Discussion Paper (10/26)

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The tuning properties of V1 neurons differ greatly over the response and layers of V1. Individual V1 neurons have strong tuning to a small set of stimuli, and can fire strongly in response to only particular visual orientations. In V1, and primary sensory cortex in general, neurons with similar tuning properties tend to cluster together as cortical columns.
Hubel and Wiesel proposed the classic ice-cube organization model of cortical columns for two tuning properties- ocular dominance and orientation but this model cannot accommodate the color, spatial frequency and many other features to which neurons are tuned. The exact organization of all these cortical columns within V1 and how LGN inputs feedforward circuits operate is still researched. The mathematical modeling has shown through Gabor transforms that local signals may produce the holistic response we see. However, these mathematical models may not tell us everything about how LGN inputs are transformed in animal models, nor can it yet explain some of the feedback we may see in LGN (perhaps explains LGN data in the Roth et. al paper).

Neurons in V1 are also sensitive to the more global organization of the scene (Lamme & Roelfsema, 2000). These response properties probably stem from recurrent feedback processing, he influence of higher-tier cortical areas on lower-tier cortical areas (as discussed in previous articles with area MT and the pulvinar). Lateral connections from pyramidal neurons may also drive feedback for the visual system (Hupe et al. 1998). Feedforward connections are thought to drive the visual perceptual process while feedback connections modulate our visual scene (Angelucci et al., 2003). Feedback originating in higher-level areas such as V4, IT, or MT, with bigger and more complex receptive fields, can modify and shape V1 responses, accounting for contextual or extra-classical receptive field effects (Guo et al., 2007).

Cells with high orientation selectivity have been found in the lateral geniculate nucleus of mice but have shown to have different properties as compared with other animals. Orientation bias was reported in cat LGN neurons and orientation-selective responses were also observed in human LGN using functional magnetic resonance imaging as we saw in previous literature. In mice, inactivating the visual cortex does not affect orientation tuning in the LGN indicating that cortical feedback is not the source of LGN orientation selectivity. Recordings also revealed that even though specific layers of mouse V1 get limited thalamic afferent signal, circuits within V1 also may tune those inputs. LGN neurons send tuned inputs to V1- the mouse LGN provides orientation-tuned presynaptic inputs to V1, and that presynaptic boutons with high orientation selectivity might constitute as much as half of the thalamic inputs in layer 4.

Neurons in the shell project to layers 1 and 2 whereas in the core they project to layers 4 and 6. It's harder to access layer 4 and derive what input it gets, so it's difficult to prove if the summation of input mean that overlapping on and off subregions can create a simple cell that is orientation selective. Thus this study aim to focus on single LGN inputs instead the summation of inputs produced by the V1 neuron. It's tests the original Hubel & Weisel cat model that proposes that summation of inputs from LGN create the orientation selectivity we see in V1. The first figure shows how they were able to track signal changes in the LGN inputs at the level of the boutons. The virus effected the calcium indicator GCaMP6s and showed pathway between

LGN and V1- that were particularly prominent for layer 4. When comparing cells in layer 4 to those in layer 1, they found that layer 4 was more axon-packed and had greater selectivity. The df/F maps showed similar responsiveness for the layer 4 and layer 1 cells. The cells were insignificantly selective to orientation as shown in figure 2i and 2j, the strongest orientation selectivity is shown in the second to last figure and last two figures of layer 1 also have high selectivity index. Figure 3 shows that layer 1 had the strongest orientation selective neurons, and layer 2/3 had some orientation-tuned LGN axons. Feed-forward inputs from LGN arrive in layer 4, with collaterals to layer 6, and feedback inputs from other cortical areas arrive mostly in superficial layers. Feed-forward outputs to other cortical areas depart from layer 2/3, feedback outputs to the thalamus depart from layer 6, and outputs to other subcortical targets depart from layer 5. Broadly speaking figure 3 shows orientation selectivity and 4 is direction selectivity and they're seeing how these properties differ in LGN axons and V1 neurons in different layers. Layer 4 has significantly lower DSI than layer 1 neurons.

As you mentioned it's important to understand the difference between OSI and Preferred Ori in the charts; the orientation preference question which bars (orientation) the neuron best responds to whereas selectivity defines how much it likes a certain bar (orientation) as compared with other ones.

