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bioscience for the future

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Vision of the Future

Vision is one of the most important senses humans and other organisms possess. Understanding the visual system of organisms spans both physics and biology, requiring knowledge of the properties of light as well as the nervous system. Through investigations of the eye and vision, students can learn about a wide range of topics, including homeostasis, the electromagnetic spectrum, behaviour, physiology and cell biology. The eye and our ability to see has fascinated scientists for centuries, from the demonstration of colour with prisms by the physicist Sir Isaac Newton to Charles Darwin's explanation of the evolution of the eye.

Suitable for Key Stage:

1 2 3 4 5

CLEAPSS

Safety checked but not trialled by CLEAPSS

Key Information

Teacher

Contents

View online

Scan the QR Code.

Key Information

Teacher

Science topics

Vision, sensory system, physiology, anatomy, adaptation, behaviour, nutrition, light, electromagnetic spectrum, science in sport.

Resources

Age

14–18 years

- Student information sheets
  - Update on current research (reading age 18)
  - How the eye works (reading age 13–14)
  - Rods and cones (reading age 16)
  - Disorders, diseases and enhancement (reading age 15)
- Student activity sheets to reinforce learning
- Student practical instructions
- Classroom PowerPoint slides
- Online games

Keywords

Iris, pupil, lens, cornea, sclera, choroid, ciliary muscle, suspensory ligaments, aqueous humour, vitreous humour, retina, photoreceptor, rods, cones, optic nerve, blind spot, tapetum, circadian, ultraviolet, polarised light, sensitivity, acuity, dilation, constriction, accommodation, myopia, binocular vision, stereoscopic vision, colour blind, photopigments, rhodopsin, trichromatic, dichromatic, near point.

The Biotechnology and Biological Sciences Research Council (BBSRC) is funding research to investigate the normal ageing process with the hope that breakthroughs will lead to improved health and wellbeing. Research is being conducted to understand how the eye works and how we can improve our health by looking after our eyes. Discoveries have been made about the effects of nutrition and ultraviolet light on our eyes, how light regulates our body clocks to ensure we remain healthy and how vision affects our sporting ability. Fundamental biological breakthroughs in understanding how flies have developed extremely fast vision, and the sensitivity of cuttlefish to light underwater, may lead to health benefits in many other areas.

Many people are living much longer lives, but a long life does not mean a healthy one and the quality of life for many older people is poor due to ill health. These new discoveries are making a difference to the way blind people live and in helping researchers tackle diseases such as cancer and the causes of heart attacks. The findings can help us understand the effects of diet, physical activity and development on the ageing process to understand risk factors for poor health and to identify interventions that can improve wellbeing. Throughout this research BBSRC encourages work that adopts the principles of the 3Rs (Replacement, Refinement and Reduction) in the use of animals, and aims to improve animal welfare.

Vitamin D and healthy eyes

Researchers have found that vitamin D reduces the effects of ageing in mouse eyes and improves the vision of older mice significantly. In the back of the eyes of mammals, like mice and humans, is a layer of tissue called the retina. Cells in the retina detect light as it comes into the eyes and then send messages to the brain, which is how we see. This is a demanding job and the retina has to have a good supply of blood to provide the energy needed. However, as we age the high energy demand produces debris and inflammation, even in healthy animals. In humans this can result in a decline of up to 30% in the numbers of light receptive cells in the eye by the time we are 70, thus leading to poorer vision.

Exposure to sunlight triggers vitamin D production in our skin but many people lack sufficient exposure to the sun. The researchers found that vitamin D reduces inflammation and helps remove debris from the retina, which improves vision in mice. The vitamin reduces the amount of debris building up in the retina and help cells in the immune system called macrophages clear up the debris and reduce the inflammation. The researchers hope that this might mean that vitamin D supplements could provide a simple and effective way to combat age-related eye diseases. The debris found in the eyes is also found in blood vessels and brain cells, so vitamin D may also help with a range of health problems from heart disease to dementia.

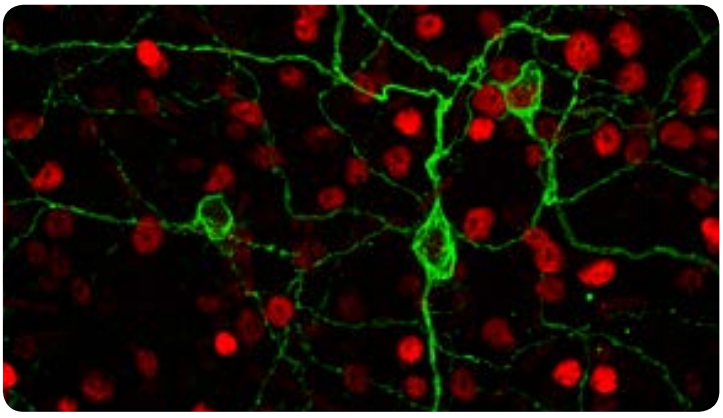
Eye

Light, body clocks and sleep

Professor Russell Foster has discovered an entirely new class of photoreceptor – specialised cells found in the retina of the eye. Scientists have known about photoreceptors in the retina called rods and cones for a long time. The rods and cones detect light and transmit the information to our brains so we can use it to generate the image of the world we see. These new photoreceptors, called retinal ganglion cells, are specialised neurons that detect environmental brightness and regulate a wide range of physiology and behaviour including the timing of our internal 24-hour body clocks, sleep patterns, alertness, mood, blood pressure and even pupil size. Ganglion cells are the site of retinal convergence where image signals detected by rod and cone cells are combined, but some specialised retinal ganglion cells detect overall brightness rather than generating an image we can see. Under normal conditions we experience a 24-hour pattern of light and dark, and our body clock uses this signal to align biological time to the environment. Disrupted sleep leads to health problems ranging from heart disease, weight abnormalities, reduced immunity, increased risk of cancer, to emotional and mental health problems.

If you think of your brain as a smartphone, the rods and cones are like the camera that takes pictures, and these new photoreceptors work like the sensor that makes your screen brighter when it is sunny.

This new discovery gives insights into treating damage to the eye and blindness. There are over 270 million people in the world with severe sight problems. It is important that doctors identify whether the photosensitive retinal ganglion cells are still working so that patient's eyes can be protected and looked after, but if the cells are no longer working, patients can be helped to regulate their sleeping patterns. These cells detect light in the blue part of the spectrum and the discovery may change the way buildings are constructed as well as the design of lighting in offices to ensure we receive enough of the correct type of light to keep us alert and healthy. This is such an important discovery because our 24 hour biological clock (circadian clock) regulates every aspect of our physiology and behaviour from physical strength to 'clock genes' that can generate a 24-hour molecular oscillation within a single cell.



Fluorescent retinal ganglion cells

Vision and sport

Does having excellent vision go hand in hand with elite sporting ability? To answer this question, researchers have teamed up with the England and Wales Cricket Board to see if good vision is required for good hand-eye coordination.

For example, in order to be able to catch a cricket ball, a player needs to anticipate the speed and direction of travel of the ball with a high degree of accuracy. But do elite cricketers have superior vision to non-elite players or novices? And if so, does this make them good athletes or does their vision simply improve with training? Vision therapy is often used by athletes in an attempt to improve sporting performance, and researchers will be investigating whether such training is effective, and what the link is between vision, the brain and sporting performance.

The team will make detailed measurements of visual function and relate these to performance in a specific aspect of cricket i.e. one-handed catching.

The research can be applied to other sports, particularly ones that feature a fast-moving ball such as football or tennis, and the results will help understand visual-motor skills in everyday tasks and could lead to developments in medical treatment and rehabilitation.

One handed catching to be tested in cricketers

Reindeer see a weird and wonderful world of ultraviolet light

Researchers have discovered that reindeer have special vision that enables them to see ultraviolet (UV) light without it damaging their eyes. UV light causes the temporary but painful condition of snow blindness in humans, but is actually life-saving for reindeer. This remarkable ability is part of the reindeer's unique adaptation to the extreme arctic environment where they live. It allows them to see things vital for their survival, in conditions where normal mammalian vision would make them vulnerable to starvation and predators. Humans and almost all other mammals could never do this as our lenses do not let UV through into the eye; instead they absorb the damaging energy and the front of the eye can be temporarily burned, turning the cornea cloudy to protect the sensitive retinas. It also raises the question of how reindeer protect their eyes from being damaged by UV.

Human beings are able to see light with wavelengths ranging from around 700nm, which corresponds to the colour red, right through all the colours of the rainbow in sequence to 400nm, which corresponds to violet. Professor Glen Jeffery and his team tested the reindeer's vision to see what wavelengths they could see and found that they can handle wavelengths down to around 350-320nm, which is termed ultraviolet because it exceeds the extreme of the so-called visible spectrum of colours.

Winter in the arctic is very severe; the ground is covered in snow and there is little light with the sun very low on the horizon making it dark for most of the time. The low sun passes through more of the atmosphere, scattering light so that the majority that reaches objects is blue or UV light. The snow can then reflect up to 90% of the UV light that falls on it.

Using cameras that can pick up UV light, researchers noticed that there are some very important things that absorb UV light and therefore appear black, standing out clearly on the white snow. This includes urine – a sign of predators or competitors; lichens – a major food source in winter; and fur – making predators such as wolves very easy for reindeer to see, despite them being camouflaged.

Reindeer in the Arctic

We can learn a lot from studying the fundamental biology of animals and other organisms that live in extreme environments. Understanding how they can cope with severe conditions can have an impact on animal welfare and has the potential to improve human health and wellbeing. This research could be used to prevent damage to the eye from UV or to develop new treatments. Maybe it will lead to more advanced sunglasses or sunscreen to protect us from strong sunlight.

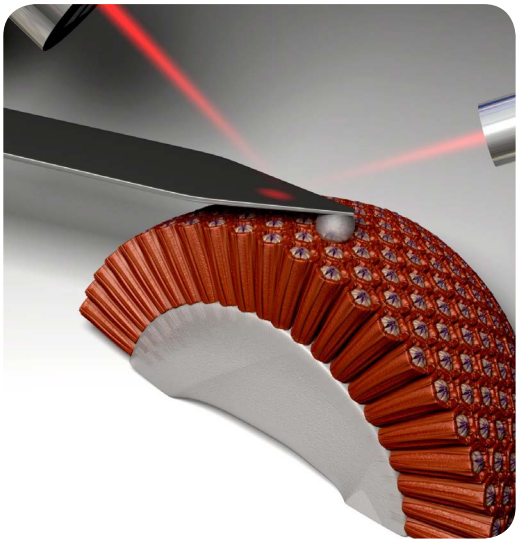
Flies have the fastest vision

Fly eyes have the fastest visual responses in the animal kingdom, but how they achieve this has long been an enigma. Researchers have discovered that this may be due to their photoreceptors physically contracting in response to light. The mechanical force then generates electrical responses that are sent to the brain much faster than, for example, in our own eyes, where responses are generated using traditional chemical messengers.

It had been thought that the ion channels responsible for generating the photoreceptors' electrical response were activated by chemical messengers as is usually the case in cell signalling pathways. However, these results suggest that the light-sensitive ion channels responsible for the photoreceptor's electrical response may be physically activated by the contractions – a surprising solution to the mystery of light perception in the fly's eye and a new concept in cellular signalling.

The ion channel in question belongs to one of the largest ion channel families in the genome, with closely related channels playing vital roles throughout our own bodies. These ion channels are increasingly regarded as potential therapeutic targets for numerous pathological conditions, including pain, hypertension, cardiac and pulmonary disease, cancer, rheumatoid arthritis, and cerebral ischaemia.

A fly's vision is so fast that it is capable of tracking movements up to five times faster than our own eyes. In each photoreceptor cell, there is a long rod-like structure, which acts as a light-guide to absorb the incident light. This rod also houses the biochemical machinery, which converts the energy of the absorbed light into the electrical responses that are sent to the brain – a process known as phototransduction.



Atomic Force Microscope measurement of photoreceptor response

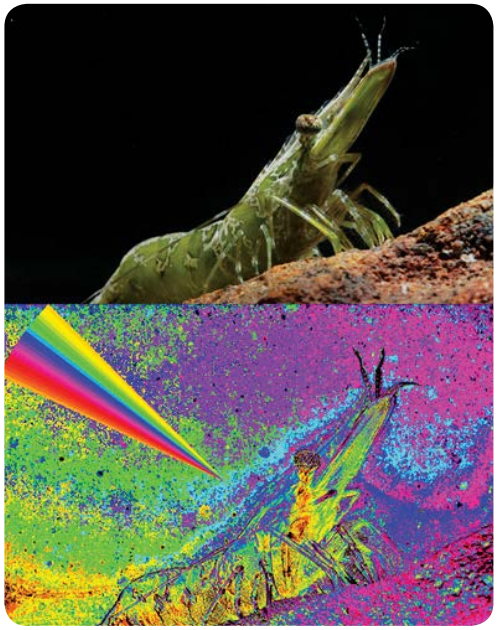
As in all photoreceptors, phototransduction starts with absorption of light by a visual pigment molecule (rhodopsin). In photoreceptors this activates an enzymatic reaction that leads to the opening of ion channels that allow stored positively charged ions such as Ca2+ and Na+ to flow into the rest of the cell thus generating the electrical response.

The key finding was that the photoreceptors physically contract in response to light flashes. The contractions were so small and fast that an atomic force microscope was needed to measure them. This revealed that the contractions were even faster than the cell's electrical response and was caused directly by the enzymatic reaction.Mechano-sensitive ion channels are actually well known, but are normally involved in transducing mechanical stimuli – such as sound in the ears, or pressure on the skin. One of their characteristics is that they can be activated extremely rapidly – perhaps explaining why fly photoreceptors have evolved this solution to phototransduction.

