

Vision Facts

Vision Facts

Questions about the Human Eye

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Vision Facts: Questions about the Human Eye

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Dedicated
to
General Wei

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Preface

Teaching the science of vision is usually done in parts. For instance, eye anatomy may be taught alone in a class. Other classes may discuss the brain regions containing the distributed neural networks that process the photons registered in the retina. It is very difficult to obtain a more global view of vision because of such separation into parts. This book attempts to ask and answer questions from all parts of the visual system and is intended to be a supplement or reference book for anyone interested in vision who is involved with any education for vision. The book is also for the scientifically curious who want to know how vision works. Using this book will lead people to say with understanding, “You don’t see with your eyes, you see with your brain”.

This book is designed to merely ask a vision question, and provide an answer. If you are interested in the question, you can read the answer and follow up with a reference provided in the text. Below is a sample of the vision questions provided in this book.

A Few Examples

What is the resolution of the eye?

Why do astronomers often cover flashlights with a red filter while stargazing?

How many distinct colors are distinguishable by the human eye?

What is color-blindness and how does it occur?

What are the types of color-blindness?

Where do the retinal ganglion cells synapse in the brain?

What role does vision play in the circadian rhythm?

What is the function of each lobe of the cortex?

What are afterimages?

What is color constancy?

How does the eye develop?

What chemical signals cause the eye to develop into its mature form?

How does alcohol during pregnancy affect eye development?

How well can a newborn baby see?

How does being born prematurely affect vision?

How does color vision develop in infants?

What is the effect of visual deprivation in infants?

What is depth perception?

How do 3D glasses work?

What is 20/20 vision?

How does aging affect vision?

Introduction

Vision begins when a photon of light hits the surface of the eye. The photon first passes through the cornea and lens, which bend the path of the light to produce a sharp focused image. Most photons are focused onto the fovea, which is responsible for central vision and contains the highest ratio of cones to rods. Rods and cones are the two types of light-sensitive cells found in the retina. Rods are very sensitive but cannot distinguish color. This makes rods very useful for dim lighting and distinguishing brightness of an object. Cones help figure out the color of what you are viewing. Since there is a high number of cones in the fovea, the central portion of one's field of view is more vibrant than the peripheral vision. Since the lens is biconvex, the image presented on the retina is upside down.

When the photon reaches a rod, the chromophore of rhodopsin, 11-cis-retinal, is excited and changes configurations into all-trans-retinal. This molecular change on a rod triggers the splitting of rhodopsin and retinal. The freed opsin activates transducin, causing G protein based signal transduction. Eventually an electrical impulse is created and propagated, reaching the presynaptic membrane. At this point, calcium ions rush into the cell, causing the release of synaptic vesicles containing glutamate. A similar process occurs in cone cells using other opsins with retinal. Glutamate, the main excitatory neurotransmitter of the central nervous system, excites either a bipolar or horizontal cell which function to integrate information from multiple photoreceptor cells. Through direct or indirect (via inhibitory amacrine cells) means, the signal then reaches the ganglion cells. Multiple ganglion cell axons combine together to form the optic nerve, which

leaves the retina at the optic disc. In this location, there are no photoreceptors which is why the optic disc is also known as the blind spot.

As the impulse travels through the optic nerve, it reaches a point known as the optic chiasm, where the optic nerve from each eye crosses over in an X-shape. At this point, the information is sorted such that the left portion of each retina's field of view (which is projected onto the right half of each retina) is sent to the right optic tract, while the right portion of each retina's visual field is sent to the left optic tract. The majority of these fibers then head to the LGN (Lateral Geniculate Nucleus) of the thalamus, an important part of the brain that sorts out most sensory information and helps determine where it goes. From here the messages are relayed to higher order neurons in various regions of the brain. Other fibers of the optic tract go to the suprachiasmatic nucleus, superior colliculus and pretectum to function in normalizing circadian rhythms, saccades and the pupillary light reflex respectively. The information at the LGN is separated into 6 layers. Layers 1 and 2 contain magnocellular cells, named for their large size, and Layers 3, 4, 5 and 6 contain parvocellular cells which are named for their small size. In between each of these layers there are koniocellular cells which are smaller than parvocellular cells. In addition to the size differences in these cells, there is also a difference in functionality. Magnocellular cells receive information from rods which are necessary for movement, depth and visual acuity. Parvocellular cells receive information from L (red) and M (green) cones, and koniocellular cells receive information from S (blue) cones. All of these cells then travel via optic radiations to the primary visual cortex (V1). From here, the information travels along one of two pathways, the "What" pathway (Ventral Stream) and the "Where" pathway (Dorsal Stream). Along both of these pathways, the visual information stops at many important visual areas including V2, V3, V4, and V5. The difference in these pathways lies anatomically in the ending and functionally throughout the whole pathway. The ventral stream ends in the inferior temporal lobe and functions in perception, visual memory, and facial, object and pattern recognition. The dorsal stream ends in the posterior parietal lobe and functions in integrating visual stimuli with skilled movements, and motion tracking.

