Daltonism, Little Brown Jobs and Me

James L. Franklin, M.D.[1]

Several years ago, on a very snowy January 2nd, my wife and I left Chicago on what seemed to be the last flight out of O'Hare that day. It would prove to be a record cold month in the Windy City. We were bound for *Tierra del fuego* (Ushuaia, Argentina) at the southern tip of South America to join a Zegrahm Expedition to the Falklands, South Georgia and the Antarctic Peninsula.

The expedition staff included Peter Harrison, an outstanding English Ornithologist, whose enthusiasm for feathered creatures knew no limitation. Besides the dedicated Birders (the ones with their lifetime lists), Peter classified the tour group into the "NEMI.s" – that is, Not Even Mildly Interested and the "BITs" – Birders In Training. Ornithology beneath the Antarctic Circle included seven species of penguins, albatrosses, skuas, petrels and terns. By the end of the trip I was hooked; a dedicated BIT.

Inspired by our experience and equipped with the appropriate birding paraphernalia: camera plus telephoto lens, binoculars and field guides, we joined Peter on a voyage to the South Pacific and numerous

[1] Read at a meeting of The Chicago Literary Club on March 21,2016

islands between Fiji to Tahiti. Visiting remote South Pacific Islands in search of indigenous tropical birds proved to be an entirely different experience. In the Antarctic, the birds were large and the penguins were flightless, one could literally walk amongst them. Seabirds were easily seen either silhouetted against snow and ice or hovering over the stern of the ship.

In the South Pacific, Seabirds were rarely seen at the stern of the ship and on the islands, the indigenous species were small and difficult to spot in the tropical vegetation. When it came to spotting birds, I was at the bottom of the class. My wife and others would patiently direct my line of vision up this or that branch but alas, I would be reduced to pretending I had seen the bird and spare them the agony of trying to help me spot our quarry.

Birders use the term, " LBJ" or "Little Brown Job" to denote a small non-descript bird. Instead of the exotic tropical birds, I felt that I was seeing only Little Brown Jobs. Thinking about these difficulties, I remembered that in medical school, we were briefly introduced to the Ishihara cards used to screen for colorblindness. [Figure #1, p.31] The cards have a circle composed of colored dots of various sizes and hues in a pattern that contains a hidden numeral that cannot be appreciated

by someone with abnormal color vision. I remember not being able to recognize the hidden numbers. Already displaying a certain predilection toward ornithology, like an ostrich, I buried my head in the sand and pursued the matter no further (more about the Ishihara test to follow).

Soon after returning to Chicago, I went for a routine eye examination and related these facts to my ophthalmologist. Locating a book of the Ishihara test cards, he flipped through the first several pages and when I failed to see a single number hidden among the dots, he intoned, "you're colorblind" and that was that.

Colorblind? Well not really, to literally be colorblind would imply a total absence of color vision. Sir David Brewster (1781-1868), a Scottish physicist who made many contributions to the field of optics and early photography in the first half of the 19th century, is credited with coining the term 'colorblind.' He would have spelled color "COLOUR" an orthography that is used throughout the United Kingdom and its Commonwealth Nations. By the middle of the 19th century, "colorblind" or "to be colorblind" also came to signify a lack of racial prejudice. Since color vision is our topic, we will not be further concerned with this second meaning.

Simply put, to be literally colorblind would be to view the world in shades of grey as in a black and white photograph. In "The Island of the Colorblind" and in *The Case of the Colorblind Painter,* the neurologist Oliver Sacks helps us understand what this would mean in human terms. "The Island of the Colorblind" recounts the author's journey to the island of Pingelap in Micronesia where total colorblindness or *achromatopsia* (*a* – without, *chroma – color, and opsia* – vision) is endemic. Congenital *achromatopsia* is due to an absence or failure of the photoreceptors in the retina that are necessary for color vision.

Pingelap is a coral atoll and nowhere is the island more than ten feet above sea level. Typhoons, which are well known in this part of the Pacific, can devastate these Pacific atolls. In 1775 a typhoon known as Lengkieki swept over Pingelap. At that time the island had been settled for eight hundred years and had a population of nearly a thousand. The typhoon wiped out most of the inhabitants leaving twenty or so survivors. Within four generations the population rapidly increased but as a result of inbreeding previously rare genetic diseases began to appear. After four generations, by the 1820s, the first children with the Pingelap eye disease – *achromatopsisa* – were recognized. The mutation may have been present in earlier generations as a recessive trait but as

long as the population was large enough, it did not make an appearance. Inbreeding made it more likely that two carriers would marry and produce offspring with the disease. At the time Sacks visited Pingelap, two hundred years after the typhoon, a third of the islanders were carriers for the gene and out of seven hundred islanders, fifty-seven were 'achromatics.' The worldwide incidence of *achromatopsia* is one in 30,000 as opposed to one in 12 on Pingelap.[2]

Afflicted children appear normal at birth but begin to squint and blink at two to three months of age. At four to five months, they cannot distinguish colors or recognize small objects at a distance. They live an almost nocturnal existence, remaining indoors through most of the day and are only able to come outside at twilight. We will return to the distinction between nocturnal and daylight vision.

The Case of the Colorblind Painter, as in many of Sack's neurologic tales, begins with a letter from a patient. In this instance a 65-year-old artist who sustained a concussion in a car accident and in the following days found that he was "absolutely colorblind." What made this case intriguing was the fact that the patient had been a successful artist

[2] *Achromatopsia* has been linked to several specific genes. A particular gene mutation, CNGB3 underlies the condition in the Pingelapese islanders.

whose knowledge of color had been extraordinary. He found that his own brilliantly colored paintings now appeared gray and void of color. A sample of the "wrongness" of things he experienced included foods that appeared disgusting due to their dead, grayish appearance and his own flesh as well as that of others appeared an abhorrent gray.