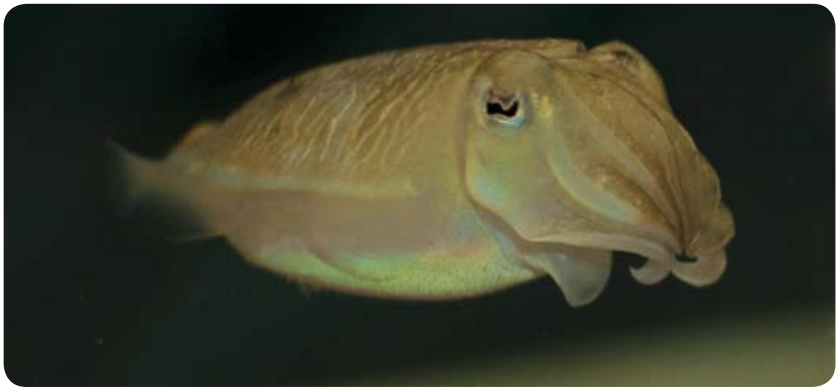
High-resolution polarisation vision discovered in cuttlefish

Squid, octopus and cuttlefish are colour blind but can see aspects of light - including polarised light - that are invisible to humans. This gives them improved vision underwater and enables them to communicate in secret without other organisms being able to see their messages. Researchers discovered they have special high-resolution polarisation vision by showing cuttlefish movies on modified LCD computer screens to test their eyesight. Just like colour and intensity, polarisation is an aspect of light that can provide animals with information about the world around them. Polarised light is used in 3D movies to project different images on to each of our eyes; the special glasses have lenses that block light with different polarisations.

Dr Shelby Temple and his colleagues gave cuttlefish an eye exam; but instead of measuring their ability to identify letters they measured the smallest difference in the angle of polarisation the cuttlefish could detect. They could not ask the cuttlefish what they could see so they took advantage of the chameleon-like colour changes that cuttlefish use for camouflage as a way of measuring whether the animals could detect a video of an object approaching them polarized light of objects approaching them. Cuttlefish respond to the slightest movement so the researchers played the cuttlefish videos and watched for changes in skin colour patterns to determine if the cuttlefish could see small changes in the light. This is particularly important in responding quickly to predators.



Shrimp as seen by us and how it might look to a cuttlefish that can see polarization angles



Cuttlefish

Amazing fact

Cuttlefish change the shape of their whole eye to move the position of the lens in order to focus, unlike humans who use muscles to change the shape of the lens.

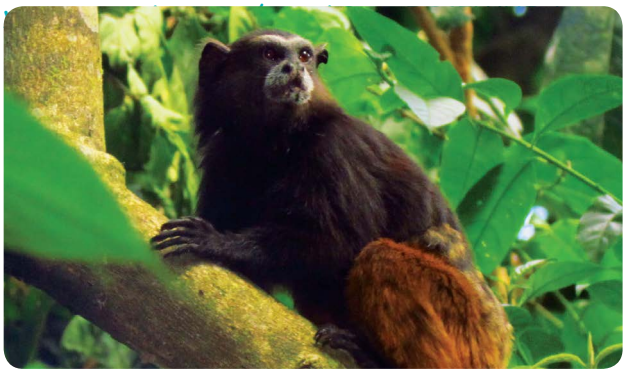
Cuttlefish also have W-shaped pupils and no blind spot, because the optic nerve is behind the retina.

The Evolution of Colour Vision

Seeing Colour – with 'colour blind' monkey vision simulations! Scan the QR code to see the video

Being colour blind is often thought to be a disadvantage, but researchers in Stirling and Cambridge have found that colour blind (dichromatic) primates in the wild are better at catching camouflaged insects. Their research, which includes controlled experiments in captivity, also found that South American Tamarin monkeys with colour vision similar to humans (trichromatic) caught more insects than those with dichromatic colour vision. Old World primates have the best colour vision of all mammals, and like most humans, have three types of colour receptor in the retina known as cone cells; this is termed trichromacy. The receptors are often termed red, green and blue, which correspond to absorbance of light with long, medium and short wavelengths respectively. Photopigments (opsins) produced in the cone photoreceptor cells absorb the light and trigger a signal that is sent to the brain. Monkeys and humans who lack the receptor for medium wavelength light are termed dichromatic and display what is known as red-green colour blindness. New World and Old World primates have separately evolved trichromatic vision and many studies have shown that they are better at noticing coloured fruit. This provides a strong selective pressure to evolve trichromacy but it does not explain why most New World monkeys remain dichromatic. It has been suggested that the colour blind primates have some advantages, such as better vision in dim light, improved spatial vision and the ability to spot camouflaged prey and predators, which ensures the genotype is maintained.

The researchers are able to carry out genetic tests on the monkeys without invasive procedures – they collect the DNA from their faeces. By combining the study of wild, as well as captive monkeys, the researchers have a good understanding of their natural history, which is enabling them to promote good welfare in captivity and improve their experiments. Through this work the scientists contribute to the Refinement of animal welfare (one of the 3 R's that represent the basic principles underlying humane experimental techniques – Replacement, Reduction and Refinement).



Tamarin monkey

Where is that nightjar?

Fiery necked nightjar and chick

Most animals face a constant risk of being attacked by predators. In response they have evolved many defenses against this, perhaps the most common being camouflage. Animals use colours and patterns to blend into the background so they can remain hidden, but scientists have recently discovered that predators can learn to read this camouflage.

Animal camouflage has been studied ever since Darwin, yet despite this scientists currently know very little about how it works in real species in the wild. For a prey animal to be camouflaged, it must be hidden from the eyes of its main predators. It's therefore essential to consider the predator's vision, rather than our own. Scientists are studying the different types of camouflage that exist in nature, how they hide prey animals from different types of predator vision, and the survival benefit they provide.

Dr Martin Stevens, Dr Claire Spottiswoode and their colleagues are studying ground nesting birds in Zambia and South Africa, especially several species of plover and nightjar. These birds nest on the ground and the adults, chicks, and eggs have incredible camouflage. The researchers are investigating how these life history stages have different camouflage in varied habitats, and how the behaviour of adult birds affects camouflage. One of the questions the scientists are asking is 'Do the birds choose backgrounds that work well with their camouflage?'

The researchers record the birds with videos that detect motion so they can film the behavior of the predators. They want to find out what species of predator eat the birds' eggs and chicks, and how camouflage affects survival. So far they have discovered that a wide range of species, each with different types of colour vision, prey upon nightjars and plovers, including mongooses, monkeys, and birds.

To test their theories the scientists have develop computer games to find out how camouflage works, and to better understand how the camouflage of individuals prevents them from being detected. One of their games, 'find the nightjar' uses images of camouflaged nightjars from Zambia with the player having to search for them and find each one. The person playing the game can see the world as either a vervet monkey or a mongoose. This choice affects the way that the nightjars and environment looks because monkeys have a similar visual system to humans and see several types of colour (such as red, green, yellow, and blue), whereas mongoose have less effective colour vision and see fewer colours (such as yellow and blue). This allows the researchers to test how effective the nightjar species are at being hidden from different types of visual system.

To play the game and read more about the research visit:
nightjar.exeter.ac.uk/where-is-that-nightjar/

How The Eye Works

Key Stage 4 **Student**

Quick experiment

1. Find a partner and take a look at their pupil
2. Have someone dim the lights in the room
3. Observe your partners pupil and note the growing diameter
4. Have the lights turned back on and observe the pupil shrinking again.

This is a reflex action that is used to stop damage to the retina at the back of the eye from too much light.

The eye is a specialised sensory organ that detects light.

The structure of the eye enables us to take in information about the world around us and each tissue has a specific and essential role.

The cornea is a tough transparent outer layer found in front of the lens that lets in light and helps to protect your eye. It also helps you focus by bending the light that comes into your eye.

Behind the cornea is the aqueous humour, a watery liquid that maintains the shape of the eye and cushions the iris and lens.

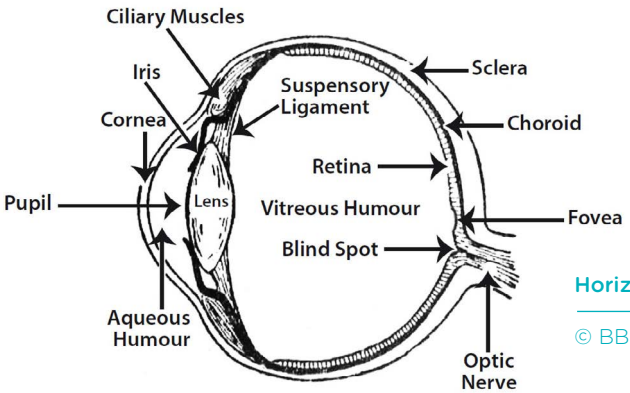
The pupil is the hole found at the front of the eye that is formed by the surrounding iris. The iris constricts or expands to change the size of the pupil. It is made of two sets of antagonistic muscles – radial and circular.

In dim light, the pupil opens wide (dilates) to let light in – the radial muscles contract and the circular muscles relax.

In bright light, the pupil closes down (constricts) to block light out – the radial muscles relax and the circular muscles contract.

Consider why it is important that the amount of light entering the eye is controlled.

If too much light enters the eye the retina may be damaged, but if there is not enough light, the photoreceptor cells won't be stimulated and we cannot see. The eye has to respond very quickly to the amount of light entering it to prevent damage. We do not even have to think about changing the size of our iris; it happens automatically because the response is a reflex action. The size of our pupil, just like our heart rate, is controlled by our autonomic nervous system and does not require any conscious thought.



Horizontal section of a human eye

How The Eye Works

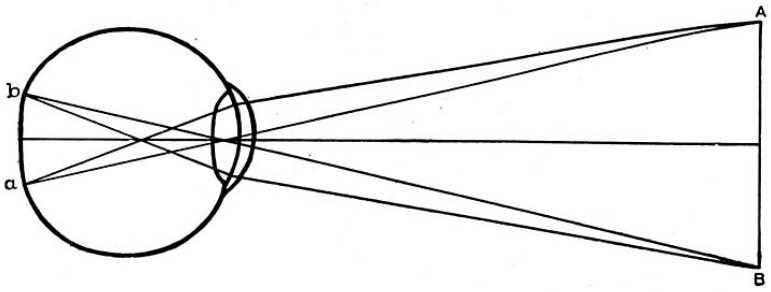
Quick experiment

1. Fill a glass beaker with cold water
2. Place a pencil in the centre of the breaker and very slowly move the pencil to the left and the right
3. What do you see? What appears to happen to the pencil?

The lens carries out fine focusing of the light on the retina. Accommodation is the ability to focus objects which are at different distances from the eye. Focusing occurs via refraction – a change in the direction light waves travel when there is a change in the speed of light as it passes from one medium into another. Most refraction occurs at the interface between air and the cornea. The lens refracts the light only slightly. Light rays from distant objects are more parallel than those from near objects and require less bending to focus on the retina.

The shape of the lens can be changed to adjust the focusing of light from objects that are close or far away. The normal lens is convex shaped and somewhat elastic. It is held in place by the suspensory ligaments that are joined with the ciliary muscles (the ciliary body is made of smooth muscle).

When the ciliary muscles contract, the suspensory ligaments slacken, resulting in bulging of the lens. The fatter lens causes greater bending of the rays of light and enables us to focus on objects that are nearby.



Focusing of light on the retina

Amazing fact

A colour blind monkey has been given full colour vision.

A monkey with red-green colour blindness (dichromacy) now has the ability to distinguish the two colours (trichromacy) following gene therapy. A virus containing the genes for the missing photopigment was injected into the retina.

When the ciliary muscles are relaxed, the suspensory ligaments tighten and pull the lens flat.

The degree of bending of the light rays is reduced and we are able to focus on objects in the distance.

As we age, the elasticity of the lens decreases. The closest you can focus is known as your near point. This may be as close as 10cm when you are young, but is likely to be 20cm by the time you are 40 years old and 80cm by the time you are 60 years old. Your far point is effectively infinity.

Glasses and contact lenses can be used to correct problems with focusing. The inability to focus on objects in the distance is known as short-sightedness (myopia) and the inability to focus on near objects is known as long-sightedness (hypermetropia). This inability to focus can be caused by problems with the lens or the shape of the eyeball, and leads to blurry vision.

Short-sightedness can be corrected with a concave lens. Long-sightedness can be corrected with a convex lens.

Light is detected by the retina at the back of the eye. The image that is formed on the retina is upside down, and our brain turns the image the right way up. The retina has receptor cells, blood vessels providing nutrients, and nerves that carry the signals to the brain. Two areas of the retina are specialised: the fovea is the main focal point where there is a high concentration of receptor cells, and the blind spot is where the nerves and blood vessels exit the retina. Because the blood vessels and nerves are on the inner surface of the eye in front of the receptor cells they must exit the eye at one point. This point is known as the blind spot because there are no receptor cells here. The blind spot is found slightly to one side of the eye towards the centre of the face while the fovea is found slightly towards the outer side of the eye.

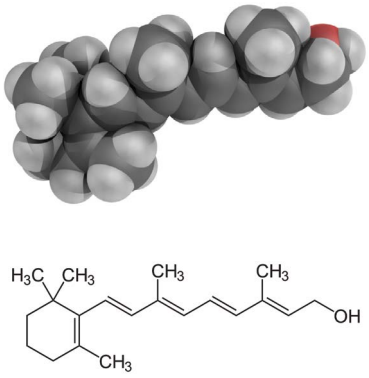
The photoreceptor cells in our retina contain photopigments that become bleached when exposed to light, creating action potentials that send impulses down the optic nerve to our brain. There are two main types of cells that enable us to see: cone cells and rod cells. The cone cells contain pigments that respond to different wavelengths of light. They work best in bright light and enable us to see in colour. Rod cells are more common than cone cells, and though they cannot detect colour, they are found all over the retina and enable us to see better in low light conditions. There is one type of rod cell and they all contain a pigment known as rhodopsin, whereas there are three types of cone cell and they each contain a different pigment made from proteins known as iodopsins.

