

Resolving the paradoxical energy efficiency of retinothalamic transmission

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In the mammalian early visual system, each action potential generated by a retinal ganglion cell (RGC) must first activate relay cells in the lateral geniculate nucleus (LGN) before reaching visual cortex. During active vision, only a fraction of the spikes travelling along the optic nerve successfully fire a thalamic relay cell, which incurs a 2 to 4-fold reduction in total number of spikes across the retinothalamic synapse in monkeys and cats. According to Barlow's principles of efficient coding (Barlow 1961), a minimum number of impulses should be used to encode as much information as possible, which implies that the retinal and thalamic neural codes cannot be equally efficient: If the retinal code is efficient, then the LGN must be losing significant amount of information by relaying only a small fraction of retinal spikes; however, if the thalamic code is efficient, then the retina must be wastefully generating many redundant spikes that convey little information. Recent work suggested that the thalamic code is more efficient because the retinothalamic synapse selectively relays the most informative retinal spikes, thereby preserving the most important information (Sincich et al. 2009; Rathbun et al., 2010; Wang et al. 2010). This raises an obvious question: Why do RGCs generate so many *useless* spikes, spikes that will never reach the visual cortex? Is this a waste of energy?

We resolved this paradox by determining the RGC code with the highest energy efficiency that synaptically drives a given LGN code. The statistics of RGC and LGN spike trains obtained from recordings (Wang et al. 2010) were analyzed with the Berger-Levy theory of energy efficient synaptic transmission (Berger & Levy 2010), which is based on an integrate-and-fire model neuron. This theory predicted that to achieve the highest amount of transmitted information per unit energy expenditure the number of presynaptic spikes should be 2 to 4-fold greater than the number of thalamic spikes, consistent with experimental observations. This suggests that the retinal spike code, despite its relative inefficiency compared to the thalamic spike code, serves as an energy-efficient substrate for the generation of the thalamic code that ultimately transmits visual information to the visual cortex.