The Human Vision System: a marvel of engineering design

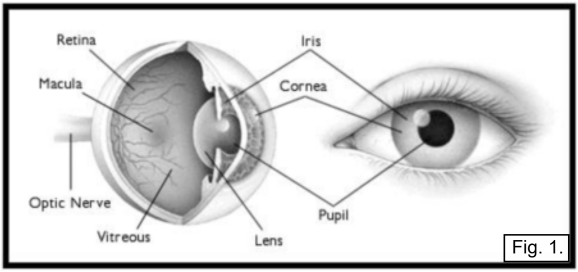

Fig. 1.

We take our eyes and vision for granted without giving much thought as to how it all works or what it is doing for us (fig. 1). In fact the eye/brain system is very complex and demonstrates sophisticated engineering design.

We automatically associate vision with our eyes, but eyes are only one part of a complete system that gathers and processes information about our surroundings and our body (figs. 2, 3). Visual information is coordinated and seamlessly analyzed by our brain to give us a 3D image of our environs in full colour! This system is highly automated and has autofocus, automatic light level adaptation and automatic compensation for head and body movement. The data stream from our eyes is processed in real time to give us a smooth representation of the world, which we perceive as a regular space around us. The brain accomplishes this by means of coordinated parallel processing, with various parts of the cortex used to provide edge detection, pattern and shape recognition, motion sensing, reflex actions, stereoscopic processing, hand/eye co-ordination etc.

Every part of this system needs to be in place and functioning properly for our vision system to be useful. This is why an evolutionary explanation of this system is woefully inadequate. Random accidental mutations cannot account for the huge amount of precise coding in our DNA, which contains the blueprint for the development and construction of our optimised vision system, starting from an embryo.

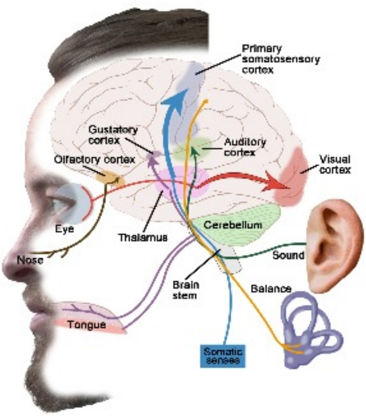

Fig. 2.

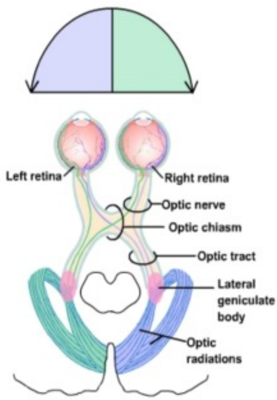

Fig. 3.

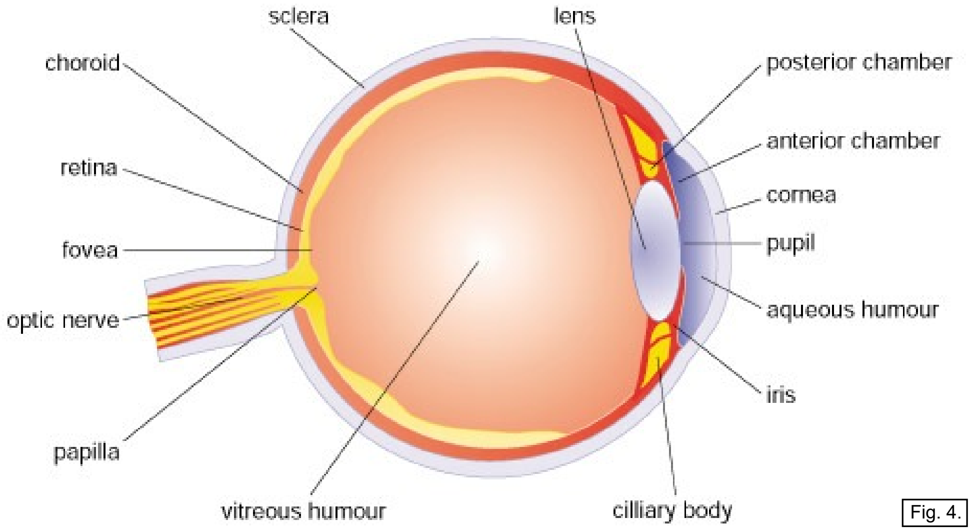

Fig. 4.

