Below is the syllabus for the course. A copy of the syllabus can also be found here.

MCB143 NEUROBIOLOGY OF VISION AND BLINDNESS

Tuesday and Thursday â€“ 1:30-2:45

Northwest Building 425

Can you attend an extra session on April 25th?

Small group sections

One on ones to discuss final paper topics

In Class - Presentation Schedule

STAFF

Instructor

Prof. Joshua Sanes

Northwest Building Room 335.30

Email: sanesj@mcb.harvard.edu

Office hours for discussing final papers

April 11: 3-5 PM

April 12: 10 AM - 3 PM (Zoom)

April 15: 10 AM - 3 PM (Zoom)

April 16: 11 AM - 1 PM

*Please email Josh and let him know if you plan to attend office hours over Zoom.

Teaching fellow:

Dr. Ryan Donahue

Northwest Building Room 335.10

Email: Ryan.Donahue@childrens.harvard.edu

Hours: by appointment

*If you want to discuss your final paper, you can email me to chat or arrange a time to meet.

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PREREQUISITES

MCB 80 or permission of the instructor.

OVERVIEW

The visual system fascinates biologists, in part because humans are such visual animals. This also makes loss of vision a pressing concern: many Americans regard blindness as the worst ailment they could get, fearing it more than Alzheimerâ€™s or AIDS. For these reasons, as well as because of its relative accessibility, the visual system is a favored model for studying fundamental aspects of neurobiology, as well as for testing novel therapeutic approaches, such as gene therapy. This course will cover key topics in

the structure, function and development of the mammalian visual system, and then use them as a basis for considering causes of blindness and potential cures.

FORMAT

Each session will cover a topic in one of the three broad areas: (1) structure and function of the visual system, from the eye through higher brain areas; (2) formation of the neural circuits that subserve vision during development and their capacity for change in adults; (3) disorders that lead to loss of vision and ways in which vision can be preserved or restored. The instructor will lecture during the first three sessions. Thereafter, each class will be divided between a lecture by the instructor and one by a student. Additional interactive segments will be scheduled as time permits.

The student lectures will center around a key paper related to the lecture topic. The goal is to cover its main points (NOT the details) and put it into context. Lectures must be rehearsed with Dr. Donahue no later than 3 days prior to the presentation.

Short papers (1-2 pages, total of 5) will provide an opportunity for students to speculate about interesting open issues in the field â€“ thinking about problems for which there are not yet solutions.

As a final project, students will write a longer paper (8-10 pages) on a topic of their choosing, on an issue in the areas of visual function, development or disease. The paper will state an important area, describe what is known today, and then propose a way to move forward - a logical next step, a key experiment, or a novel approach.

Both lectures and student presentations will be relatively informal, with plenty of opportunity for discussion. To encourage further interaction, we will also schedule two discussion sessions with a maximum of 6 students (times to be arranged), a 1:1 meetings with Dr. Donahue to rehearse presentations and a 1:1 meeting with Dr. Sanes to discuss topics for the final paper.

TEXT

There is no assigned text. Papers or chapters on specific topics will be assigned each week; pdfs will be posted on this site.

However, you may find this book useful: â€œBasic Visionâ€ R. Snowden, P. Thompson and T. Troscianko (Oxford, 2012).

For accessible overviews of areas weâ€™ll be covering, you may find these books useful:

â€œNeuroscience Exploring the Brainâ€ by Bear, Connor, and Paradiso (Wolters/Kluwer, 2016). Chapters 2-6 provide a good review of basic neuronal cell biology and physiology.

â€œPrinciples of Neural Scienceâ€ 6th edition. Kandel, Koester, Mack and Siegelbaum (eds.) (McGraw Hill, 2021). Chapters 21-25 cover the visual system. Chapters 47-49 cover activity dependent and -independent aspects of visual system development. (A few of these chapters will be assigned; pdfs will be provided.)

Copies of these books are available in the library.

A good on-line resource is https://webvision.med.utah.edu/.

Note: Readings listed below are tentative; some in later weeks may be changed depending on student interests.

