Energy efficiency of retinothalamic transmission

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In the mammalian early visual system, each action potential generated by retinal ganglion cells (RGCs) has to be relayed by relay cells in the lateral geniculate nucleus (LGN) in order to reach visual cortex. During active vision, only a fraction of the spikes travelling along the optic nerve, however, successfully fire a thalamic relay cell, giving rise to a 2 to 4-fold reduction in total number of spikes across the retinothalamic synapse (Sincich et al. 2009; Rathbun et al., 2010; Wang et al. 2010). According to Barlow's principles of efficient coding (Barlow 1961), that as few impulses as possible should be used to encode as much information as possible, the retinal and thalamic neural codes thus cannot be both efficient, explained as follows. 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 generating many redundant spikes that convey little information. Recent work suggested that the retinothalamic synapse selectively relays the most informative retinal spikes, thereby achieving a rough preservation of information (Sincich et al. 2009; Rathbun et al., 2010; Wang et al. 2010). Why do RGCs generate so many "redundant" spikes at the first place, given that those spikes will never reach the visual cortex? Is this not a waste of energy?

Here we attempt to shed light on this paradoxical situation by asking what RGC code is the most energy efficient one that synaptically drives a given LGN code. We applied the Berger-Levy theory of energy efficient synaptic transmission (Berger & Levy 2010) which is based on an integrate-and-fire model. Counterintuitively, the theory predicted that the highest amount of transmitted information per unit energy expenditure is not achieved when the ratio of numbers of pre- over postsynaptic spikes is equal to one. By taking the RGC and LGN spike train statistics obtained from experimental data (Wang et al. 2010) as well as assuming that each RGC spike is equally costly as compared to an LGN spike and that there is little housekeeping energy expenditure, the theory predicted that a 2 to 4-fold reduction in number of spikes is required to achieve maximum energy efficiency of information transmission, consistent with experimental observation. Our findings suggest that the retinal code of seemingly excessive number of spikes serves as an efficient substrate for the thalamic spike code, even though it is not an efficient code by itself.