The eye as a transducer

The eye has been compared to a camera but in fact it is more sophisticated.

The Cornea Light entering the eye (fig. 4) first goes through the cornea. This is a self-cleaning optical surface (better than man-made lenses) which provides the main refraction of the light with a power of about 40D. The surface is not spherical but roughly ellipsoid to minimize spherical aberration. The cornea has a transparency of over 95% due to the arrangement of cells and a lack of any direct blood supply. Our tear layer smoothes the cornea's optical surface thus preventing light scattering, and provides nutrients for the cells.

The Iris This is a muscle ring which gives our eye its colour and is also the first control of light input. The pupil diameter ranges from about 2mm in bright light to 7mm in low light, providing a 1:12 ratio of light entry. The diameter control is rapid and automatic via the optic and oculomotor nerves.

The Lens The biconvex eye lens provides fine control of the eye's imaging, enabling accommodation from about 15cm to infinity. This is achieved through the contraction of the ciliary muscles surrounding the lens, which changes its shape and hence power from about 20D to over 30D. The lens is crystalline but flexible and the ciliary muscles change its curvature to vary its power. The lens is aspheric and has a variable refractive index to tailor its imaging properties and to minimize optical aberrations. The lens has no blood supply and is highly transparent to visible wavelengths, whilst blocking UV light which would damage the retina.

The Retina and Choroid

The design of the retina and choroid is fascinating. The retina has a layer of

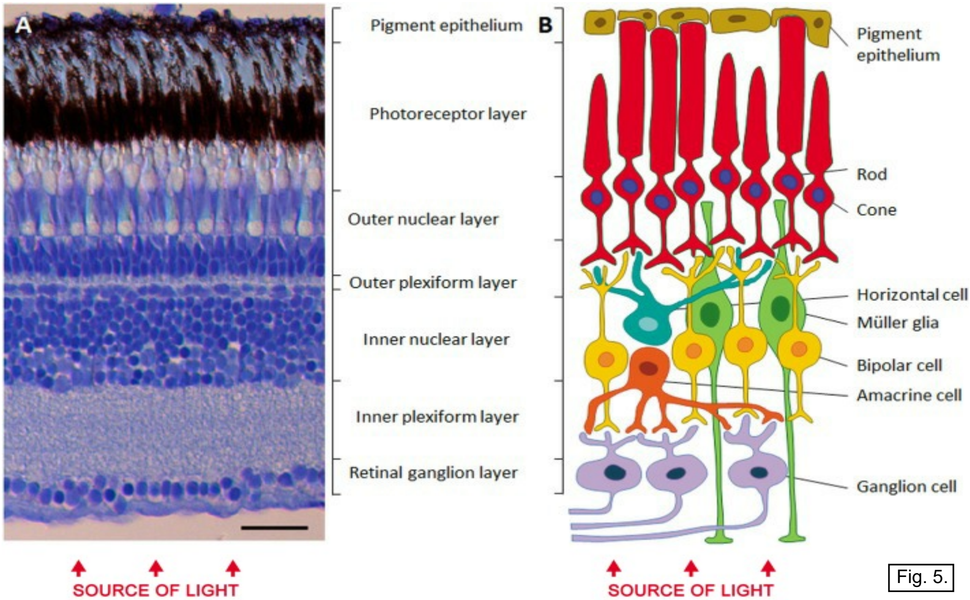

Fig. 5.

photoreceptor cells (fig. 5) which respond to photons. There are two types of photoreceptor cells, which have different functions. These cells require a good blood supply for nutrients, waste removal and energy supply, as well as nerve connections to relay information for processing.

Light enters the retina as above, but immediately encounters nerve fibres and ganglion cells, as well as bipolar cells. Underneath these are the rod and cone photoreceptor cells. The rod cells are monochrome detectors and provide functional information about the retinal image. The cone cells are much less sensitive to light but come in three varieties to detect RGB colour.