SCHEDULE FOR PAPERS

Short Paper 1: assigned 2/13, due 2/20

Short Paper 2: assigned 2/27, due 3/5

Short Paper 3: assigned 3/7, due 3/19

Short Paper 4 : assigned 3/21, due 3/28

Short Paper 5 (outline of final paper): assigned 4/4, due 4/11

Oral reports on final paper 4/18 and 4/23

Final paper is due at the end of reading period (5/1)

GRADING:

Class participation [15%]

In-class presentation [20%]

Short papers: [5@5% each, 25%]

Final paper: oral presentation [15%]

Final paper: written document (due during reading period) [25%]

There will be no midterm or final exam

OUTLINE OF TOPICS

(1) Tue Jan 23. Introduction to the visual system

Topics: Why study the visual system? Overview of the visual system and course outline. The difference between seeing and perceiving, as illustrated by optical illusions. Higher visual functions. Diseases that rob us of vision.

Lecture Slides

Background reading:

Dobbs. Blindness. National Geographic PDF

(2) Thurs Jan 25. Methods for studying visual function and dysfunction

Topics: Review of electrical and chemical signaling in the nervous system. Methods for studying visual circuits in experimental animals â€“ old and new. Methods for studying human vision â€“ what they do and donâ€™t tell us.

Lecture Slides

Background reading:

Luo L, Callaway EM, Svoboda K. Genetic Dissection of Neural Circuits: A Decade of Progress. Neuron. 2018; 98:256-281. PDF

(If you need to brush up on basic neuroscience, Bear et al. Chapters 2-6 could be useful. We have a few copies available to borrow.)

PDF PDF PDF

(3) Tue Jan 30. Photoreceptors

Topics: How photoreceptors capture photons and turn them into electrical signals. Differences between rods (specialized for sensitivity â€“ they can detect single photons!) and cones (specialized for color

vision). Adaptation: why we can see over a billion-fold range of brightness. Perception of color â€“ the complex relationship of cone signals to the colors we perceive.

Lecture Slides

Background reading:

Kandel, Koester, Mack and Siegelbaum (eds.) Principles of Neural Science, Chapter 22 PDF

(4) Thurs Feb. 1. Principles of retinal signaling

Topics: How the retina turns sensation into perception. Neural circuits that allow us to detect both increases and decreases in brightness (ON and OFF pathways), enhance our sensitivity to contrast and edges (lateral inhibition and center-surround organization), and respond to motion in specific directions.

Lecture Slides

Student presentation: Public health interventions to prevent nutritional night blindness

Sommer A. Preventing blindness and saving lives: the centenary of vitamin A. JAMA Ophthalmol. 2014; 132:115-7. PDF

Sommer A. Vitamin a deficiency and clinical disease: an historical overview. J Nutr. 2008; 138:1835-9. PDF

Background reading:

Kandel et al., Chapter 22

Masland RH. The neuronal organization of the retina. Neuron. 2012; 76:266-80. PDF

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(5) Tue Feb 6 â€“ Diseases of photoreceptors

Topics: The largest number of blinding diseases affect photoreceptors â€“ over 400 have been described â€“ and some of them are well enough understood to enable design of effective therapies. Some arise from mutations of single genes, some from environmental deficiencies or insults, and some from combinations of environmental and genetic influence.

Lecture Slides

These are your ideas about why bystander cones die.

Student Presentation: Retinal control of the circadian rhythm

Hattar S, Liao HW, Takao M, Berson DM, Yau KW. Melanopsin-containing retinal ganglion cells: architecture, projections, and intrinsic photosensitivity. Science. 2002; 295:1065-70. PDF

Berson DM, Dunn FA, Takao M. Phototransduction by retinal ganglion cells that set the circadian clock. Science. 2002; 295:1070-3. PDF

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(6) Thurs Feb 8 â€“ Gene therapy for retinal diseases

Topics: There are over 100 diseases in which mutations lead to dysfunction of photoreceptors, with partial or total blindness. Each is rare, but together they impose a large burden. Completely untreatable until recently, gene therapy now provides hope â€“ and early success in the eye is paving the way for similar therapeutic approaches to other neural and non-neural diseases.

Lecture Slides

Student Presentation:

Topic: A clinical case of optogenetic gene therapy

Sahel JA, Boulanger-Scemama E, Pagot C, Arleo A, Galluppi F, Martel JN, Esposti SD, Delaux A, de Saint Aubert JB, de Montleau C, Gutman E, Audo I, Duebel J, Picaud S, Dalkara D, Blouin L, Taiel M, Roska B. Partial recovery of visual function in a blind patient after optogenetic therapy. Nat Med. 27:1223-1229, 2021. PDF

Background reading:

Pierce EA, Bennett J. The Status of RPE65 Gene Therapy Trials: Safety and Efficacy. Cold Spring Harb Perspect Med. 2015; 5:a017285. PDF

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(7) Tue Feb 13. Parallel processing in the retina

Topics: Retinal ganglion cells send many parallel signals through the optic nerve to the rest of brain, each tuned for sensitivity for particular features. The circuits that generate feature selectivity arise from specific connections of more that 70 types of interneurons with more than 40 types of retinal ganglion cells. New molecular, morphological and physiological methods make it possible to comprehensively characterize these cell types and the circuits they form.