In his first attempt to resume painting he tried to do a still life of an arrangement of flowers applying the tints by memory. This yielded a picture that was totally incomprehensible. Only when the painting was photographed in black and white did it reveal comprehensible contours. Realizing that he could not work with colors, he began painting in black and white; at first producing abstract constructions that reflected his rage, fear and despair.

The artist's colorblindness was caused by damage to a specific area of the visual cortex necessary for color vision. His condition is referred to as *cerebral achromatopsia.* While unusual, cases have been reported for over three centuries.

On October 31, 1794 before a meeting of the Literary and Philosophical Society of Manchester, John Dalton (1766-1844) – then 28 years of age - presented his first scientific paper, "Extraordinary Facts Relating to the Vision of Colours: with observations by Mr. John Dalton,"

noting: “I was always of (the) opinion, though I might not often mention it, that several colours were injudiciously named.” The paper was published in 1798 and is recognized as the first systematic study of defective color vision. Dalton, a Quaker, was largely self-educated and as a dissenter from the Anglican Church, was barred from attending English universities. He had recently come to Manchester to teach at the “New College,” a dissenting academy.

Dalton referred to his condition as “anomalous vision.” As interest in the subject grew, it came to be known as “Daltonism.” In 1827, Pierre Prevost of Geneva, a Foreign Member of the Royal Society of London, first used of the eponym “Daltonism” in print. Throughout his long life, Dalton remained interested in his defective color vision, but beyond references to the subject in his correspondence, he never published anything further. Dalton’s major scientific contribution was his discovery of the atomic theory of chemistry that is the basis of the Periodic Table. Future chemists and Dalton’s admirers objected to having the name of their hero linked to an area that was of minor interest. Well into the 20th century the English, French and Spanish retained the term: in France, *daltonisme* and *daltonien,* and in Spain, *daltonismo.*

In his famous paper Dalton recounts how an interest in botany "obliged" him to pay more attention to colors. He often found that when he seriously asked a person if a flower was blue or pink they thought he it was in jest.

He continues:

"Notwithstanding this, I was never convinced of a peculiarity in my vision, till I accidentally observed the colour of the flower of the *Geranium zonale* by candle-light, in the Autumn of 1792. The flower was pink, but it appeared to me almost an exact sky-blue by day; in candle-light, however, it was astonishingly changed, not having then any blue in it, but being what I called red, a colour which forms a striking contrast to blue. "

He observes that others viewing the flower both in daylight and by candlelight saw no change in color while his brother saw the change in the color of the flower as he did.

Dalton enumerated the investigations he conducted into the nature of his abnormal vision:

"My observations began with the solar spectrum, or coloured image of the sun, exhibited in a dark room by means of a glass prism. I found that persons in general distinguish six kinds of colour in the solar image; namely, red, orange, yellow, green, blue, and purple. Newton, indeed, divides the purple into indigo and violet; but the difference between him and others is merely nominal. To me it is quite otherwise: —I see only two or at most three distinctions."

Dalton notes that his was not the first reference to abnormal color vision. A country clergyman named Joseph Huddart in a letter to Joseph Priestly described a shoemaker, Thomas Harris "who could not distinguish colors." In 1777, Priestly published the letter in the *Philosophical Transactions of the Royal Society.*

Dalton went on to develop a hypothesis to explain his defective vision:

"It appears therefore almost beyond a doubt, that one of the humours of my eye, and of the eyes of my fellows, is a coloured medium, probably some modification of blue. I suppose it must be the vitreous humour; otherwise I apprehend it might be discovered by inspection, which has not been done. "

Dalton clung to this explanation of his color defect and instructed his friend and physician Dr. Joseph A Ransome to perform a postmortem examination of his eyes. Dalton died at the age of 78 on July 27, 1844 and on the following day Ransome performed the autopsy. Ransome collected the fluids of one eye into watch glasses and found them to be "perfectly pellucid." He shrewdly left the second eye almost intact, slicing off the posterior pole and noting that scarlet and green objects were not distorted in color when seen through the eye. Dalton's hypothesis was refuted. Ransome did not discard the eyes; they were stored and allowed to dry in room air. The fragments were preserved

along with the Dalton Hall relics in Manchester where they narrowly survived air raids during World War II. They were then transferred to the Manchester Museum of Science and Industry. For the moment let us leave Dalton's eyes in peace and turn our attention to the mysteries of color vision and the subject of colorblindness.

The eye gathers information from light that is focused by the cornea and lens on an amazing structure, the retina. The retina transforms light, a physical stimulus, into an electrical signal that is carried to the central nervous system where it is translated into our visual world including the perception of color. The eye was held in such awe that even before Darwin published *The Origin of the Species,* it was cited as an argument for divine creation. Darwin noted that to suppose it "could have been formed by natural selection, seems, I confess, absurd in the highest possible degree." His task of course was to persuade his readers that it was indeed the product of evolution.