This arrangement may seem to be a poor design until you realize that the rod and cone cells need to be at the back of the eye to be close to the blood supply in the choroid, which is just below the epithelium. Thick blood vessels at the front of the retina would absorb light.

To overcome the need to put a network of nerve fibres at the front of the retina, it has been designed with Müller glial cells. One of their functions is to act as lossy optical waveguides, transferring photons from the front of the retinal layer down to the photoreceptors. This is a very clever piece of design work as the waveguides leak blue light which can activate the rod cells. Thus the retina can have a very high detection efficiency and still maintain a good refresh rate for the photodetectors, essential for smooth motion viewing.

The Physical Optics of the Eye

The eye is designed as a wide-angle imaging system. This means that peripheral rays must be focused on the retina, as well as the more axial rays that fall on the fovea region. This is only possible because the retinal shape is spherical and matches the image curvature. Also the cornea/lens optical layout is optimised to achieve good focus for peripheral rays and to produce minimal optical aberrations (fig. 6).

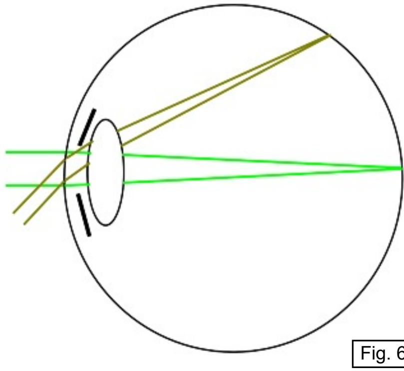

Fig. 6.

Optical aberrations can be greatly reduced by using so called symmetrical lens systems. The eye uses this design principle. The lens is an aspheric triplet and the iris is at the geometric centre of the cornea lens system.

All engineering designs involve compromise. A perfect wide-angle imaging system is impossible to produce. The cornea/iris/lens system has been designed to give good but not exceptional image quality for the foveal region, whilst maintaining reasonable optical quality in the peripheral visual field. This design is better than most man-made wide angle lens systems.

Spherical Aberration

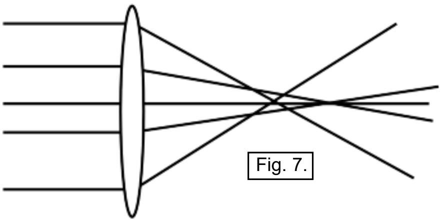

Fig. 7.

Spherical aberration is due to the non-perfect imaging of a lens with spherical surfaces. Peripheral rays are focused closer to the lens than axial rays (fig. 7). There are only two ways to cure this: one is to block out peripheral rays and the other is to use an aspheric lens. The eye uses both these techniques. The small diameter pupil helps to keep peripheral rays from being imaged and the cornea and the eye lens are aspheric. The cornea does produce some positive spherical aberration (SA) but the lens produces negative SA so compensating. This clever design strategy could not have evolved as on its own any selective advantage is slight and also there are several factors involved which need to be present simultaneously for success. Any change in the cornea shape would have to be accompanied by a corresponding precise change in the lens shape to keep the eye focusing correctly and reducing aberration.

Chromatic Aberration

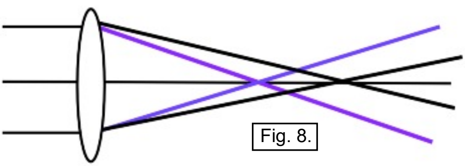

Fig. 8.

All lenses are dispersive and will focus blue light more than red light. This is called longitudinal chromatic aberration and gives an image which has coloured fringes around objects.

Man-made lens systems use achromatic doublets for objective lenses and compound eyepiece lenses to greatly reduce chromatic aberration (CA). The eye does not attempt any optical correction for CA (fig. 8). The design compromise used in the human eye is to have two carotenoid pigments in the fovea, which partially absorb the blue light. These protect the cells from shorter wavelength, potentially damaging light, and minimize the effects of chromatic aberration from the cornea and lens. The brain automatically compensates for this intrinsic colour imbalance and we see a balanced colour spectrum.