The photopigments in cone cells each absorb and respond to different wavelengths of light. These are usually described as red, green and blue receptors, although they absorb light in overlapping ranges of wavelengths. When a receptor is stimulated it sends a message to our brains. We interpret the combination of incoming messages as a range of colours. For example, yellow light stimulates both red and green receptors. When both red and green receptors are stimulated, we interpret what we see as yellow.

Colour is seen and interpreted differently by our brains in different circumstances. In the dark or in dim light, our cone cells are less effective and we are unable to see colour.

Under normal light conditions some people are less able to distinguish certain colours – this is termed colour blindness and occurs due to a lack of one or more of the photopigments. Colour blindness is quite common: 8% of Caucasian males and 0.4% of females have unusual variations in red and green colour vision. This type of colour blindness is termed dichromacy and can be due to a lack of the green or red photopigment. Individuals who have all three of the photopigments are termed trichromatic.

Rods and Cones



Retinal structure

Rod and cone cells are made of two segments: an outer section containing many pigment molecules arranged in membranes to catch incoming light, and an inner section containing the nucleus and connections to the nerve cells.

The rod cell pigment rhodopsin is made of a protein – opsin – and a compound made from vitamin A called retinal. When the retinal molecule absorbs light it changes shape, causing the shape of the opsin protein to change – this is termed bleaching.

The pigments that detect colour are found in the cone cells and are made of proteins called photopsins. There are three different types of photopigment and each cone cell contains a pigment that absorbs at different wavelengths of light. Usually called blue, green and red receptors they actually absorb overlapping wavelengths of light with the green cones having maximum absorption of yellow light and red cones having maximum absorption of orange wavelengths of light. The blue, green and red receptors are therefore often called short (S), medium (M) and long (L) wavelength receptors respectively. This overlapping spectrum of sensitivity is able to detect the full range of colours depending on the relative intensity of the light. When both the red and green cones detect light it is interpreted by our brains as the colour yellow but if the red cones detect more light than the green cones we will see orange. The colours we see are more than just the properties of light and are the result of our brains interpreting the messages we receive from our eyes.

The rods and cones are wired differently in our retina. Photoreceptors are connected to cells known as bipolar neurones which are in turn connected to ganglion cells. Fibres from the ganglion cells join up to form the optic nerve. Each cone cell only connects with one bipolar cell whereas many rod cells connect to each bipolar cell. This allows small levels of light reaching a number of rod cells to be sufficient to trigger a bipolar cell, giving good sensitivity and enabling us to see in low light conditions. This is known as retinal convergence. Unfortunately it means our rod cells are not as good at seeing detail. Acuity is the ability to see two distinct points. The further away those two points are the harder it is for our eyes to distinguish them separately. Rod cells are spread out over the back of the retina but most light is focused on the fovea and it is here that the cone cells are concentrated. At the fovea, each cone synapses individually with a ganglion cell.

The sequence of rod cell stimulation – bleaching and signalling

Amazing fact

Do you have blue, green or brown eyes? No matter what colour your eyes are, originally they would have been blue. The colour of the iris is determined by many factors including your genes and exposure to light. Babies with brown eyes are often born with blue eyes, and develop brown eyes as the pigment melanin is deposited in the iris.

1. In the dark, sodium ions move into the rod cell via non-specific cation channels and are actively pumped back out causing slight depolarisation
2. This causes continual glutamate release and prevents bipolar cells depolarising
3. When light reaches the back of the retina it is absorbed by rhodopsin in the outer segment of rod cells
4. Rhodopsin is split into its component parts – retinal and opsin
5. The presence of opsin causes cation channels in the rod cell membrane to close
6. This does not affect the sodium pump, which remains active
7. Sodium ions build up outside the membrane causing hyperpolarisation of the rod cell
8. This means no inhibitory neurotransmitter can be released from the rod cell at the synapse with the bipolar neuron
9. Bipolar neurons respond with depolarisation (inhibitory effect of the firing rod cell has been removed)
10. Action potential passes to ganglion cells which send impulses along the optic nerve to the brain.

Disorders, Diseases and Enhancements

Vision can be corrected if it is not functioning optimally, and can even be enhanced using, among other approaches, lenses and filters to change the light that is received by the eye.

The inability to focus on objects in the distance is known as short-sightedness (myopia) and the inability to focus on near objects is known as long-sightedness (hypermetropia). This can be caused by problems with the lens or the shape of the eyeball and leads to blurry vision.

If the lens is too stiff we are unable to adjust it to focus on images. As we age the elasticity of the lens decreases and we lose the ability to focus on objects close to us.

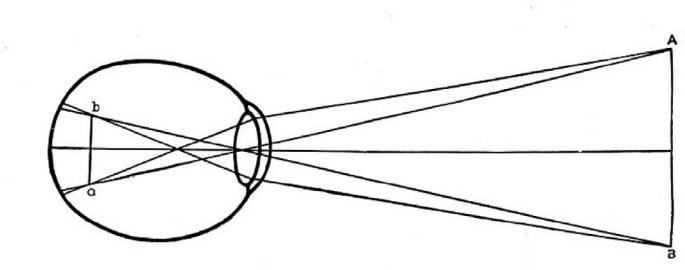
Short-sightedness can be caused by the eyeball being too long (or the lens too strong), whereas long-sightedness can be caused by the eyeball being too short (or the lens too flat).

The diagram below shows the effect of having an eyeball that is too long for the lens to be able to focus the image on the retina, causing short sight. Where the light rays join is the focus point, indicated by the letters b and a. As can be seen this occurs before the retina, leading to an unfocused image falling on the retina further back.

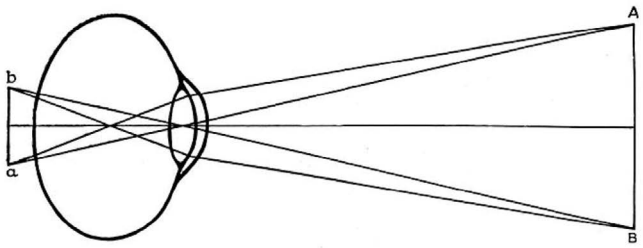
Glasses and contact lenses can be used to correct problems with focusing. Short-sightedness can be corrected with a concave (diverging) lens.

The diagram below shows the effect of having an eyeball that is too short for the lens to be able to focus the image on the retina. Once again b and a are where the light rays join to form the focus point and as can be seen this falls behind the retina leading to a blurry image being seen.

Long-sightedness can be corrected with a convex (converging) lens.



Short sight diagram



Long sight diagram

The power of a lens is measured in dioptres (D) and is determined by the lens material and the shape of the lens. The more curved the lens, the greater the bending of light and the higher the dioptre. Depending on the shape of the lens, light is bent in different directions. Converging lenses have a positive power, indicated by a plus (+) and diverging lenses have a negative power, indicated by a minus (-). The appropriate +/- sign is placed before the dioptre strength e.g. -2.0 for short sight.

In normal conditions the human lens is transparent except when, as a condition of ageing, the lens turns cloudy. The cloudy condition, called a cataract, prevents or reduces the amount of light reaching the retina. A cataract can be treated by removing the lens and replacing it with a stiff artificial one. Long term exposure to ultraviolet (UV) light is one of the causes of cataracts.

UV light also causes the temporary but painful condition of snow blindness in humans. The cornea in humans and almost all other mammals does not let UV light through into the eye; instead it absorbs the damaging energy and can be temporarily burned, turning the front of the eye cloudy to protect the sensitive retina. Human beings are able to see light with wavelengths ranging from around 700nm, which corresponds to the colour red, right through all the colours of the rainbow in sequence down to 400nm, which corresponds to violet. Light with wavelengths between 400 and 100nm are known as ultraviolet light. Short wavelength UV light causes sunburn and skin cancers and the shorter the wavelength of electromagnetic radiation, the more damaging it is to us. In environments with lots of snow, up to 90% of the UV light that falls on it is reflected, increasing the chance of sunburn and damage to the eyes.

Glass lenses have been used for a long time to correct short and long sight but there are other uses for lenses in improving vision. Early polar explorers used a simple approach to reduce the amount of sunlight they were exposed to. They wore opaque goggles made of wood or leather featuring a small slit that acted like a pinhole camera. This still enabled them to see but decreased the amount of light that their eyes were exposed to. The brightness of light is measured in lumens. Indoors it is about 400 to 600 lumens, but out in a snowy landscape it could be 12,000 lumens. Above 4,000 lumens we have difficulty seeing, due to too much light, and start to experience glare.

Back to How the eye works

Sunglasses lenses

Disorders, Diseases and Enhancements

Quick experiment

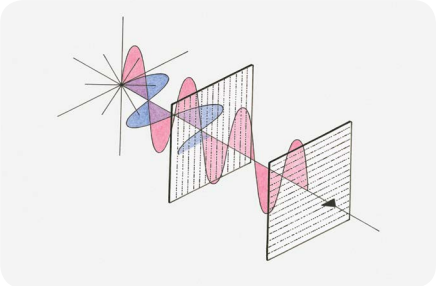
To test if your sunglasses have polarising filters:

1. Find a flat reflective surface such as a shiny table, and hold the glasses so that you are viewing the surface through one of the lenses.
2. Slowly rotate the glasses to a 90-degree angle, and see if the reflective glare diminishes or increases. If the sunglasses are polarised, you will see a significant increase in the glare.

Modern sunglasses feature a range of lenses that can filter certain light to provide improved vision. Dark filters reduce the overall amount of light and are particularly useful in bright sunlight. Yellow filters reduce the amount of blue light the eye receives. As blue light tends to scatter when it reflects off surfaces, these filters are particularly good at improving contrast. Yellow filters are ideal for use in snowy conditions and high-speed outdoor sports where the ability to see the outlines of objects and terrain is important. Due to the change in the colours seen through coloured filters they are not suitable for activities where colour distinction is required, such as aviation. Amber and brown lenses absorb blue light and some UV light, increasing contrast and clarity. For complete UV protection, a coating is added to the surface of lenses.

Light radiates out from its source along a number of planes. It can only be absorbed or pass through an object if it is in the correct alignment. When light is reflected off surfaces it is polarised. When the light hits the surface, its alignment matches that of the surface it is reflected from. Most glare from surfaces is due to horizontally polarised light. Polarised sunglasses allow vertically polarised light through and filter horizontal light out, preventing it passing through the lens and eliminating reflected light from surfaces such as water and snow.

As well as lenses in glasses, contact lenses also modify the light received by the eye. Contact lenses can correct myopia and hypermetropia. They are small transparent plastic discs that sit on the surface of the cornea. Because they are closer to the eye and move with it they produce a more accurate image of the environment on the retina. Contact lenses can be made of hard or soft plastic. Soft lenses absorb water and allow oxygen to diffuse through to the eye, and some hard lenses are also gas permeable but do not absorb water. Contact lenses can be tinted to alter vision or produce cosmetic effects and they can also be made with UV light absorbing materials to protect the eye. Custom-designed lenses that can enhance vision to better than 20/20 are even available for athletes.



Polarised light

Disorders, Diseases and Enhancements

Amazing fact

A white sclera is only found in humans and not in other primates. Theories suggest that this evolved to aid non-verbal communication in humans. The direction of gaze is more easily recognised in humans, due to the small coloured iris and contrasting white sclera, making it possible for individuals to share the location of prey or predators by looking at them, or to indicate their position in the group hierarchy by lowering their eyes and thus acknowledging the superiority of dominant individuals.

Modern developments such as eye surgery actually change the eye, not just the light entering the eye. Laser eye surgery known as LASIK, which stands for laser-assisted in-situ keratomileusis, is used to alter the shape of the cornea to correct the refraction of light. In LASIK a small blade is used to lift the front of the cornea and the shape of the cornea underneath is altered with intense highly focused pulses of light. The front of the cornea
is replaced, conforming to the new shape and healing quickly.

The laser used emits UV light and is known as a cool laser because the air and surfaces around it do not heat up. The UV light is absorbed by the surface of the cornea and only penetrates a microscopic distance as it breaks down the surface of the eye.

Glaucoma is a condition where the optic nerve is damaged, often associated with increased fluid pressure in the eye. The optic nerve injury causes changes in retinal ganglion cells, eventually causing cell death. The parts of the visual field that are affected by glaucoma match the areas of retinal cell damage.

Age-related Macular Degeneration (AMD) causes a loss of vision in the centre of the visual field (the macula is the centre of the retina). Cell debris accumulates between the retina and choroid and the retina can become detached.

Retinal detachment can occur due to disease or damage to the eye. This results in the retina peeling away from the choroid. It can progress rapidly leading to loss of vision and even blindness.

Practical Activity One

Eye dissection and UV absorption

Teacher

Introduction

Total Duration

1 hour

The experiment is divided into three stages: examination of the eye, dissection, and investigation of the properties of the eye tissues. If there is insufficient time to complete all the stages in one lesson, the eye tissues remaining from stage two can be refrigerated and saved until the next lesson to complete stage three.