Lecture Slides

Student Presentation: Circuitry of a feature detector

Zhang, Y, Kim, I-J, Sanes, JR, and Meister,M. The Most Numerous Ganglion Cell Type of the Mouse Retina is a Selective Feature Detector. Proc Natl Acad Sci U S A. 2012; 109:E2391-2398. PDF

Background reading:

Gollisch T, Meister M. Eye smarter than scientists believed: neural computations in circuits of the retina. Neuron. 2010; 65:150-64. PDF

Shekhar K and Sanes JR. Generating and using transcriptomically based retinal cell atlases. Annual Review of Vision Science 2021; 15;7:43-72. PDF

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(8) Thurs Feb 15. Special features of human vision

Topics: Although studies of model organisms such as mice teach us a lot about retinal circuitry, there are fundamental differences between the ways mice and humans see. Among mammals, primates have the highest acuity chromatic (color) vision, owing in large part to a small anatomical specialization in the retina called the fovea or macula. This region only covers ~1% of the retina but it accounts for ~50% of the output of visual information to the brain. We will discuss how the fovea differs from the other 99% of the retina, emphasizing the features that endow it with special properties.

Lecture Slides

Student Presentation:

Topic: Evolution of the vertebrate retina

Hahn J, Monavarfeshani A, Qiao M, Kao AH, KÃ¶lsch Y, Kumar A, Kunze VP, Rasys AM, Richardson R, Wekselblatt JB, Baier H, Lucas RJ, Li W, Meister M, Trachtenberg JT, Yan W, Peng YR, Sanes JR, Shekhar K. Evolution of neuronal cell classes and types in the vertebrate retina.Nature. 2023; 624:415-424. PDF

Background reading:

Martinez-Conde S and Macknik SL. From Exploration to Fixation: An Integrative View of Yarbus's Vision.

Perception. 2015; 44:884-99. PDF

(9) Tue Feb 20. Macular degeneration: the most common cause of blindness in the US

Topics: Several blinding diseases selectively affect the macula, and are therefore difficult to study in common model organisms. One is age-related macular degeneration (AMD), the leading cause of blindness in the first world. Advances in molecular biology have led to a vision-sparing treatment for common types of AMD.

Lecture Slides

Student Presentation:

Topic: Novel therapies approaches for macular degeneration (AMD)

Charbel Issa P, Barnard AR, Herrmann P, Washington I, MacLaren RE. Rescue of the Stargardt phenotype in Abca4 knockout mice through inhibition of vitamin A dimerization. Proc Natl Acad Sci.112: 8415-20 2015 PDF

Plus press release on ongoing clinical trial â€“ to be provided

Background reading:

Miller JW, Le Couter J, Strauss EC, Ferrara N. Vascular endothelial growth factor in intraocular vascular disease. Ophthalmology. 2013 Jan;120(1):106-14 PDF

Miller JW, Bagheri S, Vavvas DG. Advances in Age-related Macular Degeneration Understanding and Therapy. US Ophthalmic Rev. 2017 10(2):119-130. PDF

(10) Thurs Feb 22. Degeneration and regeneration of retinal cells

Topics: The optic nerve contains axons that run from retinal ganglion cells in the retina to brain centers. Following injury to the nerve, which transects the axons, many of the ganglion cells die and few of the survivors extend new axons â€“ loss of vision is therefore irreversible. Studies aimed at enhancing the survival of ganglion cells and enabling them to regenerate axons not only hold promise for treating retinal disorders but also lead to discovery of therapeutic targets for injury to other parts of the brain and spinal cord.