The light we see, "visible light," is a minute portion of the electromagnetic spectrum, encompassing at one-end radio and television waves of great length (hundreds of meters) to X-rays and gamma rays (the diameter of a hydrogen atom) at the other. [Figure #2, p.31] Visible light is a narrow band that resides roughly in

the middle of the electromagnetic spectrum. The wavelength of visible light lies between 380 – 760 nm (nm = 10^{-9} meters). Ultraviolet light resides beyond the short end of the visible spectrum and infrared light beyond the long or red end of the spectrum.[3]

In 1666, with the plague raging in Oxford and London, the young Isaac Newton fled to his country home at Woolsthorpe Manor in the county of Lincolnshire. During the next two miraculous years, he developed his theories of optics, gravitation and invented the calculus. It was at Woolsthrope that he performed his *experimentum cruces* (crucial experiment) on optics. When Newton passed a shaft of daylight through a prism in a darkened room, he identified seven colors: violet, indigo, blue, green, yellow, orange and red – the mnemonic "VIBGYOR" aids in remembering the sequence. This by itself was not remarkable. The rainbow effect of prisms was well known. It is what he did next that really was of great moment. He demonstrated that the spectrum of colors could be passed through a second prism and reconstituted to daylight. When he isolated the blue and the red ends of the spectrum and passed them through a second prism they could not be further

[3] We are exposed to radiant energy from the sun after it is filtered through the atmosphere to a range of 320 nm to 1,100 nm encompassing visible light but including energy in the ultraviolet region and infrared regions of the spectrum.

divided; thus a physical concept of primary colors. The German mathematician and astronomer Johannes Kepler (1571-1630) in his *Harmonice Mundi* (The Harmonies of the World) had related planetary orbits to the consonant musical intervals. Newton attempted to equate the seven colors in the spectrum to the musical pitches in an octave. In this he was led astray; his barocentric (circular) model of color vision was an approximation, it was incorrect.

Let us introduce Dalton's contemporary, the physician and polymath Thomas Young (1773-1829). His early mastery of multiple languages allowed him in later life to translate the Egyptian Coptic portion of the Rosetta stone and he contributed to the understanding of Egyptian hieroglyphics making it possible for Jean-François Champolion to decipher the Rosetta stone.

Thomas Young made outstanding contributions to our understanding of light, color and vision. His interests were so broad that he often published anonymously fearing that patients and colleagues would think he neglected his medical practice. His earliest scientific paper, published in 1793 when he was twenty years of age, described how the lens of the eye changes shape through the muscular action of the ciliary body allowing for near vision or accommodation. He

challenged Newton's particulate theory of light demonstrating that light behaved as a wave phenomenon and calculated wavelengths for Newton's seven spectral colors.

Young laid the groundwork for the trichromatic theory of color vision. In 1801 he postulated that receptors or resonators must exist in the retina for three principal colors – red, green and blue – from which all other colors could be produced. It seemed improbable that there would exist separate receptors for every conceivable hue throughout the retina. Addressing the issue of Dalton's abnormal color vision, Young suggested that there might be an "absence or paralysis of those fibers of the retina which are calculated to perceive red."

At first glance this insight is astounding not only because history would prove him to be correct but also because knowledge of the anatomy of the eye was limited to gross visual inspection. Microscopic examination of the retina still lay in the future. Further reflection on his achievement must take into the account that artists and color theorists dating back to the Renaissance, including Leonardo da Vinci, recognized that with a limited number of primary colors every conceivable hue could be created.

Thomas Young's three-receptor theory of color vision lay forgotten for some 50 years before it was resurrected in 1851 by another extraordinary scientist of the 19th Century, Prussian born Hermann Ludwig Ferdinand von Helmholtz (1821-1894). Famous for his systematic studies of Sound and Optics, Helmholtz is also credited with inventing the ophthalmoscope used by all physicians today. In resurrecting Young's conjecture, his name is linked with that of Young as the "Young-Helmholtz trichromatic theory of color vision."

The Scottish physicist, James Clerk Maxwell (1831-1879), in the short time allotted him – he died at age 48 years - is ranked along with Sir Isaac Newton and Albert Einstein as the world's three greatest scientists. Maxwell developed the mathematical concepts allowing for the expression of color in a three dimensional space. He achieved this using an ingenious top that allowed observers to quantitatively match colors. [Figure #3, p.32] He also built a "color box" - a large device of pulleys, mirrors and lenses - that objectively tested color matching and the proportion of colors required to achieve a match. These experiments confirmed Young's hypothesis and Helmholz's trichromatic theory of color vision. Using three colors, red, green and blue, Maxwell was able to match any color. With two colors, a match was not always possible.

Visitors to Maxwell's London home in the 1860s would meet his wife Katherine, who took a keen interest in her husband's experiments with the "color box." Together they collected data on their friends and sought out colorblind people concluding that most of them confused red and green.

The Camera was an appealing model for scientists in the 19th century for understanding the function of the eye. The retina had to contain some light-sensitive chemical analogous to the silver nitrate film coating the glass slides on which the earliest photographs were captured. German scientists during the second half of the 19th century laid the foundations for our understanding of the retina on two levels. They described the cellular elements responsible for vision and identified the light sensitive pigment analogous to the silver nitrate film. The German anatomist and professor at the University of Wüzburg, Heinrich Müller (1820-1864) developed the histologic techniques that allowed him to visualize the previously unseen cellular tissue of the retina. In 1870 his student, Max Schultze (1825-1874) identified the rods and cones as the cellular elements in the retina that were sensitive to light. Through a shrewd deduction in comparative anatomy, Schultze noted that birds that were primarily nocturnal had an abundance of

rods while birds that were active during daylight had few rods and many cones. He drew the correct conclusion that the rods were dedicated to night vision and the cones function in daylight.[4]