Learning outcomes

What you will need

- Sheep, pig or fish eyes.
- Dissecting equipment – trays or cutting board, forceps, scalpels (or razor), blunt and sharp probes, scissors
- Newspaper or paper towels.
- Washing up bowls or access to sinks
- Eye protection
- Aprons
- Rubbish bags
- Hand cleaning facilities
- UV sensitive card available from Philip Harris
- UV torch, emitting sufficient light in the UV-A range
- Clamp stand
- Timer
- Selection of sunglasses or filters

Students will be able to:

- Dissect an eye
- Identify internal and external anatomy of the eye, naming and locating the following parts: cornea, iris, pupil, lens, retina, sclera, vitreous and aqueous humours, choroid, optic nerve and blind spot
- Relate the structure and function of the eye tissues
- Investigate the properties of the eye tissues, their absorbance of UV light and the protection afforded by sunglasses
- Discuss eye diseases and disorders, such as long- and short-sightedness or snow blindness, describe how they occur, and name risk factors and possible preventative measures.

Practical Activity One

Teacher

Health and safety

These instructions are for guidance only. Observe Good Laboratory Practice when carrying out these activities. Wear eye protection and lab coats or disposable aprons to protect clothes. Wash hands after handling eyes (use of gloves is not required). Disinfect work surfaces with 1% Virkon, wash and autoclave dissecting instruments. Consult sections on Disposal (14.6) and Dissection (14.7) in the CLEAPSS laboratory handbook and guidance available on the CLEAPSS and Scottish, Schools, Education, Research, Centre (SSERC) webpage for further details on dissections and disinfection.

Eye dissections can be carried out in class. The most recent legislation (Animal By-Products Regulations, 2009) deals with the use and disposal of all animal parts, and includes an exemption for the use of animal by-products for educational purposes. Eyes may be removed from cattle, sheep and goats killed before the animal reached the age of 12 months.

Students will be handling sharp scissors (or a scalpel or razor) in order to dissect the eye. Students should be instructed in the very careful use of this sharp implement and vigilance should be maintained during the activity to ensure students are behaving appropriately.

Ensure a suitable UV torch is chosen. The one shown here emits light at 395–405nm at the boundary of the UV-A and visible spectrum. Light of this wavelength is not hazardous and these sorts of lights are often used in nightclubs or to test banknotes, but students should still exercise appropriate caution and refrain from shining the light in their eyes. The section on UV radiation (11.9.3) of the CLEAPSS laboratory handbook provides guidance on UV radiation.

Gloves are not essential but students should ensure any cuts or grazes are covered with gloves or a plaster. Ensure students thoroughly wash their hands after the activity.

Prior learning

Students should carry out a preparatory activity to familiarise themselves with the structures of the eye. Resources such as worksheets, animations and videos can ensure students get the most from the learning session. A number of activities are available at the end of this guide. Virtual dissections are available online for students who are unable to carry out the eye dissection.

Eye dissection videos: **www.exploratorium.edu/learning_studio/cow_eye/step01.html**

Sheep eye dissection tutorial and a variety of worksheets are available online at: **science.jburroughs.org/resources/skeleton/eye/eyetitle.html**

Practical Activity One

Teacher

Teacher preparation

Materials

When sourcing eyes it is recommended that an official supplier such as Blades Biological or Philip Harris is used (see Suppliers section). They provide preserved sheep and pig eyes respectively. Preserved eyes are easier to dissect due to a more rigid sclera that makes them easier to hold and slice open. You may find it cheaper or easier to obtain eyes from a local butcher or abattoir that may also be able to provide eyes from other organisms such as horses. When obtaining eyes from butchers, ask for the eyes to be removed with as much care as possible. It is worth considering and respecting any religious, cultural or personal objections students or support staff may have to the use and handling of any animal material, and finding alternative activities or materials. Larger eyes, such as those from horses, may provide advantages in terms of handling and the ease of identification of the key parts of the anatomy, though they may also provoke a stronger emotional response from students. An alternative source of eyes, that can prove cheaper and easier to obtain, would be from a local fishmonger who should be able to provide fish heads e.g. salmon, from which the students can remove the eyes.

To prepare for dissection, provide each group with the following items: A dissecting tray, a pre-washed eye, a pair of forceps, a scalpel or razor blade, 1 sharp probe, 1 blunt probe, 1 pair of scissors, paper towels.

Rinse the eyes to remove excess blood or chemicals and place one eye on each dissecting tray. You may also want to provide students with disposable gloves. Although gloves are not required, students may be more comfortable handling eyes without direct contact.

Introduction

Introduction

5 minutes

Inform the students that they will be learning about eye anatomy, the structure and function of the eye tissues and their properties. Share the learning outcomes with the students and recap their prior knowledge of the structure and function of the eye.

Eye Dissection Instructions

Student

Stage 1
Identification of external eye structure

Stage 1 Duration

5–10 minutes

It may help students if a labelled diagram displaying the anatomy of the eye is available for reference during the dissection (an 'Eye labelling check sheet' is provided). This will reacquaint them with the orientation of the eye and key features identified in virtual dissections or activities they have carried out prior to the dissection, and will also enable additional annotation to be made.

Students should work in pairs, taking turns to dissect the eyes, confer and make notes on their findings. They may want to record their findings with a camera.

Ensure students are wearing eye protection and aprons and that they have checked their list of required equipment before starting.

1. Examine the outside of the eye. Locate the cornea at the front of the eye and the white sclera which is a tough outer layer surrounding the eye. The eyelid may also still be attached.
2. The covering over the front of the eye is the cornea. The cornea is normally clear but turns cloudy after death. You may be able to see the iris, the coloured part of the eye, and the pupil, the dark oval in the middle of the iris behind the cornea (image 1).
3. Surrounding the eye, particularly at the back, there should be fatty tissue which cushions the eye from shocks, an optic nerve (indicated by the probe in image 2) and muscles that move the eyeball (indicated by the probe in image 3). These external muscles are termed extrinsic muscles, of which there are four in humans and six in sheep. You may need to move the muscles and fatty tissue aside to locate the optic nerve.
4. Carefully remove the eyelid, fatty tissue and muscles from around the sclera and cornea taking care not to remove the optic nerve.
5. Label the parts you have identified on a diagram of the eye.

Image 1. Sheep eye

Image 2. Optic nerve

Image 3. Extrinsic muscle

Stage 2
Examining the internal anatomy of the eye

Stage 2 Duration

30 minutes

1. Wear eye protection while opening the eye, so that you are protected if there is a sudden spurt of fluid from the eye.
2. Place the eye on the dissecting tray and turn it so the cornea faces away from you. You will need to make an incision in the sclera halfway between the cornea and the optic nerve (rear of the eye) to separate the front and rear of the eye. Use the sharp pointed scissors (or the point of a scalpel or razor blade) to make an initial cut that runs along the 'equator' of the eye (Image 4).

   A small cut approximately 4–5mm should be made to enable the tip of the dissecting scissors to be inserted into the eye. The scalpel will need to be very sharp to cut through the tough outer covering. Care is required at this point as the eye may be very slippery and can be hard to hold in place while making the cut. Ensure you cut away from yourself when making the incision.
3. Once the cut is deep enough, some fluid, the vitreous humour, may ooze out. The vitreous humour helps the eye maintain its shape and as it leaks out the eye may be harder to hold.
4. Insert the point of the scissors in the slit made by the scalpel and cut around the eye with small snipping motions.

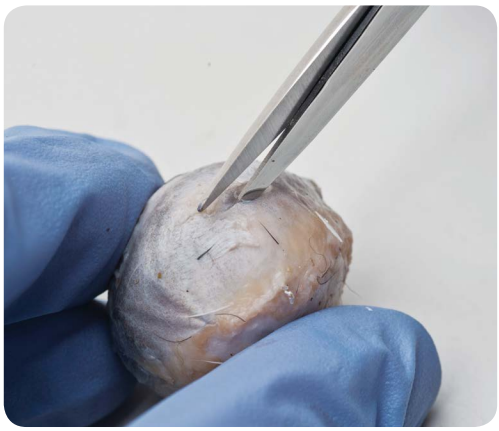


Image 4. Bisection of eye

Stage 2
Examining the internal anatomy of the eye

Stage 2 Duration

30 minutes

5. Rotate the eye as you cut until it has separated into the front (cornea) and rear (optic nerve) halves (Image 5). You may need to hold the two halves in place while you do this to make it easier to cut.

Notes:

Image 5. Separated front and rear halves of sheep's eye

6. Some of the vitreous humour is likely to leak out as you carry out this step. This clear jelly like substance is made of protein and water and may be quite gooey. It is normally clear to enable light to pass through the eye but in preserved eyes it may turn cloudy.

7. Turn your attention to the front half of the eye. Using the forceps and blunt probe remove the rest of the vitreous humour taking care not to disturb the lens, ciliary body and suspensory ligaments. This may take some effort and require you to scrape the gooey fluid out. Try to save some on one side of your dissecting tray for later investigation.

Stage 2
Examining the internal anatomy of the eye

Stage 2 Duration

30 minutes

8. Looking into the inside of the eye the lens will be visible as an oval structure held over the pupil by the suspensory ligaments (Image 6). Remove the lens and note its shape, stiffness and degree of transparency. Some of the suspensory ligaments may remain attached.

Image 6. Front half of sheep eye showing lens and iris

Image 7. Front half of sheep eye and separated lens

9. Put the lens to one side for later investigation.
10. The pupil and iris should now be clearly visible. The size of the pupil (the opening that allows light to enter the eye) is controlled by two muscle layers in the iris. One layer increases the pupil size with decreasing light intensity and the other layer reduces pupil size with increasing light intensity. In humans the pupil is circular but varies in shape in other organisms.
11. Between the iris and cornea is another cavity filled with a second semi-liquid fluid, the aqueous humour. This fluid, like the vitreous humour helps to maintain the shape of the eye. Use a razor blade to puncture a small slit at the boundary between the cornea and sclera. Then insert the scissors into the slit and cut all the way around the cornea. Remove the cornea from the front eye hemisphere. Notice the thickness of the cornea. How does it compare to the thickness of the sclera? Carefully observe the front side of the iris and pupil. Which structure of the eye would be just behind the pupil opening?

Stage 2

Examining the internal anatomy of the eye

Stage 2 Duration

30 minutes

12. Put the cornea to one side for later investigation.
13. The iris should now be clearly visible from the front of the eye. Note the size of the pupil.
14. Now turn your attention to the rear half of the eye. Remove any remaining vitreous humour. On the inside of the back half of the eyeball, you can see some blood vessels that are part of a thin fleshy film. That film is the retina. Before you cut the eye open, the vitreous humour pushed against the retina so that it lay flat on the back of the eye. The retina is made of photosensitive cells that line the posterior cavity of the eye and extend forward to the ciliary body.
15. Use your blunt probe to carefully lift and pull the retina back from the underlying choroid layer. Notice that the retina is only firmly attached to the choroid at one place. This region is the optic disc or blind spot. Here the nerve fibres from the photosensitive cells in the retina come together and form the optic nerve which carries signals to the brain. The blind spot is directly in front of the optic nerve and blood vessels that leave the eye and there are no light-sensitive cells in this region. Recall identifying the optic nerve on the exterior of the eye at the start of the dissection.
16. Remove the retina and put it to one side for later investigation

Notes:

Image 8. Retina with blood vessels indicated by probe

Stage 2
Examining the internal anatomy of the eye

Stage 2 Duration

30 minutes

17. On the back of the eye quite firmly attached to the sclera is the choroid. Identify this layer and observe its shiny reflective properties. The choroid is a dark layer that contains a high concentration of the pigment melanin to absorb light and prevent reflections inside our eyes. In many animals there is a reflective layer called tapetum. This is well developed in nocturnal animals and is particularly noticeable by the glow that can be seen reflected from cat's eyes.

Notes:

Image 9. Rear half of sheep eye showing tapetum

18. Using your sharp probe insert the point between the choroid and sclera and moving around the back of the eye carefully remove the choroid from the sclera and place to one side for later investigation. (images 10 and 11)

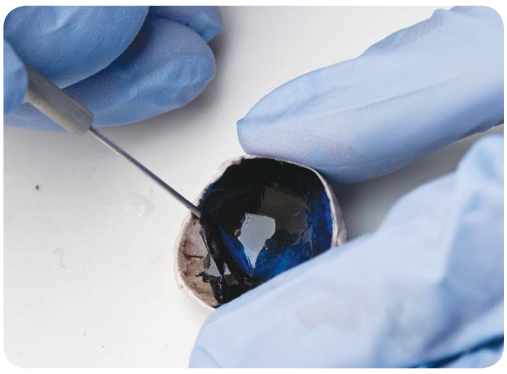


Image 10. Removal of choroid layer

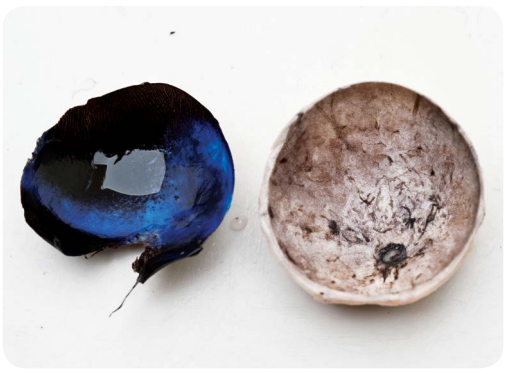


Image 11. Separated choroid and sclera layers

Eye Dissection Instructions

Student

Stage 3
Properties of eye tissues and UV absorbance

Stage 3 Duration

15 minutes

Recap the function of the cornea and lens (see sheet – How the eye works) and then test the refracting properties of the lens. The cornea carries out most of the refraction of light to direct it towards the pupil. The lens then carries out fine focusing of the light to form a sharp image on the retina.