Lecture Slides

Student Presentation:

Topic: Factors that affect regeneration of retinal axons

Goldberg JL, Espinosa JS, Xu Y, Davidson N, Kovacs GT, Barres BA. Retinal ganglion cells do not extend axons by default: promotion by neurotrophic signaling and electrical activity. Neuron. 2002 Feb 28;33(5):689-702. PDF

Background reading:

Tran NM, Shekhar K, Whitney IE, Jacobi Aâ€¦Sanes JR. Single-cell profiles of retinal ganglion cells differing in resilience to injury reveal neuroprotective genes. Neuron 2019; 104:1039-1055. PDF

He Z, Jin Y. Intrinsic Control of Axon Regeneration. Neuron. 2016 May 4;90(3):437-51 PDF

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(11) Tue Feb 27. Protecting injured retinal ganglion cells: glaucoma and multiple sclerosis *(Guest lecturer: Ryan Donahue)*

Topics: The most common causes of irreversible blindness, glaucoma, retinal ganglion cells die from a

combination of increased intraocular pressure, sensitivity of retinal ganglion cells, and peculiar geometric features of the optic nerve. Multiple sclerosis and traumatic injury can also damage optic nerve axons, leading to death of retinal ganglion cells and permanent blindness.

Lecture Slides

Student presentation:

Topic: Using developmental insights to enhance regeneration of sick retinal neurons

Lu Y, Brommer B, Tian X, Krishnan A, Meer M, Wang C, Vera DL, Zeng Q, Yu D, Bonkowski MS, Yang JH, Zhou S, Hoffmann EM, Karg MM, Schultz MB, Kane AE, Davidsohn N, Korobkina E, Chwalek K, Rajman LA, Church GM, Hochedlinger K, Gladyshev VN, Horvath S, Levine ME, Gregory-Ksander MS, Ksander BR, He Z, Sinclair DA. Reprogramming to recover youthful epigenetic information and restore vision. Nature. 2020; 588:124-129 PDF

Background reading:

Almasieh M, Levin LA. Neuroprotection in Glaucoma: Animal Models and Clinical Trials. Annu Rev Vis Sci. 2017; 3:91-120. PDF

(12) Thurs Feb 29. Primary visual cortex

Topics: Visual information passes from the retina to the rest of the brain. There are many "retinorecipient areas" responsible for reflexive behavior, but the main pathway for "conscious" vision goes through the lateral geniculate nucleus and then to primary visual cortex. Nobel Prize-winning work done at Harvard Medical School by Hubel and Wiesel elucidated the basic transformations that the cortex performs.

Lecture Slides

Student Presentation

Topic: Using stem cells to study and repair visual circuits

Falkner S, Grade S, Dimou L, Conzelmann KK, Bonhoeffer T, GÃ¶tz M, HÃ¼bener M. Transplanted embryonic neurons integrate into adult neocortical circuits. Nature. 2016; 539:248-253. PDF

Jgamadze D, Lim JT, Zhang Z, Harary PM, Germi J, Mensah-Brown K, Adam CD, Mirzakhalili E, Singh S, Gu JB, Blue R, Dedhia M, Fu M, Jacob F, Qian X, Gagnon K, Sergison M, Fruchet O, Rahaman I, Wang H, Xu F, Xiao R, Contreras D, Wolf JA, Song H, Ming GL, Chen HI. Structural and functional integration of human forebrain organoids with the injured adult rat visual system. Cell Stem Cell. 2023; 30:137-152. PDF

Background reading

Hubel DH. Exploration of the primary visual cortex, 1955-78. Nature. 1982 Oct 7;299(5883):515-24. PDF

Livingstone M. Hubel Obituary Neuron PDF

(13) Tue Mar. 5 . Introduction to ophthalmology

(Guest lecturer: TavÃ© van Zyl)

Topics: Although most of this course focuses on neural bases of visual function and dysfunction, defects in other parts of the eye - lens, iris, cornea, etc. â€“ can also lead to blindness. Dr. van Zyl, an ophthalmologic surgeon also engaged in basic research, will describe these structures and discuss what ophthalmologists do when they malfunction.

Background reading:

Capturing Light â€“ Cornea and Lens, Chapter 2 in Vision by Dowling and Dowling

(14) Thurs Mar 7. Functional architecture of the visual cortex

Topics: Hubel, Wiesel and many others analyzed the arrangement of neurons in visual cortex, discovering elaborate systems of columns, layers, patches and modules that organize cells into functional groups. Subsequently, others discovered elaborate patterns of connections that interconnect the layers and columns. We will consider how these architectural features facilitate visual processing.