Müller also noted the presence of a reddish pigment sensitive to light in the retinas of frogs and squids. In 1876 Franz Christian Boll (1849-1879), who was in turn a student of Schultze, demonstrated that the pigment was located in the rods and retained its color in the dark but bleached to colorless when exposed to light. Boll's career was cut short when he died at age thirty of tuberculosis. His work was taken up by Whilhelm Kühn (1837-1900) who succeeded Helmholz as professor of physiology in Heidelberg in 1871 where he worked on the photochemical basis of vision. Kühne extended the study of the pigment to the human retina identifying the pigment as 'visual purple.' It would be left to an American, George Wald (1906-1997), to elucidate the biochemistry of 'visual purple' naming it rhodopsin (from Greek, *rhódin*, for rose, and *ópsis* for sight). Wald, who was Jewish and the son of Polish

[4] Schultz's work confirmed the earlier observations made by a Czech anatomist, Jan Purkinje (1787-1869), who as an early riser noticed on his walks that the color of his favorite geraniums changed from dark red in the early morning light to pink, as they were lite by the morning sun. Publishing in 1825, he drew the correct conclusion that the eye contained two types of visual equipment, one for daylight and one for dawn and dusk. This phenomenon, known as the Purkinje effect, may call to mind Dalton's remark about the *Geranium zonale.*

immigrants, began his studies in Germany during the 1930s working at several famous laboratories. He was forced to return to the United States as a result of the rise of Nazism going first to the University of Chicago and then to Harvard. In 1967, he shared the Nobel Prize in Medicine and Physiology for discoveries concerning the physiological and chemical processes of vision. His lifetime of achievement in the study of the retina included the relationship of Vitamin A deficiency to night blindness, the biochemistry of rhodopsin and the sensitivity across the visual spectrum of rhodopsin and the related photo pigments present in the retinal cones.[5]

It may come as a surprise to learn that of the estimated 130 million photoreceptor cells in the human retina, 120 million are rods and only 6 million are cones. To put it another way, over 97% of the retina is dedicated to night vision. The evolutionary implication is consistent with the belief that our mammalian ancestors were nocturnal. The rods are more sensitive to light than the cones such that they respond to light that is a billionth the strength of daylight. In

[5] The photoreceptor proteins found in the cone cells of the retina that are the basis of color vision as a group are referred to as photopsins. In the L or red cones, photopsin is called 'erythrodae' (Greek *erythro* – red and *labe* – seeking), in the M or green cons, 'chlorolabe' and S or blue cone, 'cyanolabe."

daylight the intensity of the light is such that the rods cease to function, they are said to have 'bleached out.' Returning to the *achromatics* of Pingelap, who have only rods and lack cones, we understand why they cannot see in daylight. At night, our vision is colorblind because only the rod receptors are sending signals to the brain. Night vision is monochromatic. The rods are maximally sensitive to light at a wavelength of 420 nm, corresponding to the blue violet end of the visual spectrum.

The cone receptors are responsible for daylight vision and our perception of color. There are three types of cone cells in the retina; 'red', 'green' and 'blue.'[6] They are more accurately named for the position corresponding to their point of maximal sensitivity in the visual spectrum: 'L' for long, 'M' for middle and 'S' for short wave lengths. To avoid confusion the 'red,' 'green,' and 'blue' terminology is often retained. The point of maximum sensitivity represents the peak sensitivity of a curve plotting the responsiveness of the each type of receptor cell along the wavelengths of the visual spectrum. [Figure #4, p.32] Since the curves for each of the receptors overlap, all three

[6] Locating their point of maximum sensitivity in the visual spectrum, the L-cones correspond to greenish-yellow on the visual spectrum, the M-cones correspond to yellowish-green and the S-cones correspond to violet end of the spectrum.

receptors respond to a variable degree depending on the light that is falling on the retina. This is the raw material that our central nervous system and visual cortex integrates to generate our perception of color.

It is estimated that of the 6 million cones in the human retina 99% are 'red' or 'green', the 'blue' cones represent the remaining 1%. Cones sensitive to the blue end of the spectrum are distributed throughout the retina except in the very center of our visual field designed for maximal visual acuity. This anatomically distinct area, the *fovea* ("the pit"), is lacking rods and contains only 'red' and 'green' cones that are more densely packed than in any other part of the retina.[7]

With this background on color vision, we return to the subject of colorblindness. A familial component, what we now recognize as inherited or genetic, was evident in the earliest reports of colorblindness. Captain Joseph Huddart's 1777 letter to Rev. Joseph Priestley mentions that the shoemaker, Thomas Harris, had "two brothers in the same circumstance as to sight, and two other brothers and sisters who, as well as their parents had nothing of this defect." In

[7] For this reason, at night, our peripheral vision, while color blind, is more acute than our central vision. Stargazers can confirm this fact by noting that a dimly lit star will be better seen in their peripheral vision than when they attempt to look at it directly.

his paper of 1794, John Dalton also noted familial occurrences of defective color vision including that of his own brother.

Colorblindness is the first human genetic trait to be linked to a specific chromosome. The Swiss ophthalmologist Johann Friedrich Horner (1831 – 1886), known to generations of medical students for "Horner's Syndrome" and its association with tertiary syphilis,[8] presented the first scientific account of the hereditary transmission of Daltonism. He recognized that colorblind fathers have color-normal daughters who are in turn mothers of colorblind sons. Mothers who carry the gene on one of their X chromosomes have normal vision. Women also may inherit color defective vision but with a far lower frequency. One of every two daughters resulting from the union of a colorblind father and a mother who is a carrier of the colorblind gene will have defective color vision. [Figure #5, p.33]

Since the methods for testing defective color vision during the 19th century were not standardized and only partially understood, much of the data gathered on individuals with color defective vision was confusing. In 1895, Johannes Adolf von Kries (1853 – 1928), a German

[8] "Horner's Syndrome" (*Ptosis* - unilateral drooping of an eyelid, *meiosis* – a small pupil, *enophthalmos* – a sunken or depressed eyeball and *unilateral anhydrosis* - absence of facial sweating on the affected side).