Coma and Trefoil

These aberrations produce a smeared out effect for small bright light sources (like a street lamp at night). The appearance is like the tail of a comet or multiple tails. The eye does not produce noticeable amounts of these and so the design is good.

Diffraction Spread

All circular imaging systems focus parallel rays down to an Airy disc (fig. 9, left) and not a point. The size of the Airy disc on the retina is determined by the pupil diameter (fig. 9, right).This could be a problem for the eye, unless of course the size

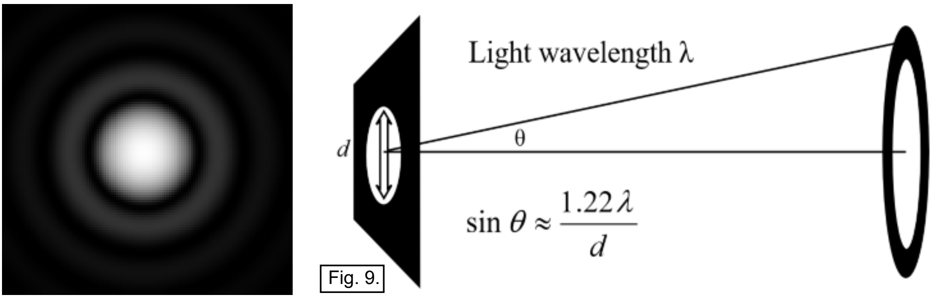

Fig. 9.

of the Airy disc is no larger than the size of a cone cell. The diameter of a cone cell is roughly 2.5μm. When the pupil diameter is about 5mm the Airy disc diameter is the same as this. Therefore, in daylight viewing conditions the cone cell density in the fovea is optimised to eliminate image degradation from pupil diffraction. This is no coincidence and shows clearly that the eye was designed to provide the best optical resolution for its size.

Image Processing

The eye has about 120 million rod cells and about 6.4 million cone cells. These cells are producing nerve impulses all the time. An interesting design feature is that the rate of firing decreases with increased light input. The biochemistry of the photoreceptors is highly complex and could not have evolved piecemeal. The system is so sensitive that individual photons can actually be detected. Nevertheless the vision biochemistry can adapt to cope with bright sunlight. The dynamic range is better than 10^8 which exceeds any man-made light transducer.

The information output from each retina has been estimated at about 10^7 bits per second. This information stream has to be processed in real time. The first stage of visual processing takes place on the retina. The nerve impulses then pass along fibres,

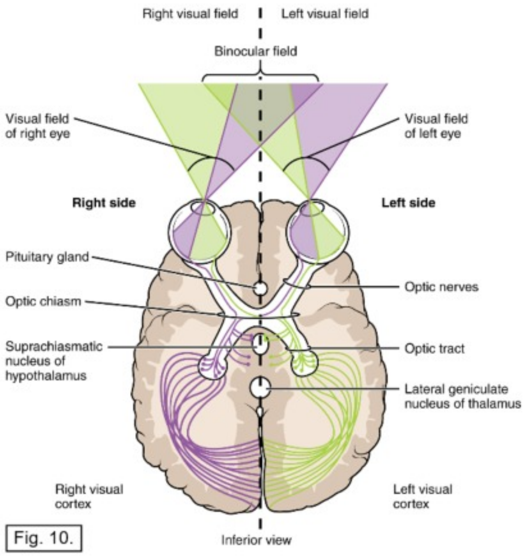

Fig. 10.

which gather together to exit the retina. The impulses go into the brain for further processing (fig. 10). Various areas in the brain simultaneously process visual information, eventually feeding it to the primary visual cortex at the back of the head. How we are aware of visual information is another debate.

Materialists argue that conscious awareness is an "emergent property" of brain organization. This is a non-statement i.e., they don't know, and have not thought through the mind/brain distinction and the non-material nature of information.

CONCLUSION

Our vision system is a truly amazing piece of engineering design which is clearly optimised to function effectively, using living cells and structures which grow from a single cell inside the mother. This is clearly NOT the product of random genetic mutations and a crude and slow selection process. Highly engineered systems are integral and cannot be thrown together by chance events. Only God could create life and make man conscious.

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