Lecture Slides

Student Presentation:

Topic: Clues to the origin of cortical columns

Adams DL, Horton JC. Shadows cast by retinal blood vessels mapped in primary visual cortex. Science. 2002 298:572-6. PDF

Background:

Hubel DH, Wiesel TN. Ferrier lecture. Functional architecture of macaque monkey visual cortex. Proc R Soc Lond B Biol Sci. 1977;198(1130):1-59. PDF

Tuesday March 12 and Thursday March 14â€“ Spring Break

(15) Tues Mar 19. Higher visual areas

Topics: Following initial cortical processing in primary visual cortex (V1), information radiates out to many other cortical areas, each specialized for detecting specific features. Some are organized into so-called â€œwhatâ€ and â€œwhereâ€ pathways, specialized for object recognition and object localization respectively.

Lecture Slides

Student Presentation:

The paper by Salzman et al. is a classic and should be the main emphasis of the presentation. The recent paper by Fetsch et al. shows how experiments of this sort can be done today. It is interesting to see that its results are similar to those of Salzman, but provide some new knowledge too.

Salzman CD, Britten KH, Newsome WT. Cortical microstimulation influences perceptual judgements of motion direction. Nature. 1990;346:174-7. PDF

Fetsch CR, Odean NN, Jeurissen D, El-Shamayleh Y, Horwitz GD, Shadlen MN. Focal optogenetic suppression in macaque area MT biases direction discrimination and decision confidence but only transiently. eLife. 2018 PDF

Background

To be decided

(16) Thurs Mar 21. Face cells and prosopagnosia (face blindness)

Topics: At the apex of visual processing are cells that respond specifically to faces and, in some cases to faces of particular individuals. These â€œface cellsâ€ are clustered in small regions of the cortex. Some people are unable to distinguish faces, even of people they know well. This is called face blindness or prosopagnosia. Might prosopagnosics have defects in face areas?

Lecture Slides

Student Presentation

Topic: Human face areas

Schalk G, Kapeller C, Guger C, Ogawa H, Hiroshima S, Lafer-Sousa R, Saygin ZM, Kamada K, Kanwisher

N. Facephenes and rainbows: Causal evidence for functional and anatomical specificity of face and color processing in the human brain. Proc Natl Acad Sci U S A. 2017; 114:12285-12290. PDF

Background

Freiwald WA, Tsao DY, Livingstone MS. A face feature space in the macaque temporal lobe. Nat Neurosci. 2009;12(9):1187-96. PDF

Tsao DY, Freiwald WA, Tootell RB, Livingstone MS. A cortical region consisting entirely of face-selective cells. Science. 2006;311(5761):670-4. PDF

(17) Tue March 26. Disorders of cortical visual areas

Topics: Injury to individual higher visual areas leads to specific visual defects, for example in recognizing words or perceiving colors. Oliver Sacks wrote captivating accounts of many of these individuals. In todayâ€™s session, three students will present some of these cases and discuss what brain lesions might account for the symptoms

Student presentations will be chosen from:

Sacks, Prosopagnosia in New Yorker PDF

Sacks, Colorblind Painter PDF

Sacks, The Man Who Mistook His Wife for a Hat PDF

Sacks, Sight-Reading PDF

Sacks, Stereo Sue PDF

(18) Thurs Mar 28. Development of the retina

Topics: The retina forms from an optic vesicle through an elaborate series of steps that includes the generation of its many cell types, their differentiation, and formation of synapses between appropriate partners. The result is the complex set of neural circuits that underlie the first steps of vision. Many lessons learned from studies of retinal development

Lecture Slides

Student presentations:

Duan X, Krishnaswamy A, De la Huerta I, and Sanes JR. Type II cadherins guide assembly of a direction-selective retinal circuit. Cell 2014; 158: 793-807. PDF

Background:

Sanes JR, Zipursky SL. Design principles of insect and vertebrate visual systems. Neuron. 2010; 66:15-36. PDF

Sanes JR, Zipursky SL. Synaptic Specificity, Recognition Molecules, and Assembly of Neural Circuits. Cell. 2020 181:536-556 PDF

(19) Tue Apr 2. Formation of projections from the retina to the brain

Topics: Axons of retinal ganglion cells find their way from the eye to the brain where they form â€œtopographic mapsâ€ that project the world onto retinorecipient areas, where the information is processed further. For decades, discovering the mechanisms of map formation was a holy grail for

developmental neurobiologists â€“ and we finally have a reasonable understanding of how it happens.