physiologist and psychologist and disciple of Herman Helmholtz, coined the terms used today in classifying defective color vision. Based on the trichromatic theory of color vision, he classified subjects as having *protanopia, deuternopia* and *tritanopia.* These terms refer to the missing cone receptor; *protanopia,* first (red), *deuteranopia,* second (green) and *tritanopia,* third (blue). [Figure #6, p. 33]

The photo pigments in each of the three cone receptors are genetically determined, chemically distinct molecules that differ from each other by only a few amino acids. These small differences account for their variable sensitivity to light across the visible spectrum. Humans with normal color vision recognize color by processing signals from the three types of cone receptors and are referred to as 'trichromats,' or as having 'trichromatic vision.' Individuals totally lacking one of the primary visual pigments have 'dichromatic' vision. Dichromats match colors by processing the differences between two color receptors. Classification is further complicated because many individuals with defective color vision have inherited genes that alter the sensitivity of one of the three cone photoreceptors, most frequently red or green. In these instances, the receptor is still functional and the affected individual still has trichromatic vision. They are classified as

having ‘Anomalous Trichromacy’ and sub-classified as *protanomaly, deuteranomaly* and *tritanomaly.* Individuals with ‘Anomalous Trichromacy’ experience a richer palette of colors than dichromats and are less likely to realize they have abnormal color vision.

We now return to John Dalton’s eyes and those desiccated fragments that have been held by the Manchester Literary and Philosophical Society. In 1995, one hundred and fifty years after his death, British scientists published a remarkable study in ‘molecular biography,’ “The Chemistry of John Dalton’s Color Blindness.” Analysis of the DNA in samples taken from the fragments of Dalton’s eyes revealed that Dalton had a single LW (Long Wave - red) gene and that he lacked the MW (Middle Wave – green) gene. Dalton had dichromatic vision and was a *deuteranope.* Their findings contradicted the traditional belief that Dalton was a *protanope* with a foreshortening of the red end of the spectrum. Reviewing Dalton’s observations of his “anomalous vision,” and the reports of Sir John Hershel and Sir David Brewster who examined Dalton, the DNA evidence was found to be consistent.

John Dalton, *requiescat in pace*!

The question may be asked why defective color vision, a sex-linked recessive trait, persists in the human genome with a frequency that rises to 8% of the male Caucasian population? In the classic example of sickle cell anemia, also inherited as a recessive trait, carriers of the sickle cell gene are more resistant to infection by the malarial parasite than non-carriers. This confers a survival advantage for carriers of the sickle cell gene and explains the persistence of an otherwise deleterious gene. A Darwinian is led to ask, does defective color vision or its carrier state confer a natural selective advantage or is it survival neutral?

The answer seems to require a broader view of the evolution of color vision. The photoreceptor pigments in the rods and cones have ancient origins within the animal kingdom. The gene for the blue cones is the most ancient and pre-dates the entire mammalian line.[9] Primates of South America, New-World monkeys, broke away from African, Old-World monkeys about 63 million years ago. The New World monkeys uniformly have dichromatic vision while Old-World monkeys, with

[9] The genes encoding 'blue' cones are located on chromosome 7, an autosome and have a different evolutionary history than the red-green cones. This means *tritanopia* and *tritanomaly* are not sex-linked traits and women and men are equally affected. They exist with an approximate prevalence of one in 10,000 individuals.

whom we share a common ancestor, evolved trichromatic vision. Our ancestors managed to duplicate the X-linked receptor gene and acquire separate classes of red and green cones. There are lines of evidence to suggest that primate trichromatic vision is as young as 30 – 40 million years old. As one author has noted; "in evolutionary terms, it as a last-minute job. No wonder it goes wrong so often."[10]

None of the Old-World primates studied thus far has been found to have a defect comparable to human colorblindness; that is dichromatic vision. This suggests in an arboreal habitat, red-green color deficiency would be a negative survival factor: for example, difficulty recognizing ripe fruit in the canopy of the forest. Once our ancestors left the forests on their long march to civilization, survival pressure against the mutation eased.

Could colorblindness or its carrier state confer a survival or sexual selective advantage? There are poorly documented references suggesting that during WW II, colorblind airmen made better bombardiers due to their ability to see through enemy camouflage: hardly a factor of evolutionary significance. Nor has anyone mustered

[10] Simon Ings, "A Natural History of Seeing," W.W. Norton & Company, 2007, p. 259.

evidence that abnormal color vision might be sexy. John Dalton and Quakers in general were known to have rather drab taste in dress.

What about the demographics of colorblindness? Dr. Shinobu Ishihara, the Japanese Ophthalmologist, who created the Ishihara color test, was born in Tokyo in 1879. He was trained in ophthalmology in both Tokyo and Germany. With the outbreak of WW I, he was asked by the Japanese military to develop a color vision test to screen conscripts for defective color vision. It is remarkable that he hand painted his first set of test plates.

Introduction of the Ishihara plates made it possible to perform larger scale population surveys for defective color vision. Across the globe, zones of high, intermediate and low prevalence have been mapped. Europe and North America show a high prevalence approaching 8% while India and China belong to the intermediate regions of 4 – 6%. Eskimos in the arctic, tribal peoples in the equatorial forests of South America, Africa and New Guinea have a low prevalence of less than 4%. In South America, strong differences exist between isolated rural areas and urban industrial regions with a gradient of colorblindness from 1.6% in semi-nomadic Andean shepherds to 8% in industrial port cities in Chile. A survey of the frequency of color

blindness among 60,000 R.A.F. men in 1943 pointed to a higher percentage in men from the western areas of Britain corresponding to regions invaded by Angles, Saxons and Jutes during the 5th and 6th centuries.[11] The distribution of defective color vision across the globe has been interpreted in a number of different ways, but one is left with the impression that colorblindness might be a serious handicap in primitive cultures. With the agricultural revolution, selective pressure relaxed allowing mutant genes to persist.