1. Place the lens separated from the eye in stage 2 onto the UV card over some lettering. What do you observe? Note the change in the apparent size of the letters. This magnification is due to refraction.

   What is snow blindness, what causes it and why do humans need eye protection in snow-covered landscapes? Research conducted on reindeer show they are able to see ultraviolet light, which is due to the transparency of their lenses and their resistance to UV induced damage to the cornea and retina.

Image 12. Sheep lens

Image 13. Experimental set-up

Stage 3
Properties of eye tissues and UV absorbance

Stage 3 Duration

15 minutes

2. Position the UV torch above the UV card and fix it firmly in place with a clamp stand (image 13). Choose a suitable distance between the card and the torch that results in 'critical' exposure of UV, as indicated by the colour change of the UV sensitive circle on the card in 20 to 30 seconds of exposure (image 14). Decide on the suitable exposure time.

Image 14. UV card before and after exposure to UV torch for 30 seconds

3. Place the dissected tissues of the eye one at a time over the circle on the UV card.

Notes:

Image 15. Retina placed over UV sensitive region of the card

4. Shine the torch for the established length of exposure time at the tissue placed on the target area of the UV card.

Stage 3

Properties of eye tissues and UV absorbance

Stage 3 Duration

15 minutes

5. Remove the tissue and record the amount of UV light that penetrated the tissue and was detected by the card. The card indicates a numeric level of exposure based on the degree of colour change. The results can also be recorded with a camera or by taking quantitative measurements using a data logger.
6. Repeat for the cornea, lens, vitreous humour, retina and choroid and establish the relative absorbance of UV light by the different tissues.
7. If you are comparing tissues from different organisms such as pigs or fish take into account the different thickness of tissues such as the lens when drawing conclusions.
8. Note any discrepancies, opacity, discolouration or occlusions in the eye. Depending on how fresh or well preserved the tissues are, the cornea, lens and humours may be somewhat opaque. In human lenses transparency has been observed not to decrease for up to seven weeks post-mortem.
9. Now that the tissues in the eye that absorb UV light have been investigated, the effectiveness of sunglasses at protecting eyes from UV damage can be measured. Students should decide on the most appropriate approach and discuss how accurately their investigations replicate conditions in real life.

Clean-up

Once all the measurements have been taken and the diagrams labelled, tissues and implements will need to be cleaned or discarded. Wrap the dissected eye in tissue paper or newspaper, and then in a double layer of plastic bags. The package should be kept in cold storage until it can be placed in an external bin on the day of refuse collection. Scissors, scalpels and other dissecting implements should be carefully collected for appropriate disinfection and washing by a member of staff. If using disposable scalpels, blades or razors they should be placed in a stout sided container, which may need to be autoclaved by a member of staff prior to disposal.

Ensure hands are thoroughly washed using a bactericidal hand wash, and that aprons are removed before leaving the room.

Practical Activity One
Eye dissection and UV absorption

Teacher

Plenary

Plenary

5 minutes

Recap the internal and external features of the eye that were identified. Relate the anatomy of the eye to the eye structure. Remind students of the effects of UV light on the eye and discuss the pros and cons of sunglasses and tinted lenses in glasses or contact lenses. You may want to discuss the eye diseases, treatments available and the benefits of preventative measures.

Suppliers

Blades Biological Limited
www.blades-bio.co.uk
Cowden, Edenbridge, Kent, TN8 7DX
tel: 01342 850 242, fax: 01342 850 924

Timstar (pigs eyes)

The Glow company provide LED UV torches that emit light at 395–405nm at a sufficient brightness to activate the colour changing section of the UV card
www.glow.co.uk

Philip Harris supply UV cards

You may wish to carry out quantitation of the results using data loggers and sensors:

Timstar Log IT data logger

Timstar UV sensor

Philip Harris UV sensor

Eye Dissection Report Form

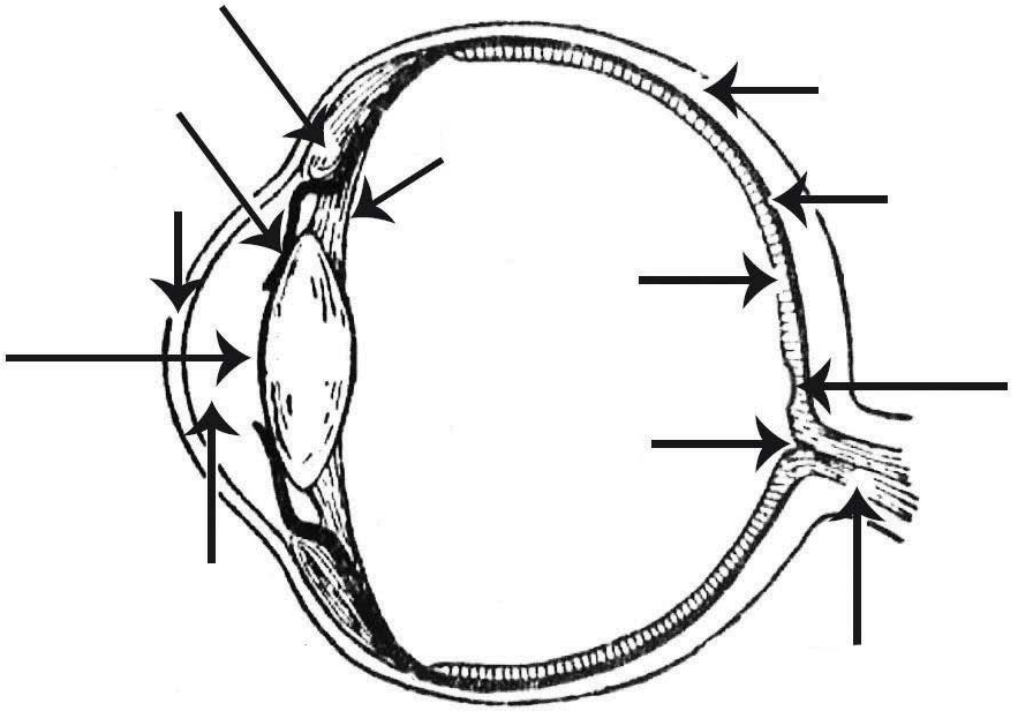
Student

Date:

Name:

Label the following tissues once you have identified their location in the dissected eye:

Cornea, iris, lens, pupil, aqueous humour, suspensory ligaments, ciliary muscle, ciliary body, vitreous humour, retina, optic nerve, choroid, sclera, fovea, arteries and veins, eye muscle.



UV Transparency Report Form

Student

Date:

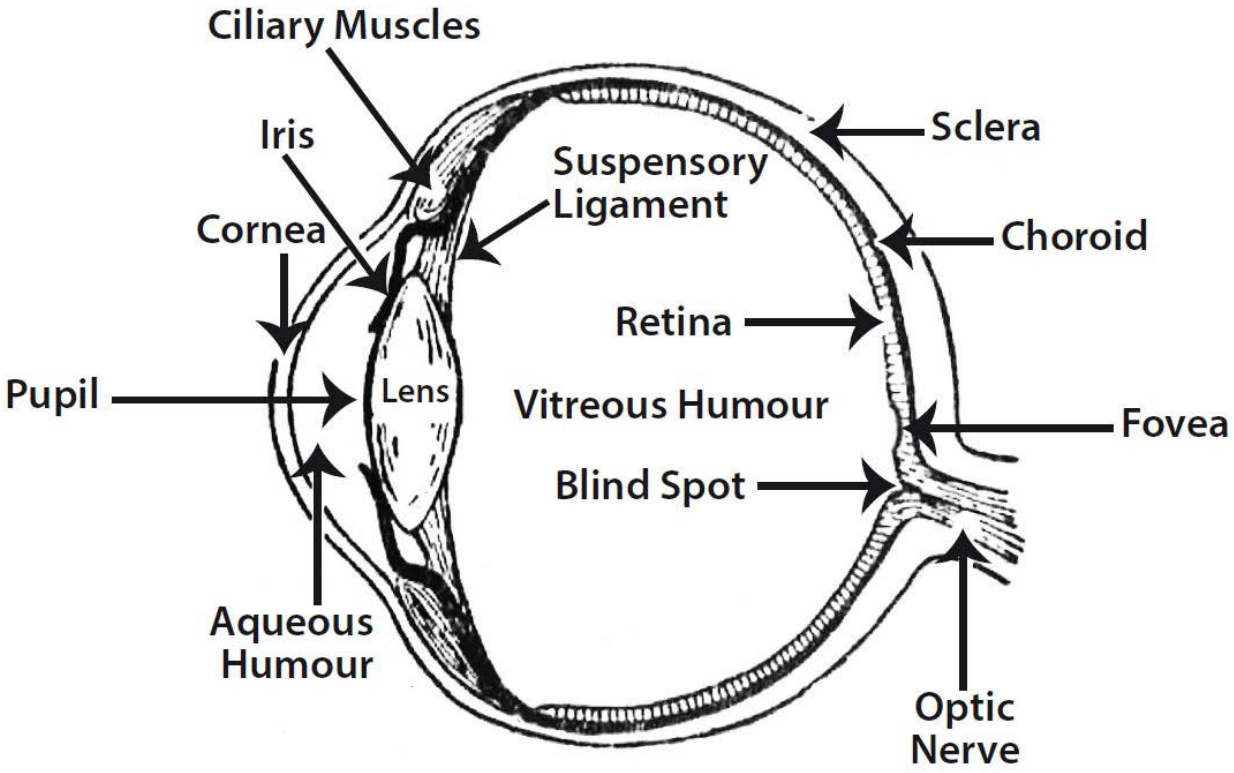
Name:

Tissue	UV transmission

Sunglasses	UV transmission

Eye Labelling Check Sheet

Student



Structure-Function Matching Task

Student

Cut out and match the structures of the eye to their functions

CORNEA	Contains light-sensitive cells, rods for dim light, cones for colour. It sends nerve impulses to the brain.
SCLERA	Where blood vessels and nerves join the eyeball.
MUSCULAR IRIS	Receives nerve impulses from the retina and sends them to the brain.
PUPIL	Hold the lens in place.
AQUEOUS HUMOUR	A transparent window in the front of the eye.
LENS	A jelly that fills the back of the eye.
VITREOUS HUMOUR	A hole that allows light through (in front of the lens).
RETINA	Changes the thickness of the lens when focusing.
BLIND SPOT	Controls how much light enters the eye and alters the shape of the pupil.
OPTIC NERVE	Helps focus a picture. Held in place by the suspensory ligaments and ciliary muscles. It can change shape.
CILIARY MUSCLES	A watery liquid that fills the front of the eye.
LIGAMENTS	The protective white outer layer of the eye.

Structure-Function Matching Task

Teacher

Answers

CORNEA	A transparent window in the front of the eye.
SCLERA	The protective white outer layer of the eye.
MUSCULAR IRIS	Controls how much light enters the eye and alters the shape of the pupil.
PUPIL	A hole that allows light through (in front of the lens).
AQUEOUS HUMOUR	A watery liquid that fills the front of the eye.
LENS	Helps focus a picture. Held in place by the suspensory ligaments and ciliary muscles. It can change shape.
VITREOUS HUMOUR	A jelly that fills the back of the eye.
RETINA	Contains light-sensitive cells, rods for dim light, cones for colour. It sends nerve impulses to the brain.
BLIND SPOT	Where blood vessels and nerves join the eyeball.
OPTIC NERVE	Receives nerve impulses from the retina and sends them to the brain.
CILIARY MUSCLES	Changes the thickness of the lens when focusing.
LIGAMENTS	Hold the lens in place.

Practical Activity Two

Binocular vision and the illusory pendulum

Teacher

Learning outcomes

Total Duration

45 minutes

Students will be able to:

- Suggest the purpose of binocular vision.
- Investigate hand-eye coordination in relation to binocular vision.
- Investigate the effect of decreased light level on the ability to perceive the distance of objects.
- Discuss the effect of visual ability on sporting ability.

Health and safety

What you will need

- Tennis ball
- Dark filter
- Pendulum (string and ball of Plasticine will suffice)
- Recording sheets

Optional

- Eye patch

The instructions are for guidance only. Choose a suitable area and provide sufficient room for throwing and catching of the tennis ball and swinging of the pendulum so that no hazards will be produced by missed catches. Particular care should be taken by students if they alter or restrict their normal vision with filters or by covering one eye.

Practical Activity Two

Binocular vision and the illusory pendulum

Teacher

Background

Humans and some other mammals have binocular vision; our eyes are at the front of our head. This means both of our eyes receive similar but not identical images. Our brain converts these two sets of signals into one three-dimensional image. Binocular vision provides the ability to judge distance and depth better than monocular vision but has the disadvantage of a narrower field of view.

Primates and predators such as dogs have binocular vision, this enables good judgement of distances, ideal for moving through tree tops or spotting prey. Prey species tend to have their eyes on either side of their head. This gives them better all-round vision for spotting predators sneaking up on them but does not provide good binocular vision.

The illusory pendulum effect is due to the way eyes adapt to low levels of light.

1. Initially pupils dilate to let more light enter the eye but as light levels decrease this is insufficient and the receptors take longer to collect the light, somewhat like increasing the exposure on a camera.
2. If one eye takes longer to collect light than the other it will receive a different image of the world. When there is a moving object, such as a pendulum or ball, the two eyes will see the object in different places.
3. Our brains are used to processing the two different images we normally receivefrom each eye and to creating a 3D view of the world.
4. When this happens watching the pendulum, the brain adjusts for the two different images of the pendulum.
5. The brain thinks the image received later from the covered eye means the pendulum is further away and this creates a 3D effect in our brains that makes the pendulum appear to move in an arc.