Neurons, in the Kondo article, prefer 90 and 0 (it may be horizontal or vertical, respectively) and respond most strongly to that. These represent cardinal direction, the residual cardinal bias will be tuned only for horizontal and vertical directions and movement (up or down). Orientation and direction tuning in the mouse can thus be seen at the level of the RGC and LGN can have higher preference and orientation preference. Population of neurons tuned to left-right or up-down direction can synapse in layer 4 and be directional selective without the summation of inputs predicted by Hubel and Weisel model. But their model may be held up still since the line-up of selectivity in layer 4 (shown in figure 2) may show that it is generated based on alignment of responses to an orientation. In figure 3 a, b, c the distribution of orientation selectivity is not very selective, the neurons however show a larger range of selectivity. There is a bias for cardinal direction in axons but not in neurons.

Roth et.al paper

The other paper tries to get the function of input from LP and other areas, and they show some similar data to the Kondo article. Both had shown that the layer 2/3 neurons had been much more orientation selective. The gOSI is similar in each at 0.3 and 0.4, these difference can be explained by the particular methods each experiment used. This study aims to compare the function for axon inputs from LGN or LP. For some background, LP doesn't get input from retina, but from many visual areas; LP gets input from many area, being a higher order thalamic nuclei like Pulvinar.

The Sherman and Guillery hypothesis states that the Pulvinar integrates info from multiple visual areas (Guillery & Sherman, 2006). This hypothesis attempts to parse the drivers and modulators in the early visual system. The drivers represent the main information to be relayed, and the modulators modify the thalamocortical relay. Although retinal inputs are thought to be the main source of information for geniculate relay cells they only make up 5% synapses (Van Horn et al.,

2000). Information is needed from higher order modulatory synapses like those in the Pulvinar and LP. The LP often works in concert with the Pulvinar, since the pulvinar contains some input from the midbrain that appears to be driver (Kelly et al., 2003), the lateral posterior nucleus receives driver input thus it can help integrate motor and visual inputs. The dLGN receives direct retinal signals and can relay to V1, so it may be modulated by higher order nuclei. In the LGN there is more direct retinotopic mapping whereas LP may show coarser retinotopy. LP and dLGN both respond to saccades and movement as it maps the visual scene, but LP may be the main source of information in discerning visual motor continuity.

The first figure highlights the anatomy of LGN, V1 and LP, each with different taggers. An important distinction between this and other animal models may be that mice interneurons are essentially missing from all thalamic nuclei except the lateral geniculate nucleus (Arcelli et al, 1997). The transfer of information by dLGN into V1 and cortex is thus important to how it will integrate visuomotor information and feedback. Figure 1c shows the actually experiment for tagged virus, tdTomato was used for recording axon boutons in LP. LP boutons were restricted to layer 1 and 5. In mice the layer 5a is somewhat an extension of layer 4, and in the mice all layers will get thalamic inputs. The dorsal LGN is somewhat modulated by the ventral LGN, and it will In the last figure of 1c, distribution of boutons in layer 1 is somewhat striated (shows subliminar differences) however this is mostly covered by the axons.

In figure 2c the top shows not directional selective bowtie shape, but these have good OSI and bottom- very directional selective. In figure 4 in the Kondo paper, layer 4 neurons gave a higher gOSI than layer 2/3 but they seem to have the same directional selectivity, this however doesn't seem to be the case for the Roth paper figure 2. The single LGN bouton change respond to single polar orientations (0 or 90 degrees), and LP similarly shows some direction sensitive neuron. Based on how much they overlap you can tell the stage the cells are it in perception, showing that thalamus can carry info that contains orientation sensitivity but that may be more finely computed by V1.

Figure 3 compares LGN boutons in layer 1, 2/3 and LP , the DSI shows the selectivity for directional movement. The size of receptive field for bouton is 1-1 to LGN to RF, LP's RF is way larger LP and is not smooth. The LP off region shows very noisy, disparate data. In figures c, d explains that asymmetry of RF has a higher aspect for pink yet the tuning is weaker for LP then LGN, this doesn't completely add up. In the Fitzpatrick paper- you can tell orientation from shape/aspect ratio, but this isn't apparent in the figures in this paper. However the lack of correspondence from ratio to orientation maybe explained by noise in the data creating the oblong shape.

