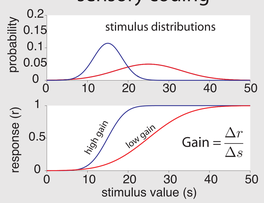
Efficient coding of visual motion signals in area MT and smooth pursuit.

B. Liu and L.C. Osborne
Department of Neurobiology, The University of Chicago, Chicago IL, USA.
THE UNIVERSITY OF CHICAGO

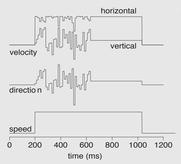
1. Introduction:

Performance in sensory-motor behaviors guides our understanding of many of the key computational functions of the brain: the representation of sensory information, the translation of sensory signals to commands for movement, and the production of behavior. Eye movement behaviors have become a valuable testing ground for theories of neural computation because the neural circuitry has been well characterized and eye movements can be tightly coupled to cortical activity (Osborne et al., 2005-9). Here we show that smooth pursuit eye movements, and the cortical sensory signals that mediate them, demonstrate the hallmarks of efficient sensory coding. Barlow (1961) proposed that neurons should adapt their sensitivity as stimulus conditions change in order to maintain efficient coding of sensory inputs. Evidence for efficient coding of temporal fluctuations in visual contrast has been observed in the retina, lateral geniculate nucleus, and visual cortex (Wark et al., 2009, Sharpee et al., 2006). We asked whether adaptation to stimulus variance generalizes to higher cortical areas whose neurons respond to features of visual signals that do not drive adaptation in the sensory periphery, and whether such adaptation impacts performance of visually-driven behavior. Specifically, we have studied the impact of dynamic fluctuations in motion direction on the gain of smooth pursuit and found neural correlates of pursuit adaptation in cortical area MT.

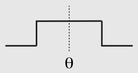
Barlow's hypothesis of efficient sensory coding



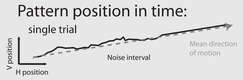
2. Experiments:



Stimuli: Stochastic motion perturbations (in direction or velocity) drawn from a uniform distribution



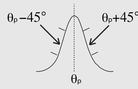
Pattern position in time:

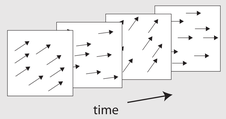


Pursuit Experiment: perturbation is applied to translation of target across screen

MT Experiment: motion perturbation applied to within aperture motion of a random dot kinetogram in the RF

Extracellular single unit recording in awake, fixating monkeys



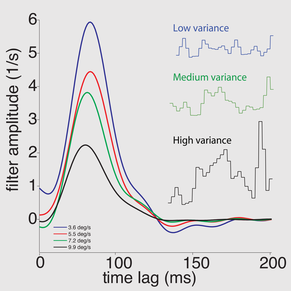


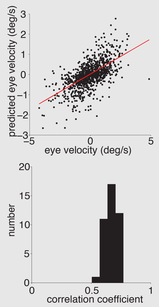
3. Linear analysis:

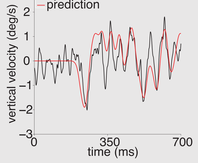
Response gain scales inversely with motion variance for MT neurons and pursuit

$$\hat{e}(t) = \int_{-\infty}^{t} d\tau h(\tau) s(t-\tau)$$

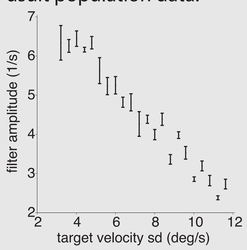
Pursuit



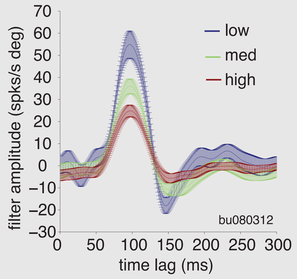


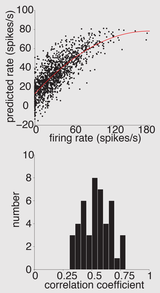


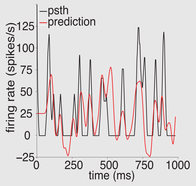
Pusuit population data:



