Activity dependent development of maps in the visual system

Activity type

- Sensory
    - species
        - mammals
        - non-mammalian vertebrates
        - invertebrates
    - ~~**ignore this Sensory literature for now**-- too much literature for a 2000 word review limit?~~
        - just do very brief overview in intro with statement that here we focus on intrinsic activity patterns in visual system and refer to other recent reviews?
    - When?
        - Before eye opening and experienced visual patterns
            - Melanopsin
        - After eye opening
            - Hubel and Wiesel
- Spontaneous
    - What?
        - species
            - mammals
                - can occur before vision– long gestational timecourse
            - non-mammalian vertebrates
                - does not occur before vision– short gestation
        - patterns described in vitro
            - early development - before eye opening
                - retinal waves
                    - TODO: shatz, Wong, Feller work
                    - TODO: J. Zhou work
                - TODO: Subplate references, former shatz postdoc at Univ Maryland
        - patterns described in vivo
            - early development - before eye opening
                - rat
                    - early network oscillations (ENOs)
                        - TODO: Konnerth fiber optic calcium imaging
                    - ‘spindle bursts’
                        - spindle shaped field potential oscillations in visual cortex [1]
                - mouse
                    - retinal waves
                        - primary source of patterned activity throughout neonatal visual system [2]
                        - (Siegel, Lohmann Curr Biol 2012) [3]

                - possibly recorded retinal waves?
                - more likely ‘spindle bursts’
                - which might be same as the independent spontaneous V2 activity we saw [2]
        - around eye opening
            - ferret
                - TODO: Weliky literature in LGN and cortex
            - rat
                - ‘spindle’ bursts
                    - TODO: Colonnese, Khazipov work
        - ~~after eye opening~~
            - **much literature in adult**
                - monkey, cat, ferret, rodent, etc
            - patterned activity
                - TODO: Recent Konnerth peri-eye opening calcium imaging paper with direction sel
                - intrinsic signal imaging
                    - Stryker work
                    - A. Grinvald work
                - multicell recordings
                - any mutlichannel recordings in newborn monkey (hubel wiesel just did single electrodes?)
                - ~~fast traveling waves~~
                    - adult
- Where?
    - retina
        - Retinal waves propagate among RGCs [2]
    - LGN
        - Mouse
            - Spontaneous bursting among dLGN neurons sensitive to retinal input [4]
            - Inferred by matched retinal driven patterns in V1 and SC [2]
        - Ferret
            - TODO: Weliky literature in LGN
    - superior colliculus
        - Retinal waves drive collicular neurons [2]
    - visual cortex
        - Retinal waves propagate to cortical neurons [2]
        - Retinal input modulates synchronous calcium signals in cortical neurons [3]
        - Retinal input can drive spiking multiple unit activity in cortical neurons [1]
        - TODO: Colonnese, Khazipov work
        - TODO: Weliky literature in cortex
- When?
    - Before eye opening and experienced visual patterns
        - Before birth for some species
            - Monkey, human, cat

        - After birth for some species
            - rodent, ferret, cat
    - After eye opening
        - experiential pattern replay/dreams
            - analogs to hippocampal - place cell replays (Wilson work) for learning and memory?
            - Y. Dan visual pattern replay paper
- Why?
    - activity dependent circuit establishment and refinement– lessons from other systems
        - *short blurb on other systems*
        - chick neuromuscular junction (lichtmann sanes)
        - spontaneous motor circuit activity V. Hamburger & (Petterssen Nature paper)
    - activity dependent visual map development
        - anatomical - structural
            - axon sprouting
                - xenopus, zebrafish literature?
                - LGN and SC
                    - rodent
                        - mouse
                            - TODO: beta2 nAchR ko mouse
                            - TODO: N. Spitzer reference on activity-dep Ca2+ growth
            - axon refinement
                - xenopus, zebrafish literature?
                - LGN and SC
                    - rodent
                        - mouse
                            - beta2 nAchR ko and transgenic mice show that nAChR mediated spontaneous activity in the retina is essential for retinotopic map refinement, eye specific segregation [5]
                            - RGC refinement and deficits in beta2 nAchR ko occurs at the level of single RGCs [6]
                - cortex
                    - cortico-collicular axon arborizations [7].
                        - Nice DiI reconstructions of cortico-collicular axons in rat
            - dendrite growth?
                - cortico-collicular recepient cells in SC,
                    - Recent constantine-paton paper [7].
                        - Cortico-collicular axons needed for ‘caliber 3’ dendritic filopodia density.
                        - Eye opening regulates spine density in ‘caliber 3’ dendrites
                - Golgi or DiI analysis in ferret, cat, monkey, or rodent cortex?
                    - Ruthazer and Olavarria paper
                - Golgi or DiI analysis in LGN or SC?
            - dendritic refinement
                - spine dynamics?
                    - TODO: xenopus literature?, H. Cline