Given the high prevalence of inherited defective color vision, it is somewhat surprising that the first written account in western literature did not appear until Joseph Huddart's letter to the Royal Society in 1777.[12] There is no mention of the disorder in the Old Testament or ancient writing of the near East. William Ewart Gladstone (1809-1898), who served as Prime Minister on four separate occasions during the reign of Queen Victoria, was a noted scholar of classical literature. In his

[11] Vernon, P.E. and Stracker, R.A. Distribution of colour blindness in Great Britain, Nature, 152:690,1960

[12] An account in the *Philosophical Transactions of the Royal Society,* 1684, by D. Tuberville of "Several Remarkable Cases in Physick Relating Chiefly to the Eyes" is sometimes cited as the first published account of colorblindness. "A maid two and twenty years came to me from Banbury, who could see very well, but no color besides black and white." However, this is not regarded as a case of Dalton's anomalous color vision.

essay, *Homer's Perceptions and the Use of Colour,* Gladstone characterized the poet's color system as "founded upon light and darkness" and noted that the Greek's perception of color had not much improved by the time of Aristotle. Colorblindness has been cited as a possible explanation for this phenomenon. A German philologist, Lazarus Geiger (1829-1870), found the same pattern in ancient literature of India and the Near East. In the 20th century, American anthropologists, Brent Berlin and Paul Kay, surveyed color terminology in the languages of isolated societies. They found that the acquisition of color terminology followed a predictable pattern. A term for black and white was universal, where three color terms were used, red was next then yellow, green and blue were added in that sequence. Recent studies of the Himba tribe in Northern Namibia, a group lacking a signifier for the color blue, tested the ability of tribesmen to identify a blue square in an array of green squares projected on a computer screen. As opposed control subjects, the Himba struggled to 'see' the blue square. The fascinating implication is that language might tune our brain to experience the colors we see. Perhaps one should posit another category of colorblindness, *"lexicological*."[13]

[13] DVD, William Lidwell, How Colors Affect You: What Science Reveals, Lecture 1,

This personal essay on the subject of color vision and colorblindness has focused on a historical and evolutionary view of the topic. There is much that remains to be discussed. We have not elaborated on what is known about how the brain constructs our perception of color. There is the history and current status of legal issues and safety restrictions related to defective color vision. There are social issues pertinent to career paths where defective color vision might present limitations. Recalling those Little Brown Jobs, instead of Birding, perhaps I should confine my activity to armchair Ornithology. I will also leave for another occasion my adventures attempting to learn to paint with watercolors at the Palette & Chisel Academy of Fine Arts on Chicago's Near North side.

Once one is on the lookout, colorblindness has a way of creeping up on you. I want to close with a few examples.

Members of The Chicago Literary Club who attended Steppenwolf Theater's 2015 excellent adaptation by Frank Galati of John Steinbeck's "East of Eden" might remember these lines taken from the novel:

Kate Trask: "Give me a sermon Mr. Mouse."

The Meaning of Color, The Great Courses 2013

Adam Trask: "No I won't because I seem to know that there's a part of you missing. Some men can't see the color green, but they may never know they can't. I think you are only part of a human. I can't do anything about that. But I wonder whether you ever feel that something invisible is all around you. It would be horrible if you knew it was there and couldn't see it or feel it. That would be horrible."

In February of 2015 a flurry of interest surfaced on the Internet and in the news media describing the anomalous colors some observers perceived when viewing a blue and black dress.[14] While the most observers saw the dress as blue and black, there were a minority that insisted it was gold and white. I thought the confusion might arise in rare individuals who were lacking blue cones or *tritanopes*. Numerous expert opinions appeared offering explanations for the phenomenon but a consensus was never reached highlighting the complexity of color perception.

Because multiple mutant variants of the color receptor genes have appeared on the X-chromosome, instances of human 'tetrachromats (four separate color photoreceptors) have been documented. Tetrachromatic vision may occur in women when different mutant genes for the red/green cone photoreceptors are present on both of

[14] Related Links:
http://www.nytimes.com/interactive/2015/02/28/science/white-or-blue-dress.html
http://www.wired.com/2015/02/science-one-agrees-color-dress/

their X-chromosomes. The implication is that such an individual might perceive rare subtleties in color; in one instance a woman could segment the visual spectrum into ten different colors. The subject has been recently examined by a group of investigators at the University of San Diego. Women with four photo-pigment genotypes were found to perceive significantly more chromatic hues when compared to normal female and male trichromatic controls.[15] Might these findings explain gender differences in color behavior; for example fashion?

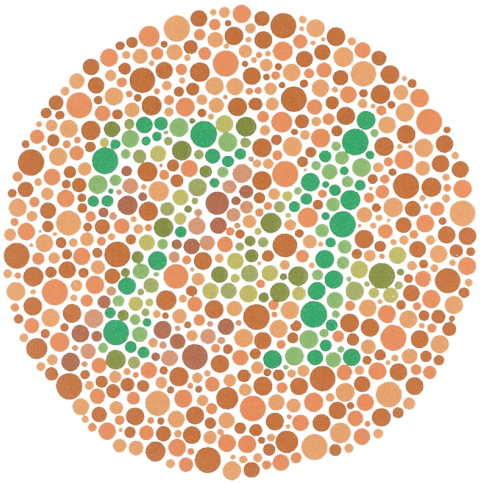
I would like to thank Gerald A. Fishman, M.D., director of the Pangere Center For Inherited Retinal Diseases at The Chicago Lighthouse in the Westside Medical District, who met with me to discuss this topic. Dr. Fishman also evaluated my color vision defect performing a color-matching test, a Nagel anomaloscope and concluded that my color vision defect is congenital *deuteranomaly*. While I am not a true *deutranope* like John Dalton, perhaps therein lies a thread that resonates with my fascination for the history of science.