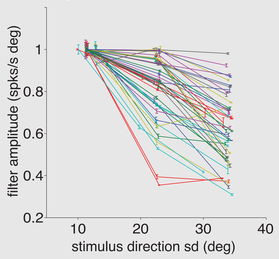
MT neurons



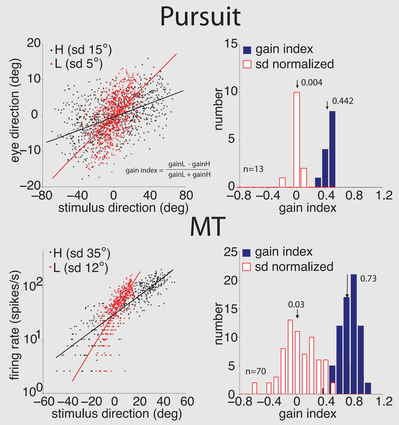




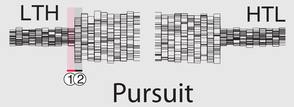
MT Population data:



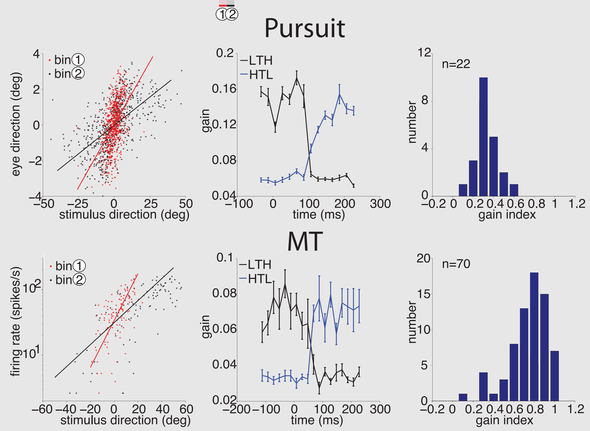
4. Gain adaptation to target motion variance:



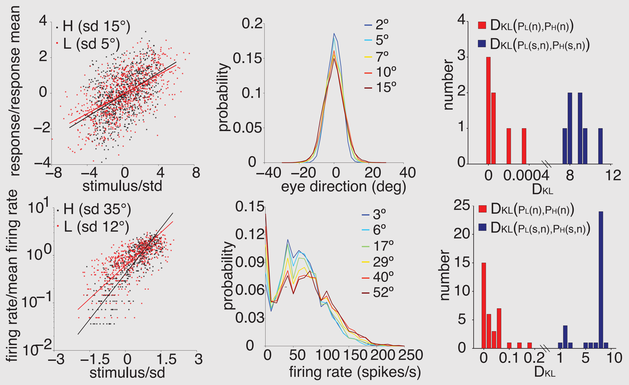
5. Dynamics:



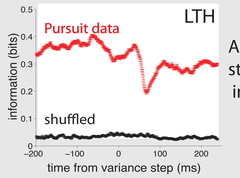
step change in motion variance



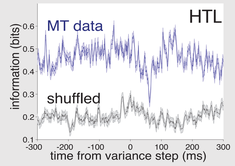
6. Equal gains with SD scaled stimulus



7. Mutual information



Adaptation maintains stimulus information in pursuit behavior



Adaptation may maintain stimulus information in MT neural responses

8. Discussion:

Motion senstive cortical neurons encode time-varying motion signals efficiently by rapidly adapting the gain of their responses to changes in stimulus variance. Neural sensitivity to fluctuations in motion (direction or velocity) is therefore context-dependent. When the variance of motion signals shifts, MT neurons rescale their gain to maintain a similar distribution of firing rates, avoid saturation, and optimize motion contrast sensitivity. Pursuit eye movement behavior -visual tracking of a moving target - benefits from efficient cortical coding of motion. When target motion variance is low, pursuit and cortex become more sensitive to perturbations and vice versa such that the information encoded about motion remains constant. The gain adaptation is rapid. Shifts in the joint distribution of stimulus and response are substantial within 20ms. Detecting the variance step from neural or pursuit responses within single trials requires a longer integration of sensory evidence. We find that these gain changes cannot be accounted for by saturation - they occur when the highest observed firing rate is below the peak firing rate of the neuron (or eye velocity), however this work does not identify a mechanism. These data suggest that feature selective cortical areas are themselves capable of efficient sensory coding and that efficiencies in cortical coding can be relevant to behavioral performance.

1. Barlow HB. Sensory Communication, 217-34, 1961. 2. Osborne LC and Lisberger SG. J Neurophysiol 102: 2013-25, 2009
3. Osborne LC, Lisberger SG, Bialek W. Nature, 437: 412-6, 2005. 4. Sharpee TO, Sugihara H, Kurgansky AV, Rebrik SP, Miller KD. Nature, 439: 936-42, 2006.
5. Wark B, Fairhall A, Rieke F. Neuron 61: 750-61, 2009. 6. Wark B, Lundstrom B, Fairhall A. Curr Opin Neurobio 17: 423-29, 2007.

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