- cell migration
    - rodent
        - cortex
            - interneurons
                - TODO: recent Fishell paper
                - TODO: recent ZJ Huang papers
                - TODO: Ben-Ari, JB Manent activity dependent interneuron migration in vitro model
    - higher mammals
        - cortex
            - TODO: Chalupa monkey retinal wave evidence and ferret in vitro
            - unknown but gestational times for both excitatory and inhibitory cell migration overlaps significantly with likely period for retinal waves
- functional - physiological
    - synapse maturation
        - retinocollicular synapse
            - Increased AMPA/NMDA ratios and AMPA quantal amplitudes during first postnatal week [8]
            - burst activation in vitro capable of inducing LTP [8]
            - delayed maturation and greater LTP at beta2-/- nAchR ko synapses [8]
    - retinotopy
        - Altered retinotopic map in beta2 nAchR ko mice in SC (first order connections) [9]
            - using tungsten microelectrode extracellular recordings
            - physiological receptive fields elongated along nasal-temporal axis
        - Altered retinotopic map in beta2 nAChR-/- mice in SC (first order connections) [10]
            - using instrinsic signal imaging
            - retinotopic map preferentially disrupted (elongated) along anterior-posterior (nasal-temporal) axis of SC
        - Altered retinotopic map in beta2 nAchR -/- mice in V1 (second order connections) [11]
            - Intrinsic signal imaging of mouse V1 for visual space map
            - Extracellular microelectrode recordings for single cell receptive fields
            - Preferential disruption (elongation, scatter, response amplitude) along the visual space azimuth (nasal-temporal axis)
            - They speculate that waves regulate ephrinA gradients to explain the nasal-temporal disruption since travelling waves had not been found to have a preferred direction at the time
        - Cortico-collicular alignment of retinotopy (quaternary order connections) [12]
            - Transgenic mice, tracer injections, intrinsic signal functional mapping
            - Used ephA3ki/ki (knock in) mice crossed with beta2 nAchR -/- mice for the crucial experiment in Figure 6.
            - These mice have duplicated retinocollicular map, but only a single, non-matched corticocollicular projection when no cholinergic waves are present.

        - eye specific segregation
        - ocular dominance columns
            - development of ODCs in ferret [13]
                - epibatidine injections and tracer injections
                - ocular dominance bias index with extracellular microelectrode recordings
                - spontaneous cholinergic activity in retina required for cortical ODC formation
            - TODO: Crair, Stryker
        - orientation selectivity
            - TODO: Crair, Stryker
            - TODO: Recent Fitzpatrick work
            - TODO: ongoing J. Cang unpublished work? (look at abstr from SFN, our CSHL conf last year)
        - direction selectivity
            - TODO: Recent Konnerth peri-eye opening calcium imaging paper
            - TODO: Recent Fitzpatrick work (the reprogramming of selectivity)
- How?
    - Permissive
        - Spatiotemporal pattern does not matter
            - Perhaps just absolute levels of activity needed?
            - homeostasis, celluar growth and survival?
    - Informative
        - Spatiotemporal pattern does matter
            - Temporal activity pattern
                - Time scale
                    - eye-specific segregation
                        - before eye opening
                            - Synchronous activation of RGCs in both eyes with ChR2 disrupts eye-specific segregation in SC and LGN [14]
                            - Relevant window for spike timing differences of RGCs in both eyes within 100s of milliseconds [14]
                                - chR2 stimulation of RGCs, anatomical segregation analysis in SC
                - Mechanism
                    - Coincident pre-post synaptic activity - Hebbian plasticity
                        - Dependent on NMDA-R?
                            - maybe yes?
                                - TODO:
                                - HP Xu recent work?
                            - maybe not?
                                - LTD independent of NMDA-R activation in mouse [#Ziburkus:2009]
                                    - in vitro explant with extracellar field potentials and high freq stim to mimic retinal waves

            - bidirectional maturation
              - finds LTD early between birth and eye opening
              - finds LTP after eye opening through critical period
              - cites [#Butts:2007] for bidirectional synaptic strength changes in single LGN cells
          - L-type calcium channel plateau potentials at developing LGN neurons [#Lo:2002]
          - retinogeniculate PSC bursting is independent of NMDAR activation (NMDAR1 ko mice, ex vivo, extracellular)[4]
          - HP Xu recent work?
      - Independent of NMDA-R?
        - endocannabinoid induced LTD?
          - but this type of activation still requires NMDA activation? [15]
            - this type of coincidence detection reviewed elsewhere [15]
        - mGluR-VSCC-IP3R-eCB coincidence detector [16]
          - this form of LTD independent of postsynaptic NMDA receptors
          - detects firing coincidence at 125 ms time scale (*versus 25 ms time scale for NMDA dependent LTP*)
          - described at L4 to L2/3 synapses in somatosensory cortex
        - bistable switch in spike statistics for postsynaptic neurons?
          - critical level of coincident presynaptic activity needed to cause spike?
            - during early development?
              - biophysical membrane and cable properties different in immature neurons
                - more voltage gated calcium conductance
                - less sodium channels
              - lower fidelity spike transmission initially?
    - Non-coincident – alternate, lagged timing based plasticity rule?
- Spatial activity pattern
  - Unknown
    - experiment needed: to control spatio-temporal activity patterns

before start of vision

        - Analagous to the classic Sensory activation experiments
            - owl prism experiments Knudsen
            - cat goggle experiments