Figure 4 shows the position in visual space and the difference between LGN and LP boutons. The LP is spread out and scattered, showing very little clustering, whereas the V1 is clumped clearly showing a defined receptive field. Figure 4d quantifies the amount of scatter and figure 4e shows the individual recordings- and cumulative distributions of visual field space. When you add boutons cluster gets larger for dLGN (receptive field coverage) but the spread reaches a limit. That plateau for LP corresponds to a bigger area of visual space, and can accept more boutons before reaching that limit. The V1 neurons pool info across other V1 cells laterally so the RF may be bigger than LGN but still smaller than LP.

In figure 5a it presents the virtual reality with gratings based on speed of the mouse on a ball. In the uncoupled condition it is not based on running speed, but just played back from a previous trial. However in this article, they didn't subtract out visual stimuli response.
In figure 5b the saccades that mouse makes- recording the change in the activation with movement. The inferred firing rate (filtered version delta f/ f) is made by converting it into spikes. This just captures initial onset of it in bottom line, comparing it to firing rate and the change in movement. Figure 5c shows the saccade triggered spike for boutons is inferred, that's how they got saccade triggered spike. The article makes claim that the LP response is bigger, but in dark it seems to be reduced, but the right doesn't show that. The LP may signals motion and is much more responsive than the dLGN in this task.

In figure 6 the VF, virtual env, RS is in an open loop condition. In 6A they measure the running speed, corresponding to the LGN bouton and LP bouton, the chart shows the running speed tuning curve (the high running speed is shown at the top). Example curves for boutons of dLGN are also shown responding to speeds. In 6B the condition is not coupled and it also shows speed modulated by firing rate. 6C shows the RS vs. VF , bottom does not have a significant number of boutons that respond or convey info about running. This may be a confound of visual stimulus that was used in the uncoupled condition, and it is not accounted for in these results. In 6d if this and C are correlated then it is related to listening to running and not the visual stimuli, for dLGN it is trending toward the running speed and responsiveness. This suggest movement is integrated by the LP and the LGN gets some feedback about motion from LP.
In 6E this shows D more clearly, the LP is weaker on the bottom showing little response to -RS. The dLGN only correlated in the closed loop condition, the neuron is more predictive of running. dLGN appears cardinal, it is a closed loop, and the angle don't show degree - just the value for VF or RS. dLGN responds best to +VF or +RS. In 6F, the speed tuning for negative VF is shown, the neuron is suppressed for running and when the stimuli is not coupled the same bouton prefers fast running (in LP). The dLGN has similar tuning curves in closed and open loop conditions for running speed. The right shows the anti-correlation in -VF, LGN are also anticorrelated and show more at -1 for -VF then it shows LP shows greater responsiveness

In figure 7A it shows the subtracted open loop and closed loop condition, the closed loop in yellow, open in blue, red is blue minus yellow. The left shows subtractive inputs blue minus yellow, and in the right figure they added blue + yellow. If the visual stimuli was identical, then these results would definitively conclude that running and visual flow speed were much more prevalent in LP than in dLGN projections. At the top of 7A they compared response to subtraction and sum. 7b shows the categorization of boutons based on if they are correlated, the ones with highest predictive power are shown in this figure.
In 7C the blue lobe and yellow correspond to +RS or -VF, and are correlated in either loop. The individual bouton is also correlated to the difference or summation of these.
The dLGN is not encoding difference or sum but LP does; a lot of LP signals fire when there is a difference in VF and RF. Other boutons had higher values after subtraction.
In 7E there is a big decrease LGN, but in open loop there was a difference causing more activity but in the closed loop it was less responsive, and the summed activity had no change. They seem to be be coding for running and differences in how optic flow corresponds to the real world. A

lot of responses come from LP and LGN that are more correlated for difference of RF and VF. There is more response for open loop (decoupled) condition in the LP but not many LGN that respond to the difference. LP encode mismatch, but few LGN do. The LGN can be informative RS + VF in the open-loop condition, when optic flow is consistent.

These two papers overall show that previous models are inconsistent for mice. The original Hubel and Weisel model may not apply for the inputs from LGN summing into a function for V1 output for orientation and directional selectivity. In summary, at the level of bouton we can have limited information about OSI that is processed for mice and feedback from higher order thalamic nuclei can be reprocessed in LGN projections and V1. The role of LGN axons projecting into layer 4, may be modulatory instead of entirely related to the retinotopic world and orientation selectivity. The second paper similarly suggests that inputs from LGN into V1 may convey information about optic flow and other more complex visual processes than we previously thought.