Back to How the eye works

Practical Activity Two

Binocular vision and the illusory pendulum

Teacher

Introduction

Duration

5 minutes

Ask students to suggest why we have two eyes and why they are located on the front of our face, side by side. Share the learning outcomes with the students and recap their prior knowledge of the function of the eye.

Activity 1: Investigating binocular vision

Duration

5 minutes

1. Hold a pen or pencil at arm's length in one hand
2. Use one finger of the other hand to quickly touch the end of the pen
3. Repeat this ten times using rapid movements to touch the pen
4. Record the number of clean hits
5. Repeat with one eye closed
6. Hold two pens at arm's length, one in each hand and with their points towards each other
7. Touch the points together
8. Now close one eye and try again. What difference does it make if two eyes are used?

Activity 2: Illusory pendulum

Duration

10 minutes

1. One student (the experimenter) should practise swinging the pendulum (one can be made from the ball of Plasticine and string), in a straight arc across the line of sight in a regular rhythm.
2. The other student (the participant) should sit about two metres from the pendulum and observe the path of the pendulum as it swings from left to right and back again.
3. The participant should then cover one eye with the dark filter. You may want to use a pair of sunglasses with one of the lenses removed.
4. The student should record their observations and then swap with their partner.

Practical Activity Two

Binocular vision and the illusory pendulum

Teacher

Activity 3: Testing binocular vision

Duration

15 minutes

1. Organise the students into pairs and provide one student with a tennis ball.
2. Students should stand apart facing each other at a distance where they are reasonably confident they can reliably catch a tennis ball with one hand.
3. Students should practice catching the ball and decide on a suitable distance. They will need to measure or mark out this distance to ensure they maintain it between throws.
4. The ball should be thrown ten times, with the number of successful catches recorded.
5. The activity should be repeated with one eye covered, once again recording the number of successful catches.
6. Students should then repeat the activity with the other eye covered.
7. The activity can then be carried out using a filter in front of one eye in the same way the illusory pendulum activity was conducted.
8. Do the students observe one eye to be better at detecting distance than the other?
9. You may want to discuss with students factors that may affect the results and the ability to carry out a fair test such as the consistency of the throw, and whether using a hand or an eye patch to cover the eye will affect the results.

Practical Activity Two

Binocular vision and the illusory pendulum

Teacher

Plenary

Amazing fact

The illusory pendulum effect can only be observed if you have two eyes, yet the scientist who first described it was a German astronomer called Pulfrich who was blind in one eye.

Discuss with students their results and the advantages and disadvantages of monocular vision (wider field of view but poorer judgement of distance), and binocular vision (narrower field of view but better judgement of distance).

Discuss the impact of decreased vision in one eye on sporting abilities.

It is worth discussing with students whether the colour of the pendulum would change the size of the illusory pendulum effect, considering the different numbers of receptors in each eye that would be able to detect the light from the pendulum at different light intensities. How could this be measured?
Recap with students the difference between rod and cone cells and their ability to work at low light levels.

Would the colour of balls used in sport affect players' ability to see them and should games be halted due to poor light?

Discuss the advantages and disadvantages of wearing corrective glasses or contact lenses during sport.

Why do sportsmen close one eye for certain activities such as shooting?

Practical Activity Two

Student

Binocular vision and the illusory pendulum

Activity A: Investigating binocular vision

Duration

5 minutes

1. Hold a pen or pencil at arm's length in one hand
2. Use one finger of the other hand to quickly touch the end of the pen
3. Repeat this ten times using rapid movements to touch the pen
4. Record the number of clean hits
5. Repeat with one eye closed
6. Hold two pens at arm's length, one in each hand and with their points towards each other
7. Touch the points together
8. Now close one eye and try again.

What difference does it make if two eyes are used?

Activity B: Illusory pendulum

Duration

10 minutes

1. Work in pairs.
2. Get a pendulum (one can be made from a ball of Plasticine and string), and find a suitable place to carefully swing it back and forth in a low arc.
3. Draw a straight line on a piece of paper or use a pencil stuck to the desk with Plasticine as a marker to ensure the pendulum swings in a straight line.
4. Practise swinging a pendulum in a straight arc across the line of sight in a regular rhythm.
5. Your partner should sit about two metres from the pendulum and observe the path of the pendulum as it swings from left to right and back again.
6. Cover one eye with the dark filter and repeat. You may want to use a pair of sunglasses with one of the lenses removed.
7. Mark on the paper, or with your finger, the centre of the swing the pendulum is making as it goes round.
8. Record your observations and then swap with your partner.

Practical Activity Two

Binocular vision and the illusory pendulum

Student

Activity 3: Testing binocular vision

Duration

15 minutes

1. Work in pairs.
2. You will need a tennis ball and a suitable place to carefully throw it underarm to your partner.
3. Stand apart facing each other at a distance where you are reasonably confident you can reliably catch a tennis ball with one hand.
4. Practice catching the ball and decide on a suitable distance. If you cannot easily catch the ball move closer together.
5. Measure or mark out this distance to ensure you maintain it between throws.
6. Throw the ball ten times recording the number of successful catches.
7. Repeat the activity with one eye covered and record the number of successful catches.
8. Repeat the activity with the other eye covered.
9. Repeat the activity using a filter in front of one eye as you did with the illusory pendulum activity.

Do you observe one eye to be better at detecting distance than the other?

Practical Activity Two

Binocular vision and the illusory pendulum

Student

Date:

Name:

Vision	Successful hits on pen
Binocular vision	/10
Monocular vision – left eye	/10

	Successful catches (%)
Binocular vision	
Monocular vision – left eye	
Monocular vision – right eye	

Practical Activity Two

Binocular vision and the illusory pendulum

Student

Date:

Name:

Record your observations here:

Practical Activity Three

Investigating colour vision

Teacher

Learning outcomes

Total Duration

1 hour

Students will be able to:

- Identify their own level of colour discrimination.
- Investigate colour vision.
- Explain reflection, absorbance and filtering of light and the effect on colour.
- Discuss vision disorders, describe how common they are, how they evolved and why they are maintained in the population, and possible non-genetic causes.

Health and safety and ethics

What you will need

- Ishihara test on printed sheets or PowerPoint slides
- Coloured lenses or filters

The activity does not present any health and safety risks but be mindful that some students may be unaware that they have any deficiency or anomalies in their colour vision. Students may be upset to discover they perceive colours differently to their peers and they should be reassured that this is quite common.

It is worth pointing out to students the theories concerning the advantages of being trichromatic or dichromatic (see Current Research – the evolution of colour vision). It is thought that the ability to see colour initially evolved in fish with four photopigments and that two of these were lost with the evolution of mammals that were primarily nocturnal. The ability to see different wavelengths of light varies across the animal kingdom as well as amongst humans. Because our brains interpret the signals we receive from our eyes, it is impossible to know how others perceive colours and this is readily apparent when people try to agree on the description of colours such as violet and mauve or rose and pink.

It is also worth noting that due to the genetic cause of colour vision variance, this may lead to students asking awkward questions or jumping to conclusions about the inheritance of these traits from their parents. Although red-green colour vision is determined by genes carried on the X-chromosome, there are a number of these genes, as well as genes that encode for photopigments that absorb blue wavelengths of light that are not found on the X or Y chromosomes (autosomal genes). The human genome project has found 19 different chromosomes and 56 different genes that influence colour vision. This can lead to varied forms of colour vision due to crossing over and recombination events. There are also other causes of decreased colour vision including vitamin A deficiency and over exposure to ultraviolet light. It is common for individuals to have colour vision that is different from their parents and it should not be assumed that colour vision is a trait that is simply passed down from either parent.

Practical Activity Three

Investigating colour vision

Teacher

Background

The Ishihara test was the first widely adopted colour perception test for red-green colour deficiencies. It was developed in 1917 by Dr Shinobu Ishihara, a professor at the University of Tokyo. The test involves identifying numbers or lines on 'plates' that are made up of a circle of different coloured and sized dots. The dots which form numbers and lines of dots are clearly visible to those with normal colour vision, and invisible, or difficult to see, to those with a red-green colour vision defect. There are now a number of other colour blind tests but the Ishihara test is the most well known, consisting of 38 plates. The Ishihara test can only be used to detect red-green colour blindness.

Students can investigate the effects of looking at the Ishihara plates with a red or green filter. A red filter will only allow red light through and a green filter will only allow green light through thus simulating, to a degree, being unable to detect green light or red light respectively. However, is this an appropriate simulation? Are students now unable to detect the numbers and lines in the Ishihara plates?

This activity enables the properties of light, filters and reflection to be discussed along with the potential of glasses to correct colour vision differences. Can coloured glasses help colour blind individuals? How do apps in mobile devices simulate colour blindness?

Back to The evolution of colour vision

Introduction

Recap with students the colours they can see, the spectrum and wavelengths of light and the principles of light reflection and absorption. Introduce the Ishihara test.

You can print out the Ishihara test in colour for students to use at their own pace or you can download the slide presentation. Note: due to differences in screens, projectors and printers the colours may not be reproduced exactly as they are meant to be seen on an Ishihara test.

Students should carry out the Ishihara test with and without filters before consulting the answers.

1. Students should work in pairs and both complete the test before checking the answers.
2. Students should view the Ishihara plates and their partner should record either the numbers seen or their ability to trace any lines they can see.
3. The test should be repeated with red or green colour filters.
4. If possible try repeating the test using a smartphone or tablet app that simulates colour deficiency.

Practical Activity Three

Investigating colour vision

Teacher

Extension

Are both eyes the same? Students can test their eyes separately. If colour blindness is genetic both eyes should have the same colour vision. Do the students' observations support this?

Plenary

Discuss the observations. Ask students to explain their observations in terms of the light reflected and absorbed by the coloured dots on the Ishihara plates. Discuss the effect on the perceived colours of adding a filter and ask students to suggest explanations for their observations. Can filters recreate colour blindness? Can tinted lenses enable colour blind individuals to see certain colours?

Suppliers

Filters are available from Philip Harris [Reference/webpage no longer available – October 2016]

Practical Activity Three

Ishihara test

Student

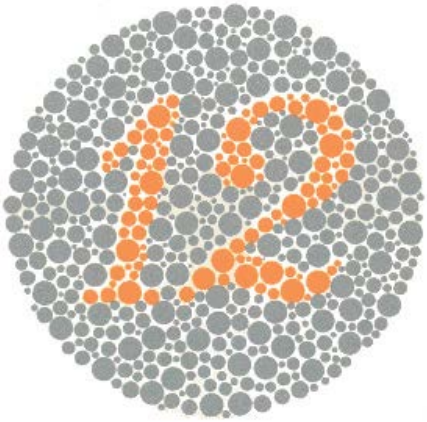
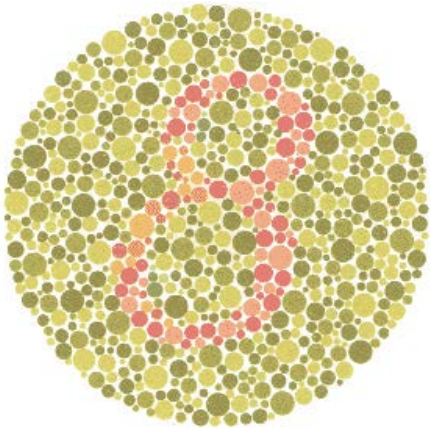


Plate 1



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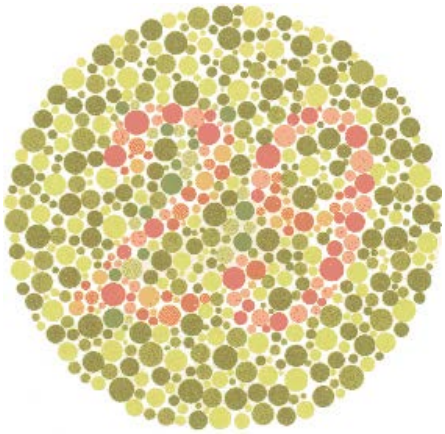

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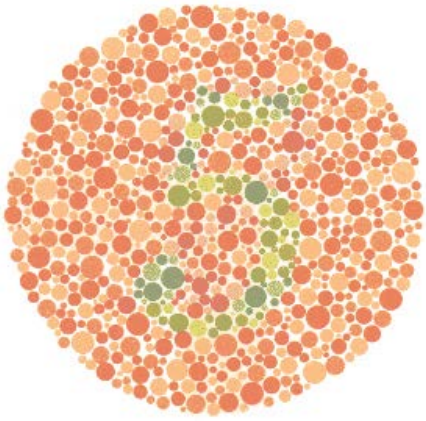

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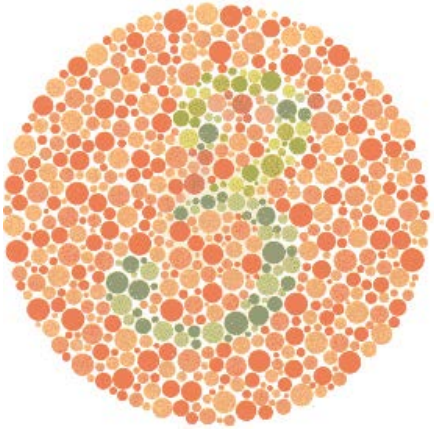