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Questions

Part I

The Visual Pathway

1 The Eye

- Q1** What are the important parts of the eye involved in detecting light?
- Q2** What is the cornea?
- Q3** What is the iris?
- Q4** What causes eye color?
- Q5** What is the pupil?
- Q6** What is the lens?
- Q7** What is the ciliary body?
- Q8** What is the ciliary muscle and what is its role in vision?
- Q9** What is the aqueous humor and what is its function?
- Q10** What is the vitreous humor and what is its function?
- Q11** What is the optic nerve?
- Q12** What is the retina?
- Q13** What is the fovea?
- Q14** What is the resolution of the human eye?
- Q15** What is the macula?
- Q16** Why is the macula yellow?
- Q17** What is the tapetum lucidum?
- Q18** What is the retinal pigment epithelium?
- Q19** What is the choroid?
- Q20** What is the sclera?

2 Detection

- Q21** What is sensory transduction?
- Q22** What types of neurons are found in the retina?
- Q23** What are the layers of the retina?

- Q24** How do the layers of the retina work together?
- Q25** What are photoreceptor cells?
- Q26** What are the two types of photoreceptors?
- Q27** What is the difference between the rods and cones?
- Q28** How many rods are there in an average human retina?
- Q29** How many cones are there in an average human retina?
- Q30** What is the distribution of rods and cones throughout the retina?
- Q31** What is the structure of a photoreceptor cell?
- Q32** What is rhodopsin?
- Q33** How do rods detect light?
- Q34** What happens when a rhodopsin molecule becomes activated?
- Q35** What is the absorption spectrum of rhodopsin?
- Q36** What is the Purkinje effect and why does it occur?
- Q37** What is photobleaching?
- Q38** Why do astronomers often cover flashlights with a red filter while stargazing?
- Q39** How do cones detect light?
- Q40** What are the absorption spectra of the three types of photopsin?
- Q41** Why is vitamin A important for the proper functioning of the eye?
- Q42** What is disc shedding?
- Q43** Why must light rays pass through the non-photosensitive elements of the retina before reaching the photoreceptor cells?
- Q44** How many distinct colors are distinguishable by the human eye?
- Q45** How can only three types of cone cells detect possibly up to 10 million different colors?
- Q46** What is the Young-Helmholtz trichromatic theory?
- Q47** What are the proportions of the three types of cones in the fovea?
- Q48** What is color-blindness and how does it occur?
- Q49** What are the types of color-blindness?
- Q50** What percentage of the people are color-blind? Who are at risk of this condition?
- Q51** How is color-blindness diagnosed?

3 Retinal Circuitry

- Q52** How does a neuron receive and transmit signals?
- Q53** What is a receptive field?

- Q54** How does receptive field size affect spatial acuity?
- Q55** How does the size of receptive fields vary throughout the retina?
- Q56** What is center-surround antagonism?
- Q57** What are bipolar cells?
- Q58** What are the types of bipolar cells?
- Q59** What are horizontal and amacrine cells?
- Q60** What is the function of horizontal cells?
- Q61** What is the function of amacrine cells?
- Q62** What are ganglion cells?
- Q63** What are Mach bands?
- Q64** What is the Craik-O'Brien-Cornsweet illusion?
- Q65** What are the ON and OFF channels?
- Q66** How do the ON bipolar cells respond to a cone detecting light?
- Q67** How do the OFF bipolar cells respond to a cone detecting light?
- Q68** How do the ON and OFF channels function with rod cells?
- Q69** What is the advantage of having both ON and OFF channels?
- Q70** What are the types of retinal ganglion cells?
- Q71** What are midget cells?
- Q72** What are parasol cells?
- Q73** What are bistratified cells?
- Q74** What are intrinsically photosensitive ganglion cells?
- Q75** What is the midget system?
- Q76** What is the parasol system?

4 Subcortical Structures

- Q77** What is the optic chiasm?
- Q78** What are the optic tracts?
- Q79** How does a lesion of a single optic tract (left or right) affect a person's ability to see?
- Q80** Where do the retinal ganglion cells synapse in the brain?
- Q81** What is the lateral geniculate nucleus (LGN)?
- Q82** How is the lateral geniculate nucleus (LGN) structured?
- Q83** What are parvocellular cells?
- Q84** What are magnocellular cells?
- Q85** What are koniocellular neurons?
- Q86** What are the optic radiations?

- Q87** How does a lesion of a single optic radiation affect a person's ability to see?
- Q88** Where else in the brain, besides the LGN, do the fibers of the optic nerve synapse?
- Q89** What is the superior colliculus?
- Q90** What is the pretectal area?
- Q91** What is the pupillary light reflex?
- Q92** What is the suprachiasmatic nucleus?
- Q93** What role does vision play in the circadian rhythm?
- Q94** What is blindsight?
- Q95** What is the Anton-Babinski syndrome?