And so, John Dalton, *Salud,* I salute you.

[15] Kimberly A. Jamieson et. al., Richer color experience in observers with multiple photopigment opsin genes, Psychosomatic Bulletin & Review, 2001, 8, (2), 224-261.

Illustrations:

Figure #1 – Ishihara Test Plate, p. 2



Example of an Ishihara color test plate

The numeral "74" should be clearly visible to viewers with normal color vision. Viewers with dichromacy or anomalous trichromacy may read it as "21", and viewers with achromatopsia may not see numbers.

Figure #2 p. 10

Visible Light in the Electromagnetic Spectrum

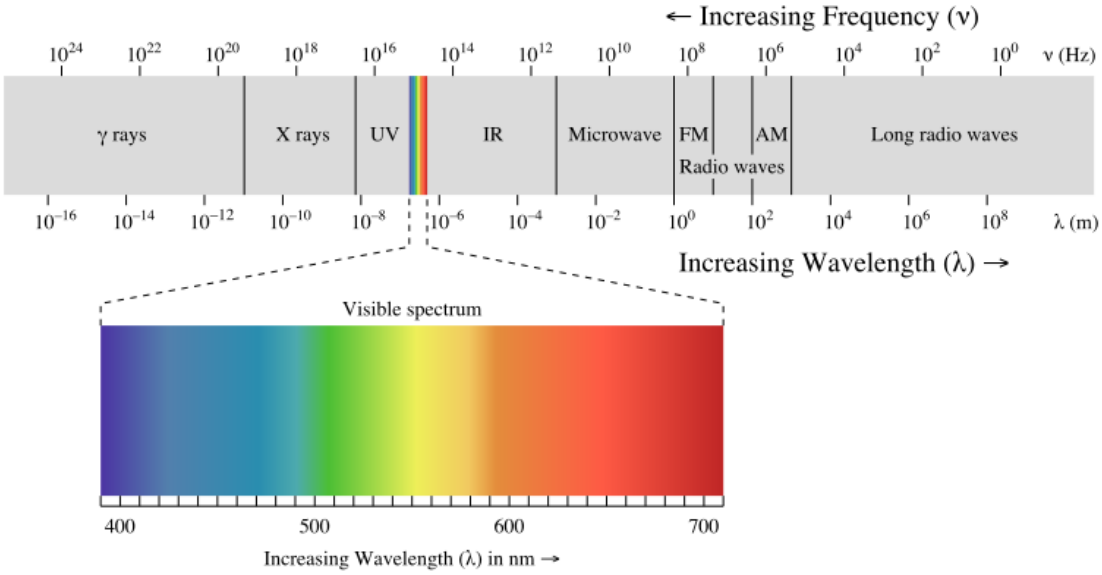
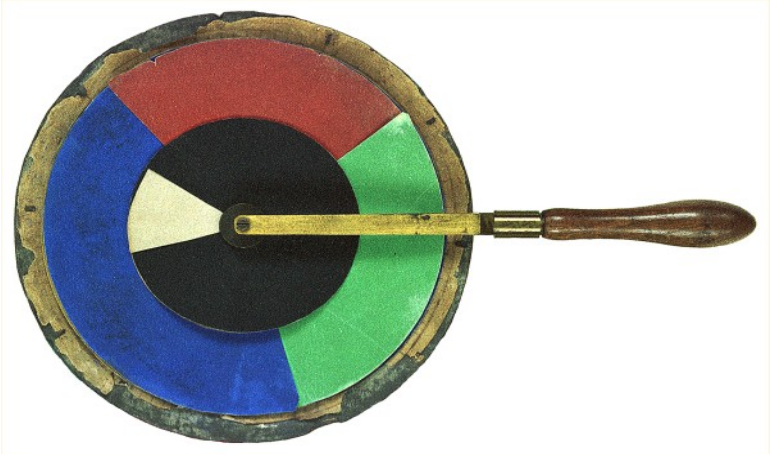
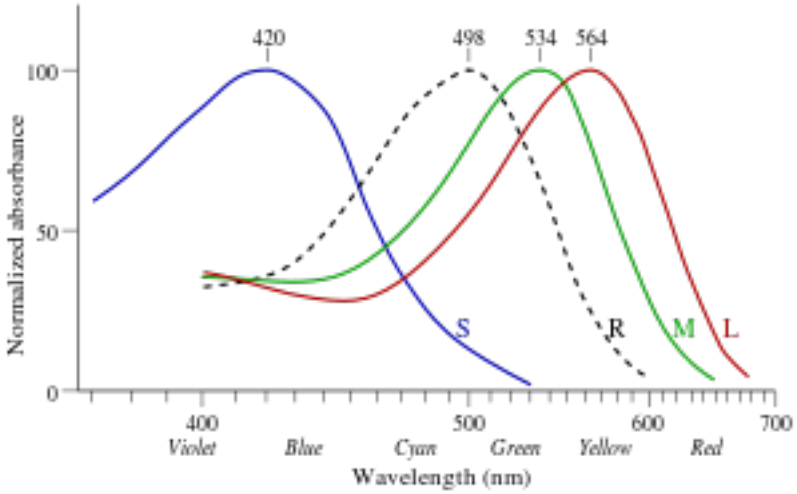


Figure #3 p. 14
The James Clerk Maxwell Color Top



With the spinning top, colors red, variable proportions of green and blue are used to match a test color.