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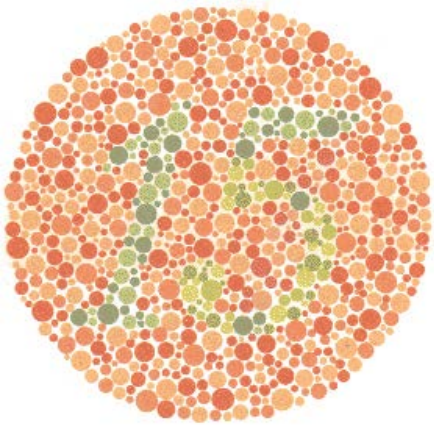
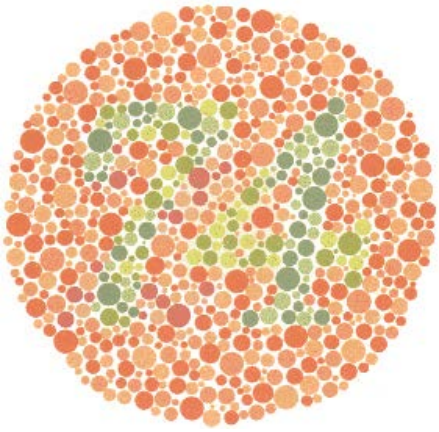


Plate 6

Practical Activity Three

Ishihara test

Student



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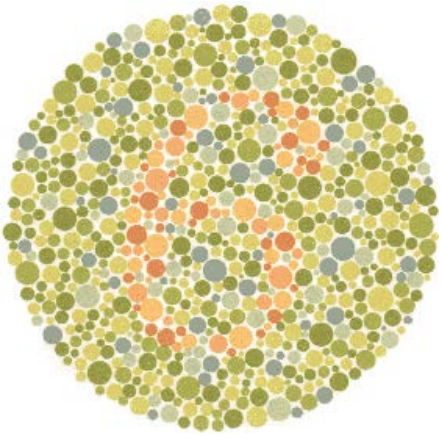

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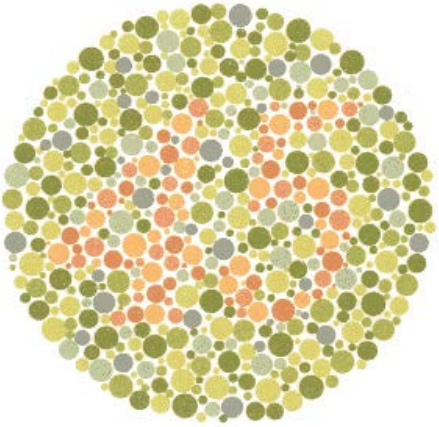

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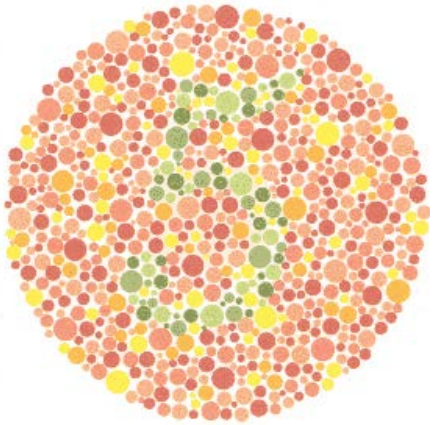

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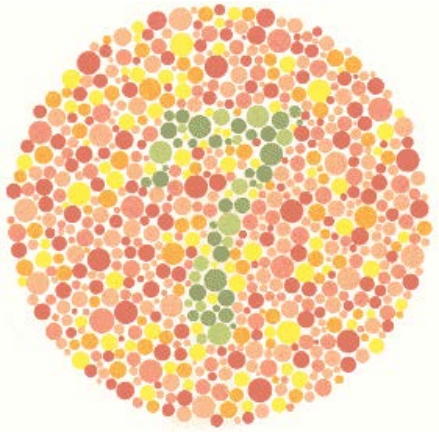

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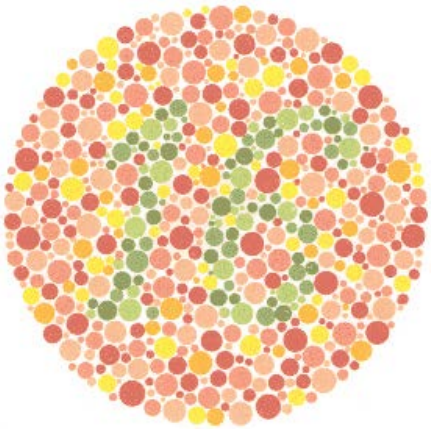


Plate 12

Practical Activity Three

Ishihara test

Student

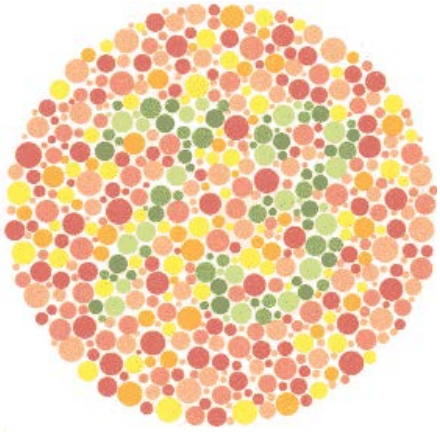
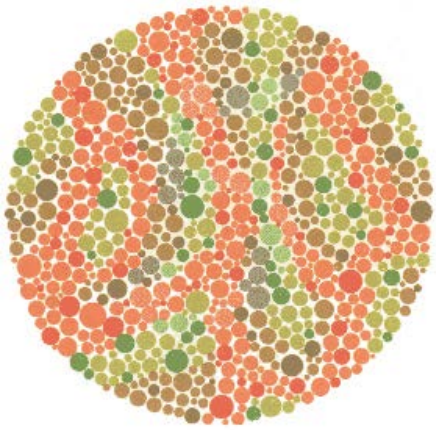


Plate 13



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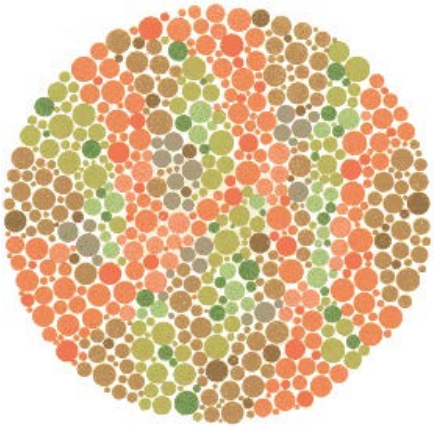

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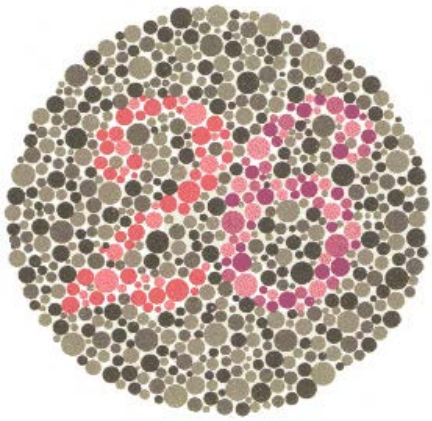
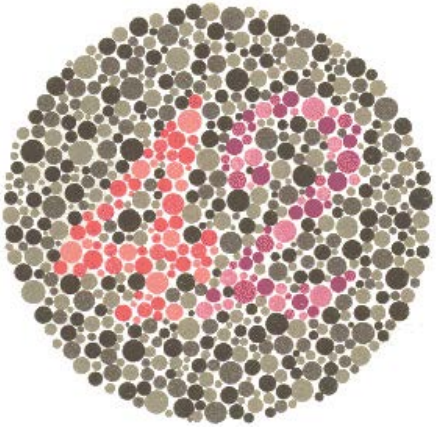


Plate 16



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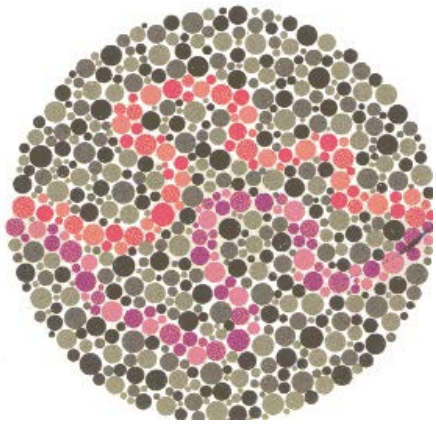


Plate 18

Practical Activity Three

Ishihara test

Student

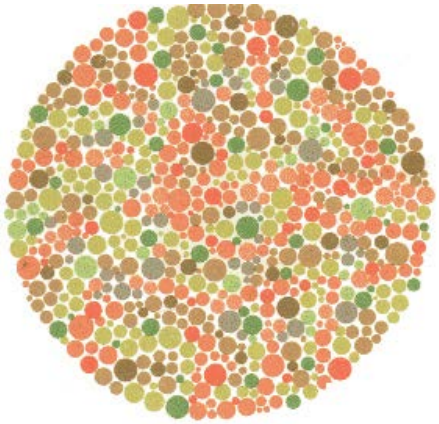
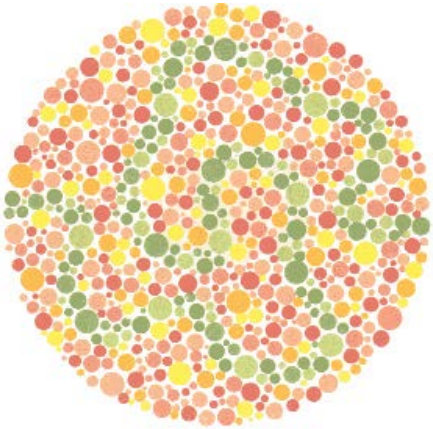


Plate 19



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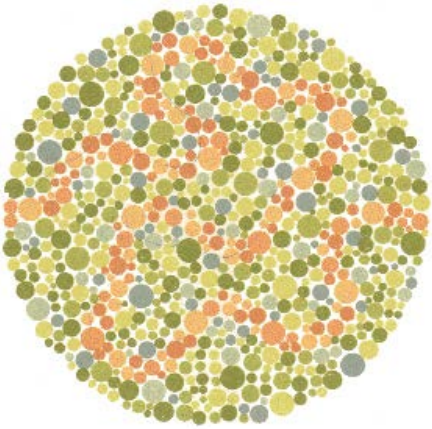

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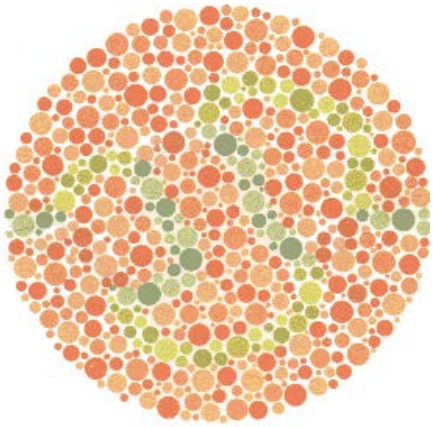


Plate 22

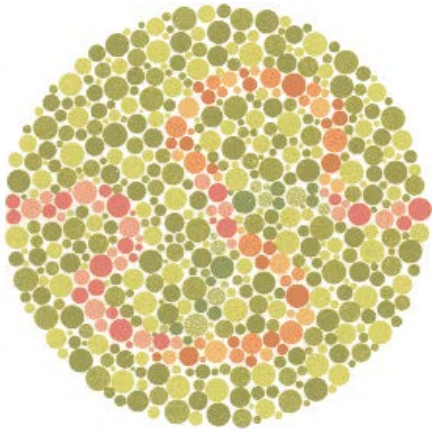


Plate 23

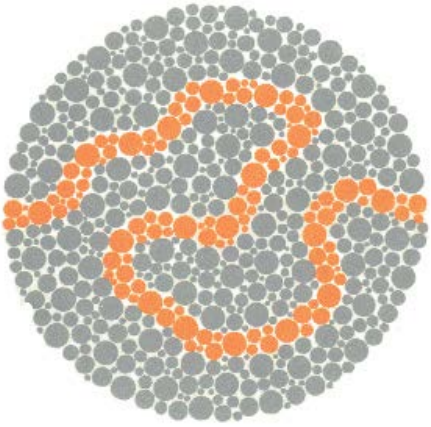


Plate 24

Practical Activity Three

Ishihara test

Student

Ishihara results

Plate	What did you see?	Colour vision
1	12	Everyone should be able to see a number 12, even those with total colour blindness. This test can check if someone is answering honestly
2	8	Normal colour vision
	3	Red-green colour blindness
	Nothing	Total colour blindness
3	29	Normal colour vision
	70	Red-green colour blindness
	Nothing	Total colour blindness
4	5	Normal colour vision
	2	Red-green colour blindness
	Nothing	Total colour blindness
5	3	Normal colour vision
	5	Red-green colour blindness
	Nothing	Total colour blindness
6	15	Normal colour vision
	17	Red-green colour blindness
	Nothing	Total colour blindness
7	74	Normal colour vision
	21	Red-green colour blindness
	Nothing	Total colour blindness
8	6	Normal colour vision
	Nothing	The majority of colour blind people cannot see this number clearly
9	45	Normal colour vision
	Nothing	The majority of colour blind people cannot see this number clearly
10	5	Normal colour vision people will see a number 5 clearly
	Nothing	The majority of colour blind people cannot see this number
11	7	Normal colour vision
	Nothing	The majority of colour blind people cannot see this number clearly
12	16	Normal colour vision
	Nothing	The majority of colour blind people cannot see this number clearly