Lecture Slides

Student Presentation:

Topic: The long journey from the eye to the brain

Williams SE, Mann F, Erskine L, Sakurai T, Wei S, Rossi DJ, Gale NW, Holt CE, Mason CA, Henkemeyer M. Ephrin-B2 and EphB1 Mediate Retinal Axon Divergence at the Optic Chiasm. Neuron. 2003. 39: 919-935

Background:

Petros TJ, Rebsam A, Mason CA Retinal Axon Growth at the Optic Chiasm: To Cross or Not to Cross. Annu. Rev. Neurosci. 2008. 31:295-315.

Herrera E, Erskine L, Morenilla-Palao C. Guidance of retinal axons in mammals. Seminars in Cell & Development. 2019. 85: 48-59. PDF

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(20) Thurs Apr 4. Roles of activity in formation of visual circuits

Topics: Although early steps in circuit assembly are genetically specified â€“ hard-wired â€“visual input later sharpens, tunes and rearranges connections to retrofit each of our brains to our own body and experience. We will discuss how this happens, and how molecular cues and activity interact.

Lecture Slides

Student Presentation:

Topic: Profound effects of activity on functional architecture of the cortex

Law MI, Constantine-Paton M. Anatomy and physiology of experimentally produced striped tecta. J Neurosci. 1981 Jul;1(7):741-59*

*This is the paper to present but the student should be aware of a preceding short report (Science, 1978) and a follow-up (Reh and Constantine Paton, 1985) and mention them briefly.

Background reading:

Sanes JR. Experience and refinement of synaptic connections. Chapter 56 in: Kandel ER, et al., eds., Principles of Neural Science, 2021. PDF

Wiesel TN. Postnatal development of the visual cortex and the influence of environment. Nature. 1982; 299:583-91. PDF

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(21) Tue April 9. Critical periods

Topics: Childrenâ€™s brains are far more malleable than those of adults. This period of enhanced plasticity, often called a critical or sensitive period, is observed for all modalities, but was studied first and is best understood in the visual system.

Lecture Slides

Student presentation:

Topic: Are we born with the ability to recognize faces? (These papers present opposing views on how the brain â€œlearnsâ€ to recognize faces. The presenters will debate the two views.)

Arcaro MJ, Schade PF, Vincent JL, Ponce CR, Livingstone MS. Seeing faces is necessary for face-domain formation. Nat Neurosci. 2017; 20:1404-12. PDF

Ratan Murty NA, Teng S, Beeler D, Mynick A, Oliva A, Kanwisher N. Visual experience is not necessary for the development of face-selectivity in the lateral fusiform gyrus. Proc Natl Acad Sci U S A. 2020; 117:23011-23020. PDF

Background reading:

[same as session 20]

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(22) Thurs Apr 11. Plasticity of visual function in adults

Topics: It was once though that major changes in visual function were restricted to the critical period in early postnatal life. Accordingly, amblyopic (cortical blindness, usually of one eye) resulting from childhood visual dysfunction, was once thought to be irreversible. Recent work has shown, however, that the critical period can be â€œreopenedâ€ in adulthood, and plasticity restored to a substantial extent.

Lecture Slides

Student presentation:

Topic: Restoring plasticity in the adult brain

Fong MF, Duffy KR, Leet MP, Candler CT, Bear MF. Correction of amblyopia in cats and mice after the critical period. Elife. 2021; 10:e70023. PDF

Background reading:

HÃ¼bener M, Bonhoeffer T. Neuronal plasticity: beyond the critical period. Cell. 2014 Nov 6;159(4):727-37 PDF

(23) Tue Apr 16. Therapies of the future

Topics: New modalities being tested to restore vision, including implants of stem cells, delivery of light-sensitive proteins, prosthetics that bypass the retina altogether, and machine learning approaches to enhance low level vision or let people â€œseeâ€ through their auditory or touch systems.

Lecture Slides

Student presentation

Topic: Virtual reality for the blind

Liu Y, Stiles NRB, Meister M. Augmented reality powers a cognitive assistant for the blind. eLife. 2018;7e37841 PDF

Background reading:

Sahel JA, Roska B. Restoring Vision. Nature. 2018; 577:359-367. PDF

Lasker/IRRF Initiative: Restoring vision to the blind. 2014 PDF

(24) Thurs Apr 18. Student presentations on final papers

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(25) Tue Apr 23. Student presentations on final papers

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FINAL PAPERS DUE Wednesday May 1 5PM (End of reading period)