Figure #4 p. 18
Photosensitivity Curves for Rods and Cones



George Wald plotted the absorbance of rod pigment (black curve), then later the absorbance of cone pigments (red, green, and blue curves)

Figure #5 p. 20
Sex-linked Inheritance of Colorblindness, p. 20
(Panel on the Left demonstrates male Inheritance and on the Left female inheritance)

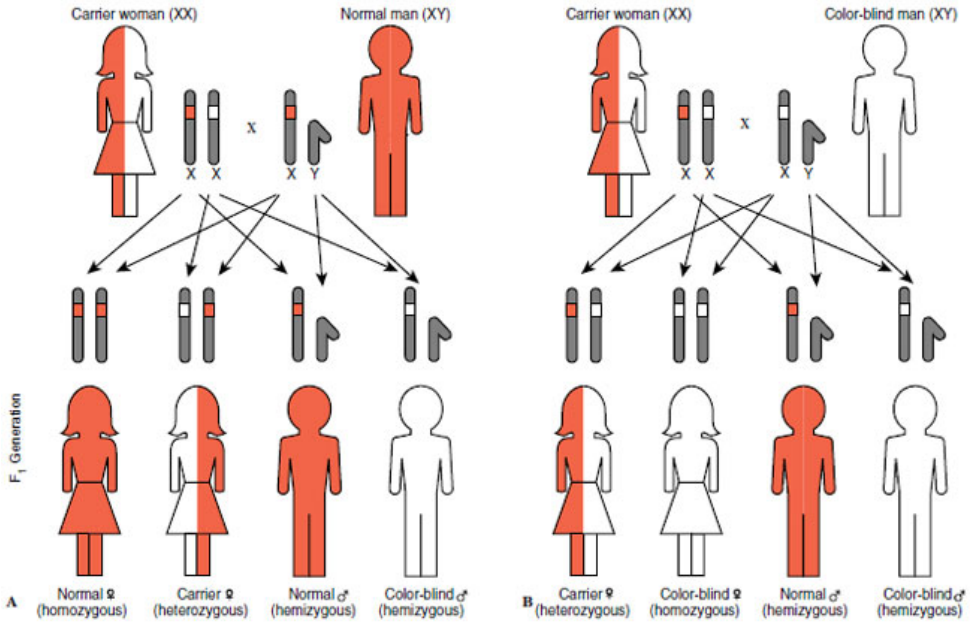


Figure #6 p. 21
Classification of Colorblindness p. 20

Prevalence of color blindness

	Males	Females
Dichromacy	2.4%	0.03%
Protanopia (red deficient: L cone absent)	1.3%	0.02%
Deuteranopia (green deficient: M cone absent)	1.2%	0.01%
Tritanopia (blue deficient: S cone absent)	0.001 %	0.03%
Anomalous Trichromacy	6.3%	0.37%
Protanomaly (red deficient: L cone defect)	1.3%	0.02%
Deuteranomaly (green deficient: M cone defect)	5.0%	0.35%
Tritanomaly (blue deficient: S cone defect)	0.0001 %	0.0001 %

Selected Bibliography on Color Vision and Color Blindness

Books:

Cruz-Coke, Ricardo (1970) Color Blindness: An Evolutionary Approach, Charles C Thomas, USA

Gregory, R.L. (1978) Eye and Brain: the psychology of seeing, Third Edition, MGraw Hill, NY Toronto

Ings, Simon (2007) A Natural History of Seeing: The art & Science of Vision, W.W. Norton & Company, New York

Sacks, Oliver (1995) An Anthropologist On Mars; Seven paradoxical Tales, Vintage Books, New York, London

Sacks, Oliver (1998) The Island of the Colorblind, Vintage Books, New York

Valberg, Arne (2005) Light Vision Color, John Wiley & Sons, England

Wasserman, Gerald S. (1978) Color Vision: An Historical Introduction, John Wiley & Sons, Inc.

Articles of Historical Interest from Scientific American:

Jeremy Nathans, The Genes of Color Vision, Scientific American: 42-49, February 1989

Edward MacNichol,Jr. Three-Pigment Color Vision. Scientific American 211:48-56, December 1964

Richard H. Masland, The Functional Architecture of the Retina,

W.A.H. Rushton, Visual Pigments and Color Blindness. Scientific American 232: 64-74, March 1975

W.A.H. Rushton, Visual Pigments in Man, Scientific American, 207: 120-132, November 1962

George Wald, Life and Light, Scientific American 201:92-108, October 1959

Biography:

Michel Meulders (translated and edited by Laurence Garey) , Helmhotz: From Enlightenment to Neuroscience, The MIT Press, Cambridge Massachusetts, 2010

Basil Mahon, The man who Changed Everything: The Life of James Clerk Maxwell, John Wiley & Sons, Ltd. England, 2004

Andrew Robinson, The Last Man who Knew Everything: Thomas Young, The Anonymous Genius Who Proved Newton Wrong and Deciphered the Rosetta Stone, Among Other Surprising Feats, A Plume Book, USA, 2007

Articles
Colorblindness:

Hunt, DM et. al. The Chemistry of John Dalton's color blindness. Science 1995: 232: 203-210
Fishman, Gerald A. John Dalton: Though in Error, He Still Influenced Our Understanding of Congenital Color Deficiency. Opthalmic Genetics2008:29:162-165