5 Cortical Circuitry

- Q96** What is the great-grandmother cell hypothesis?
- Q97** What is the cerebral cortex?
- Q98** What is the function of each lobe of the cortex?
- Q99** Where in the cerebral cortex do the optic radiations synapse?
- Q100** What is the primary visual cortex?
- Q101** How is the primary visual cortex structured?
- Q102** What is a retinotopic map?
- Q103** What are the types of cells in the primary visual cortex?
- Q104** What are simple cells?
- Q105** What are complex cells?
- Q106** What are end-stopped cells?
- Q107** What is the motion after effect illusion, and how does it work?
- Q108** What are "blobs"?
- Q109** What is the Hering opponent process theory?
- Q110** What are afterimages?
- Q111** Which theory is correct: the trichromatic theory or the opponent theory?
- Q112** What are single-opponent cells?
- Q113** Since there are very few blue cone receptors in the fovea, how is the color blue able to be perceived?
- Q114** What are double-opponent cells?
- Q115** What is color constancy?

- Q116** What are “interblobs”?
- Q117** Who are David Hubel and Torsten Wiesel?
- Q118** What are ocular dominance columns?
- Q119** What are orientation columns?
- Q120** How are blobs, ocular dominance columns, and orientation columns spatially arranged relative to each other?
- Q121** What are higher-order visual areas?
- Q122** What is V2?
- Q123** If cytochrome oxidase staining in V1 forms blobs, what does the same stain show in V2?
- Q124** What are “thin stripes”?
- Q125** What are “thick stripes”?
- Q126** What is retinal disparity?
- Q127** What are “inter-stripes”?
- Q128** What are illusory contours?
- Q129** What is border ownership?
- Q130** What is figure-ground segregation?
- Q131** What is V3?
- Q132** What is V4?
- Q133** Is V4 the “color area”?
- Q134** What are “globes”?
- Q135** What are “interglobes”?
- Q136** What is MT?
- Q137** What is the two-streams hypothesis?
- Q138** What is the dorsal stream?
- Q139** What is the ventral stream?

Part II

Development

1 Fetal Development

- Q140** When do the eyes begin development?
- Q141** Where are the eyes derived from?
- Q142** How does the eye develop?
- Q143** What chemical signals cause the eye to develop into its mature form?
- Q144** What are transcription factors?
- Q145** What role does Pax6 play in the development of the eye?
- Q146** What happens when there is a problem with Pax6?
- Q147** What role does SHH play in the development of the eye?
- Q148** What happens when there is a problem with SHH?
- Q149** What is the persistent pupillary membrane?
- Q150** What is coloboma?
- Q151** How does alcohol during pregnancy affect eye development?

2 Newborns and Infants

- Q152** How well can a newborn baby see?
- Q153** How does being born prematurely affect vision?
- Q154** What is the Fantz preferential looking method?
- Q155** What is the habituation method?
- Q156** How does color vision develop in infants?
- Q157** What is the effect of visual deprivation in infants?
- Q158** What is depth perception?
- Q159** What is stereopsis?
- Q160** What are some visual cues besides stereopsis that are used in depth perception?

- Q161** How do 3D glasses work?
- Q162** When does a newborn acquire depth perception?
- Q163** How does a newborn acquire depth perception?

3 Children

- Q164** What is a conjunctivitis, or pink eye?
- Q165** What is refractive power?
- Q166** What is myopia?
- Q167** What type of lens is used to treat myopia?
- Q168** What is hyperopia?
- Q169** What type of lens is used to treat hyperopia?
- Q170** What is astigmatism?
- Q171** What are common instruments used in an eye exam?
- Q172** What are common tests used in eye exams?
- Q173** What is 20/20 vision?
- Q174** What is an eyeglass prescription and how is it notated?
- Q175** What are LASIK and PRK, and what is the difference between the two?
- Q176** What are night contacts and how do they work?
- Q177** What are childhood cataracts?
- Q178** What is amblyopia?
- Q179** What causes strabismus?

Part III

Aging

- Q180** How does aging affect vision in general?
- Q181** How does the performance of the visual system deteriorate with age?
- Q182** What are the effects of aging on the muscles of the eye?
- Q183** How does aging affect the sclera?
- Q184** How does aging affect the cornea?
- Q185** How does aging affect the iris and the pupil?
- Q186** How does aging affect the lens?
- Q187** What are cataracts and why do they occur?
- Q188** Can cataracts return after surgery?
- Q189** What is presbyopia and how is it treated?
- Q190** What are bifocal and progressive lenses?
- Q191** How does aging affect the retina?
- Q192** What are the effects of aging on seeing in the dark?
- Q193** What is age-related macular degeneration (AMD)?
- Q194** What are floaters?
- Q195** What is retinal detachment?
- Q196** What is glaucoma?
- Q197** How is glaucoma treated?
- Q198** How can diabetes cause damage to your vision?
- Q199** What is temporal arteritis?
- Q200** What can be done to reduce the risk of developing eye diseases with age?

Answers
