Synergistic Coding of Multiple Stimulus Parameters in MT and Implications for Smooth Pursuit

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Introduction
Analysis of sensory-motor behaviors can be very useful for increasing our understanding of the computations being performed by circuits within the brain. Visual smooth pursuit, a task in which the eyes move to stabilize the retinal image of a target, provides an ideal testbed for this type of analysis, as minimal motor noise is added to initial sensory estimates of an object’s retinal image motion. Neurons in the middle temporal area (MT) of the primate extrastriate visual cortex have been shown to be selectively responsive to retinal image motion, and exhibit direction and speed-preferential spike tuning. Here, we use information theory to analyze how MT neurons’ responses can simultaneously code for direction and speed of stimulus motion, and if synergy in their responses persists to the level of smooth pursuit behavior. We define synergy as the difference between the information about the joint stimulus distribution and the sum of the information about direction and about speed (Brenner et al., 2000). We record individual neurons’ responses to motion steps, finding that within 100ms of the onset of stimulus motion, all cells in our sample exhibit synergistic coding of these two parameters while also exhibiting separable tuning. We also examine the mutual information between stimulus motion and eye velocity in macaque smooth pursuit, finding that there is more information about the joint encoding of stimulus parameters than about the sum of them. We ask whether the observed synergy is due to effects of pairs of spikes encoding more information about the stimulus in their ISI than the sum of the information carried by both spikes separately, and find that the sampled cells range from synergistic temporal encoding to redundancy, failing to account for the homogeneity of synergy.

Experiments
MT Task Pursuit Task

Decoding Models
Vector Decoding Scalar Decoding

Poisson model unit

Temporal coding from spike pair synergy

Speed and direction are encoded synergistically in MT neurons and pursuit

Discussion
Direction and speed tracking errors during pursuit initiation are correlated. Eye direction-speed covariation is not predicted by vector-averaging decoding models or by the 2D structure of tuning in MT neurons. Despite the separability of MT tuning functions, direction and speed are encoded synergistically in single unit responses, and thus more information can be decoded about theta, v jointly (the motion vector) than the sum of information about the components individually. The synergy in direction-speed coding in MT arises from the tuning function itself and a Poisson model generates the same “synergy”. An analysis of two spike patterns shows that MT neurons can be truly synergistic and encode more information with temporal patterns than in the firing rate. We conclude that a “motion vector” rather than “component” (scalar) decoding model may recover more motion information and better predict behavioral data.


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