The Lateral Geniculate Nucleus - Not a simple relay

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Main Takeaway

- LGN is traditionally presented as a relay structure
- This article presents the LGN as a structure that performs a diverse set of functional processes
**Layout of the LGN**

- LGN receives driving input from the retina and projections drive visual cortex (V1).

- Retinal projections are segregated by eye function as they enter the structure.

- This organization forms the basis of the retinotopic map in V1.

Nassi & Callaway, 2009
Retinal Driving of LGN Neurons

- Retinal inputs can elicit action potentials in LGN neurons, and smaller EPSP’s called S-potentials measured extracellularly.

- This neuron is operating near 50% efficiency.

Weyand, 2015
Classical and Extra-classical Receptive Fields

- Classical Receptive Fields (CRF) can be modeled as the sum of two Gaussians
- Stimuli presented to Extra-classical Receptive Fields (ECRF) modulate the response to stimuli in the CRF

Jeffries, Killian, & Pezaris 2014
Thalamic and Cortical Interactions

- Feedback projection from Layer VI of visual cortex and ascending projections from the brain stem

Weyand, 2015
Function 1: “Housekeeping”

- The LGN re-orders and segregates the input from the retina by
  - Eye
  - Functional group
  - Center Polarity

- This computational efficiency allows for efficient access of non-retinal inputs to selective populations of retinal groups.
Supports for Amplification and Integration

- Feedforward inhibition and lagged cells
  - Implements a form of feedforward inhibition not found in the retina
  - Generates temporal diversity

Weyand, 2015

Feedforward inhibition

Weyand, 2015
Functional Properties of Lagged Cells

- Panel (a) shows the probability that a nonlagged cell will respond after receiving retinal input.

- Panel (b) shows that a lagged cell, after an initial probability of being triggered to fire, the probability of firing decreases.
  - The sole excitatory input to the cell has the effect of inhibiting it.

Saul, 2008
Functional Properties of Lagged Cells

- Panel (a) shows the a nonlagged cell’s excitatory transient response to a spot flashed at four levels of luminance.

- Panel (b) shows that a lagged cell responding with an inhibitory, followed by a slow build in activity.

Saul, 2008
Function 2: Retinal Signal Amplification

- Amplification by multiplexing generates copies of the same retinal ganglion cell
  - When implemented with lagged cells, creates differences in efficiency among LGN Neurons

- Because the LGN neurons are driven by a single RGC, the possibility for inducing synchronic activity in cortex

Weyand, 2015
Function 3: Integration of Retinal Inputs

- Integration of retinal inputs creates receptive fields in the LGN that have no retina counterpart.

Weyand, 2015
Amplification/Integration in Different Species

- Monkeys
  - S-potential analysis shows LGN neurons are predominantly driven by single RGC
  - Multiplexing is not common in Monkeys

- Cat
  - LGN Y-cells in cat are most commonly driven by multiple RGC’s
  - Multiplexing of retinal input in the cat is rampant, yet is minimal in the monkey.
Function 4: Luminance and Contrast Gain Control

- Contrast changes can vary by orders of magnitude
  - To maintain sensitivity absolute coding is not implemented

- Contrast gain control mechanisms distributes sensitivity across contrast ranges.
  - Maximal at low contrast, minimal at high contrast

- Produces a scaled output sensitive to local conditions, not absolutes

Mante et al., 2005
**Candidate Contrast Gain Control Mechanisms**

- Triadic Glomerulus: active at high levels of retinal activity, increasing inhibition of relay cells and decreasing gain.

- Magnocellular and parvocellular neurons in the retina and LGN differ sharply in contrast gain control.
  - Magnocellular neurons are more sensitive at lower contrast. (Saturates ~.1)
  - Parvocellular neurons retain a linear correlation with contrast. (Saturates ~.64)

- LGN modeling studies were very successful if both luminance and contrast are held within the range associated with viewing natural images.
Function 5: State affects retinogeniculate transmission efficacy

- Efficacy increases as state moves from slow-wave to REM to wakefulness.

- LGN anatomy provides a mechanism for this to occur.

- Reality has efficacy hovering at ~50%.
Function 5 (continued)

- State-dependent effects appear tied to visually driven activity, state effectively amplifies retinal signals in an activity-dependent manner.

- In wakefulness, longer interspike intervals between retinal spikes has greater success in driving LGN spikes than it does under anesthesia.
Function 6: Cortical Feedback Provides Context

- Neurons in layer VI provide a large feedback projection to LGN
  - The principle of graceful degradation “Puts sensory input into the proper perceptual ballpark”

- Initial processing in LGN feeds to cortex, which is then fed back to the prior stage, provides context based on cortical activation
  - Cortex operates as an agent that prunes retinogeniculate activity into a more selective product.

Sillito, Cudeiro, & Jones, 2006
Activity with/without Cortical Feedback

- Two orthogonally drifting gratings
- Without feedback, stronger but more variable response
- With feedback, less active, but also more selective

Sillito, Cudeiro, & Jones, 2006
Temporal Coding of Spatial Information

- Unique checkerboard patterns were presented with center at CRF, and extending beyond

- Temporal signatures uniquely identified each pattern

Golomb et al., 1994
Temporal Diversity

- There is temporal diversity in the LGN, meaning that different response latencies exist in LGN than in retina.

- This property supports 2 underlying functions of the LGN:
  - Efficient coding
  - Directional selectivity
Function 7: Efficient Coding of Retinal Input

- The visual system has evolved to optimally encode natural image statistics.

- Efficient coding of retinal input
  - Visual input from real images is highly redundant.
  - Lagged cells can support de-correlating these redundant images, increasing efficiency.
Function 8: Support for Directional Selectivity

- Response of lagged cells is shifted about a quarter cycle, relative to nonlagged cells

- Combined signals producing constructive interference signals motion in one direction, destructive information signals motion in other direction

Saul, 2008
Oculomotor Signals

Two sources of oculomotor signals that may modulate LGN activity:

1. Corollary signals: copy of a motor output signal (from motor cortex) sent to LGN

2. Proprioceptive signal: signal from muscle spindle receptors
Function 9: Mixing of Oculomotor Signals

This leads to 2 purposes:

1. Saccadic suppression (allows us to realize what is actually moving, rather than where our eyes are moving during these saccades)
2. Retinal reafference (disambiguates self-movement from movement of environment)
Function 10: Head-centered Frame of Reference

- Establishing head-centered frame of reference begins in LGN

- Motion In occluded eye still generates a signal in LGN when first initiated, then stops when eye comes to rest in new steady state
Questions?

- Why don't all animals use the mechanism of LGN amplification and integration of retinal inputs, given that this mechanism is functional? What are the possible downsides of such a mechanism?

- What are ways that we can begin to test these types of functions in humans? (i.e. Are these functions implemented in human LGN?)

- What role does LGN play in common motion illusions (apparent motion, motion adaptation)?