    - Instructive role of spatial activation hinted at by Hong-Ping's paper? [5]
    - Necessitates the temporal activity mechanisms with an additional spatial dimension
    - Spatial patterns setup in periphery (RGCs) and communicated across levels of visual organization [2]

Figure: Schematic of visual cortex primary and secondary areas, pathway illustration, and summary of retinal influence? (incl Olavarria work?)

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1. Hanganu, I. L., Ben-Ari, Y., and Khazipov, R. (2006). Retinal waves trigger spindle bursts in the neonatal rat visual cortex, J Neurosci, 26(25), 6728–36
2. Ackman, J. B., Burbridge, T. J., and Crair, M. C. (2012). Retinal waves coordinate patterned activity throughout the developing visual system, Nature, 490(7419), 219–25
3. Siegel, F., Heimel, J. A., Peters, J., and Lohmann, C. (2012). Peripheral and central inputs shape network dynamics in the developing visual cortex in vivo, Curr Biol, 22(3), 253–8
4. Mooney, R., Penn, A. A., Gallego, R., and Shatz, C. J. (1996). Thalamic relay of spontaneous retinal activity prior to vision, Neuron, 17(5), 863–874
5. Xu, H.-p., Furman, M., Mineur, Y. S., Chen, H., King, S. L., Zenisek, D., Zhou, Z. J., Butts, D. A., Tian, N., Picciotto, M. R., and Crair, M. C. (2011). An instructive role for patterned spontaneous retinal activity in mouse visual map development, Neuron, 70(6), 1115–27
6. Dhande, O. S., Hua, E. W., Guh, E., Yeh, J., Bhatt, S., Zhang, Y., Ruthazer, E. S., Feller, M. B., and Crair, M. C. (2011). Development of Single Retinofugal Axon Arbors in Normal and beta2 Knock-Out Mice, J Neurosci, 31(9), 3384–99
7. Phillips, M. A., Colonnese, M. T., Goldberg, J., Lewis, L. D., Brown, E. N., and Constantine-Paton, M. (2011). A synaptic strategy for consolidation of convergent visuotopic maps, Neuron, 71(4), 710–24
8. Shah, R. D. and Crair, M. C. (2008). Retinocollicular synapse maturation and plasticity are regulated by correlated retinal waves, J Neurosci, 28(1), 292–303
9. Chandrasekaran, A. R., Plas, D. T., Gonzalez, E., and Crair, M. C. (2005). Evidence for an instructive role of retinal activity in retinotopic map refinement in the superior colliculus of the mouse, J Neurosci, 25(29), 6929–38
10. Mrsic-Flogel, T. D., Hofer, S. B., Creutzfeldt, C., Cloez-Tayarani, I., Changeux, J.-P., Bonhoeffer, T., and Hubener, M. (2005). Altered map of visual space in the superior colliculus of mice lacking early retinal waves, J Neurosci, 25(29), 6921–6928
11. Cang, J., Rentería, R. C., Kaneko, M., Liu, X., Copenhagen, D. R., and Stryker, M. P. (2005). Development of precise maps in visual cortex requires patterned spontaneous activity in the retina, Neuron, 48(5), 797–809
12. Triplett, J. W., Owens, M. T., Yamada, J., Lemke, G., Cang, J., Stryker, M. P., and Feldheim, D. A. (2009). Retinal input instructs alignment of visual topographic maps, Cell, 139(1), 175–85
13. Huberman, A. D., Speer, C. M., and Chapman, B. (2006). Spontaneous retinal activity mediates development of ocular dominance columns and binocular receptive fields in v1, Neuron, 52(2), 247–254
14. Zhang, J., Ackman, J. B., Xu, H.-P., and Crair, M. C. (2011). Visual map development depends on the temporal pattern of binocular activity in mice, Nat Neurosci, 15(2), 298–307
15. Duguid, I. and Sjöström, P. J. (2006). Novel presynaptic mechanisms for coincidence detection in synaptic plasticity, Curr Opin Neurobiol, 16(3), 312–22

16. Bender, V. A., Bender, K. J., Brasier, D. J., and Feldman, D. E. (2006). Two coincidence detectors for spike timing-dependent plasticity in somatosensory cortex, J Neurosci, 26(16), 4166–77