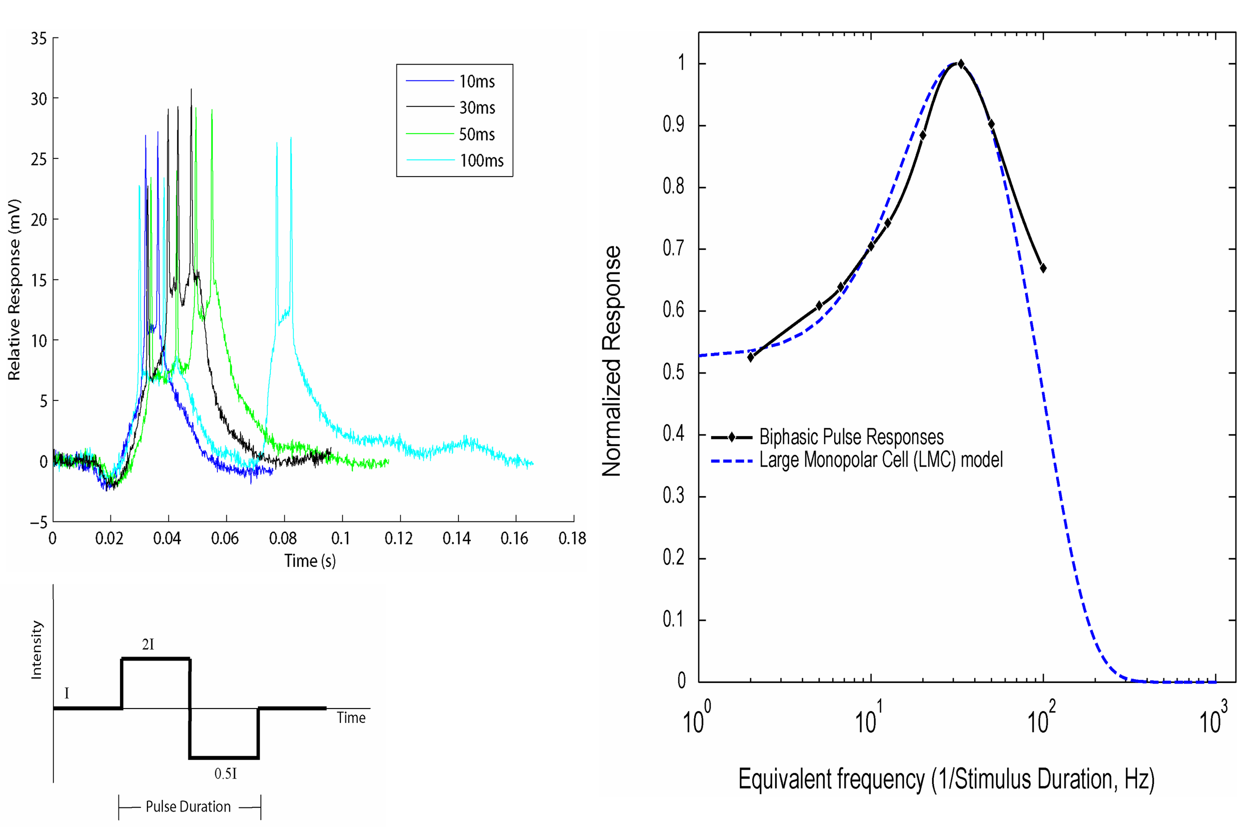
This model suggests these neurons respond to *Spatiotemporal Novelty*: max response to changes in luminance beyond those recently seen, and of opposite sign in different parts of receptive field. Should be especially sensitive to *motion* of small objects (i.e., with positive and negative contrast gradients within receptive field); suggests role in motion detection, in particular, small targets?

Relatively low contrast sensitivity seen in prior experiments may be an issue: will response to low-contrast objects be facilitated by 'right kind' of stimulus (e.g., small moving object)?

NEW EXPERIMENTAL FINDINGS



Above: Independent Adaptation. Electrophysiological recordings of rectified transient neurons from the medulla of the fly. Shows the adaptations to 'on' and 'off' light pulses (5ms) with interval between pulses varied. The intensity change for the increment and decrement values are equal in contrast, with opposite polarity.



Above: Temporal response. Response to biphasic pulses of various durations at left. Note 'on' and 'off' responses fuse with facilitation for 30-50ms durations. Comparison of transient cell response to LMC impulse response in the frequency domain, at right. Jansonius and van Hateren (1991) interpret response to stationary sinusoidal stimuli as indicating 'poor temporal resolution' relative to other laminar cells, but temporal domain response shows they are just as fast.

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