Practical Activity Three

Ishihara test

Student

Plate	What did you see?	Colour vision
13	73	Normal colour vision.
	Nothing	The majority of colour blind people cannot see this number clearly.
14	Nothing	People with normal vision or total colour blindness should not be able to see any number.
	5	Red-green colour blindness.
15	Nothing	People with normal vision or total colour blindness should not be able to see any number.
	45	Red-green colour blindness.
16	26	Normal colour vision.
	6, faint 2	Red colour blind (protanopia) people will see a 6, mild red colour blind people (protanomaly) will also faintly see a number 2.
	2, faint 6	Green colour blind (deuteranopia) people will see a 2, mild green colour blind people (deuteranomaly) may also faintly see a number 6.
17	42	Normal colour vision.
	2, faint 4	Red colour blind (protanopia) people will see a 2, mild red colour blind people (protanomaly) will also faintly see a number 4.
	4, faint 2	Green colour blind (deuteranopia) people will see a 4, mild green colour blind people (deuteranomaly) may also faintly see a number 2.
18	Purple and red lines	Normal colour vision should be able to trace along both the purple and red lines.
	Purple line	Protanopia (red colour blind) should be able to trace the purple line.
	Red line, with increased difficulty	Protanomaly (weak red vision) may be able to trace the red line, with increased difficulty.
	Red line	Deuteranopia (green colour blind) should be able to trace the red line.
	Purple line, with increased difficulty	Deuteranomaly (weak green vision) may be able to trace the purple line, with increased difficulty.
19	Nothing	Normal colour vision or total colour blindness should be unable to trace the line.
	Wiggly line	Most people with red-green colour blindness can trace the wiggly line, depending on the severity of the condition.
20	Green wiggly line	Normal colour vision should be able to trace a green wiggly line.
	Nothing	Most people with any form of colour blindness will be unable to trace the correct line.
21	Orange wiggly line	Normal colour vision should be able to trace an orange wiggly line.
	Nothing	Most people with any form of colour blindness will be unable to trace the correct line.
22	Blue-green/yellow-green wiggly line	Normal colour vision should be able to trace the blue-green/yellow-green wiggly line.
	Blue-green and red line	Red-green colour blind people will trace the blue-green and red line.
	Nothing	People with total colour blindness will be unable to trace any line.
23	Red and orange wiggly line	Normal colour vision should be able to trace the red and orange wiggly line.
	Red and blue-green wiggly line	Red-green colour blind people will be able to trace the red and blue-green wiggly line.
	Nothing	People with total colour blindness will be unable to trace any line.
24	Wiggly line	Everyone should be able to trace this wiggly line.

Practical Activity Three

Ishihara test

Student

Ishihara results

Plate	What did you see?
1	No filter:
	Red filter:
	Green filter:
2	No filter:
	Red filter:
	Green filter:
3	No filter:
	Red filter:
	Green filter:
4	No filter:
	Red filter:
	Green filter:
5	No filter:
	Red filter:
	Green filter:
6	No filter:
	Red filter:
	Green filter:
7	No filter:
	Red filter:
	Green filter:
8	No filter:
	Red filter:
	Green filter:
9	No filter:
	Red filter:
	Green filter:

Practical Activity Three

Ishihara test

Student

Ishihara recording sheet

Plate	What did you see?
10	No filter:
	Red filter:
	Green filter:
11	No filter:
	Red filter:
	Green filter:
12	No filter:
	Red filter:
	Green filter:
13	No filter:
	Red filter:
	Green filter:
14	No filter:
	Red filter:
	Green filter:
15	No filter:
	Red filter:
	Green filter:
16	No filter:
	Red filter:
	Green filter:
17	No filter:
	Red filter:
	Green filter:
18	No filter:
	Red filter:
	Green filter:

Practical Activity Three

Ishihara test

Student

Ishihara recording sheet

Plate	What did you see?
19	No filter:
	Red filter:
	Green filter:
20	No filter:
	Red filter:
	Green filter:
21	No filter:
	Red filter:
	Green filter:
22	No filter:
	Red filter:
	Green filter:
23	No filter:
	Red filter:
	Green filter:
24	No filter:
	Red filter:
	Green filter:

Practical Activity Three

Investigating colour vision

Teacher

Links and references

S. Ishihara, Tests for colour-blindness (Handaya, Tokyo, Hongo Harukicho, 1917)

Online Ishihara colour blindness test
www.colour-blindness.com/colour-blindness-tests/ishihara-colour-test-plates

Alternative colour blindness tests
www.opticien-lentilles.com/daltonien_beta/new_test_daltonien.php

Website about colour blindness featuring a colour blind simulator
www.colblindor.com

Nuffield practical activity: Investigating how we see colour
www.nuffieldfoundation.org/practical-biology/investigating-how-we-see-colour

Video: Seeing Colour – with 'colour blind' monkey vision simulations!
www.youtube.com/watch?v=yRQ17WUBrIg

Video: TED talk about colour blindness
www.ted.com/talks/neil_harbisson_i_listen_to_color.html

App: Chromatic vision simulator This app simulates how individuals with colour blindness see the world using the built-in camera.
itunes.apple.com/app/chromatic-vision-simulator/id389310222?mt=8

App: Colour blend
For Android smartphones and tablets. This app identifies the colour of whatever is currently in view of the camera, displaying the colour in words as well as the RGB value. Colour Blend is particularly useful for people who suffer from any form of colour blindness.

Practical Activity Four

Acuity and the visual field

Teacher

Learning outcomes

Total Duration

1 hour

Students will be able to:

- Measure their visual range, acuity and identify their blind spot
- Investigate the distribution of cone cells in the retina
- Investigate the effect of decreased light level on acuity

Health and safety and ethics

The instructions are for guidance only. Choose a suitable area and provide sufficient room for carrying out the investigations. Particular care should be taken by students if they move around the classroom while focusing their attention on distant objects. These activities should be carried out with students who volunteer as they may be embarrassing for some students.

Prior learning

Students should recap 'How the eye works' ensuring they understand the function of the cornea, lens and anatomy of the eye. An understanding of the limits of the ability of the lens to focus light and the arrangement of cells and tissues in the back of the eye will be an advantage.

Practical Activity Four

Acuity and the visual field

Teacher

Background

Our eyes have a visual range defined by our ability to focus light, detect frequencies of light and differentiate signals received by the retina. Vertebrates live in a variety of environments and have specialised visual sensory systems adapted to their needs – be it evasion of predators, mate selection or foraging for food. Differences in the vertebrate eye range from the ability of the cornea to allow light into the eye to the pigmentation of the choroid layer at the back of the eye controlling the amount of reflected light.

The cornea carries out the majority of light focusing on the retina with the lens carrying out fine focusing. In order to see distant objects the eye needs to focus light rays that are almost parallel, requiring less refraction by the lens than near objects. Near objects require a higher degree of accommodation and hence a rounder lens which requires greater contraction by the ciliary muscles. If the lens is too stiff we are unable to adjust it to focus on images. As we age the elasticity of the lens decreases and we lose the ability to focus on objects close to us.

The distribution of rod and cone cells in the retina and the pigments they contain determines the light that can be converted into electrical signals and sent down the optic nerve. Cone cells are not evenly and spherically distributed across the retina. There are differences in the distribution of cells in the fovea and periphery as well as varying proportions of the three cone cell types throughout the retina.

As light levels decrease so does acuity. Below a certain level of light only the rod cells are able to detect light. They are distributed amongst cone cells and due to retinal convergence they have greater sensitivity, but combining signals to trigger retinal ganglion cells decreases their ability to distinguish the light received from two distinct points.

At one point in the eye there are no rod or cone cells. The blood vessels and nerves of the retina are on the inner surface of the eye in front of the receptor cells. They must exit the eye at one point. This point is known as the blind spot because there are no receptor cells here. The blind spot is found slightly to one side of the eye towards the centre of the face while the fovea is found slightly towards the outer side of the eye.

Teacher preparation

Little preparation is required for these activities. You will need to print sufficient copies of the student sheets in advance. A suitable space to conduct the activities is required. Visual acuity sheets will need to be attached to a wall and a suitable distance for viewing them will be required. If possible, use a room where light levels can be adjusted.

Practical Activity Four

Acuity and the visual field

Student

Stage 1

Measuring visual range

What you will need

- This piece of paper
- A ruler
- Coloured pens (red, green and blue)
- Visual field map or square ruled paper

1. Work in pairs. This activity can be carried out wearing glasses
2. Hold this piece of paper to your nose and slowly move it away from your face
3. Stop when you can focus on the letters. This is known as your near point. Measure the distance between the paper and your eye
4. Your far point is potentially infinity though other factors limit your ability to see objects at great distances. Next time you are out at night look up at the sky and you will be able to see objects that are millions of light years away – the stars.

Practical Activity Four

Acuity and the visual field

Student

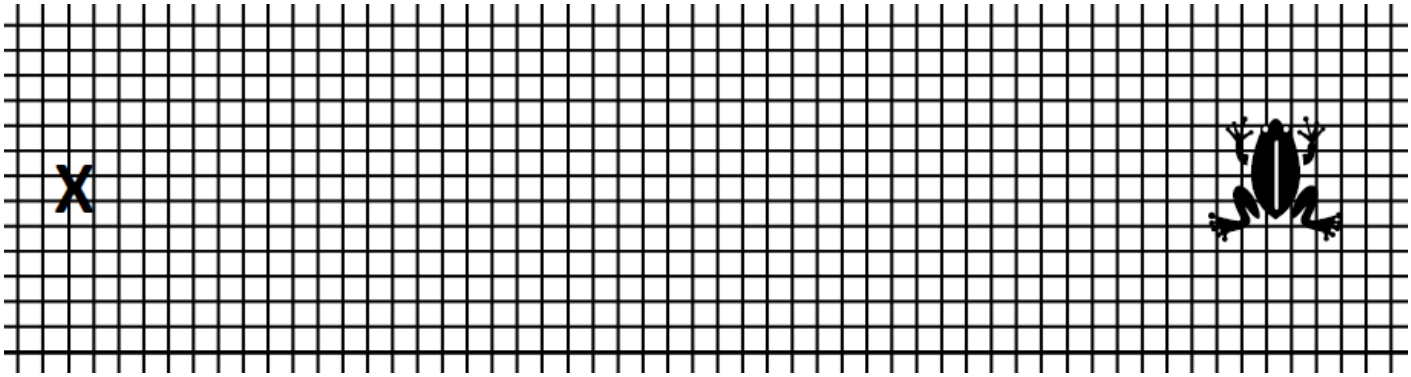
Stage 2

Identifying your blind spot

What you will need

- This piece of paper
- A ruler
- Coloured pens (red, green and blue)
- Visual field map or square ruled paper

1. Hold the paper at arm's length. This activity can be carried out wearing glasses
2. Close your left eye and stare at the X with your right eye
3. Slowly bring the paper towards you until the image of the frog disappears
4. What do you see where the frog was? Why?
5. Repeat with your right eye closed
6. Does the frog disappear?
7. Draw a diagram of the eye using a ruler to draw lines showing the direction of the light rays to explain why the frog disappears.



Numeracy extension task

The distance between the cross and the frog is 13.5cm. The image of the cross falls on the fovea and the image of the frog falls on the blind spot.

Using the principle of similar triangles calculate the approximate distance between the blind spot and the fovea. The distance between the front of the eye and the retina is about 1.7cm.

Hint: The triangle formed by the X, frog and front of your eye is proportional to the triangle formed by the front of your eye, blind spot and fovea. The distance to your eye and the distance between the front and back of your eye are in the same proportion as the distance between the X and frog, and your fovea and blind spot.

Practical Activity Four

Acuity and the visual field

Student

Stage 3

Peripheral vision

1. Hold a pen at arm's length out to your side at shoulder level.
2. Stare straight ahead.
3. Slowly move the pen round towards the front of you and note the point at which you can see it.
4. This indicates the edge of your peripheral vision.

Stage 4

Mapping your visual field

1. Work in pairs. This activity works better if any glasses are removed.
2. Lay the visual field map template flat on the desk (square ruled paper can be used instead of the visual field map template).
3. Position your eyes at your near point as calculated earlier (Stage 1).
4. Cover one eye and stare at the centre of the paper with your other eye.
5. Your partner should slowly bring the blue pen into your field of view at '3 o'clock'.
6. When you can see the blue pen, tell your partner to stop.
7. Your partner should now draw a blue dot on the square paper.
8. Your partner should now move to '4 o'clock' and repeat the same procedure at each hour point making a dot on the paper until they get back to '4 o'clock'.
9. You should now join up the blue dots with the blue pen. This indicates the distribution of photoreceptor cells on your retina.
10. You can now repeat the activity with your other eye to see if there is any difference in the distribution of photoreceptors in either eye.
11. Repeat the activity with red and green pens using the same procedure. This will indicate the approximate distribution of red and green cone cells in your retina.
12. Do you see any difference in the distribution of rod and cone cells?
13. If there are individuals in your class with red-green colour blindness they may be willing to compare your visual field to theirs.

Practical Activity Four

Acuity and the visual field

Student

Stage 5

Acuity

Visual Acuity

1. Attach the piece of paper featuring two black dots to a wall.
2. Walk approximately 7m away from the wall.
3. Slowly walk towards the paper and stop where you can see the two dots as separate.
4. Measure the distance from where you are standing to the paper.

Colour Acuity

1. Carry out the experiment as above but one dot should be black and the other dot should be blue. To make your own test draw dots 2mm in diameter, 1mm apart.
2. Repeat using a red dot and then a green dot instead of the blue.
3. If possible reduce the light level in the room and repeat the activity.

Practical Activity Four

Acuity and the visual field

Student

Visual Range, Blind Spot and Acuity Report Form

Student

Date:	Name:

Near point =	cm
Distance between eye and X =	cm
Distance between X and frog =	11 cm
Distance between fovea and blind spot =	cm
Distance at which black dots could be seen as separate =	cm
Distance at which black and blue dot could be seen as separate =	cm
Distance at which red and green dots could be seen as separate =	cm

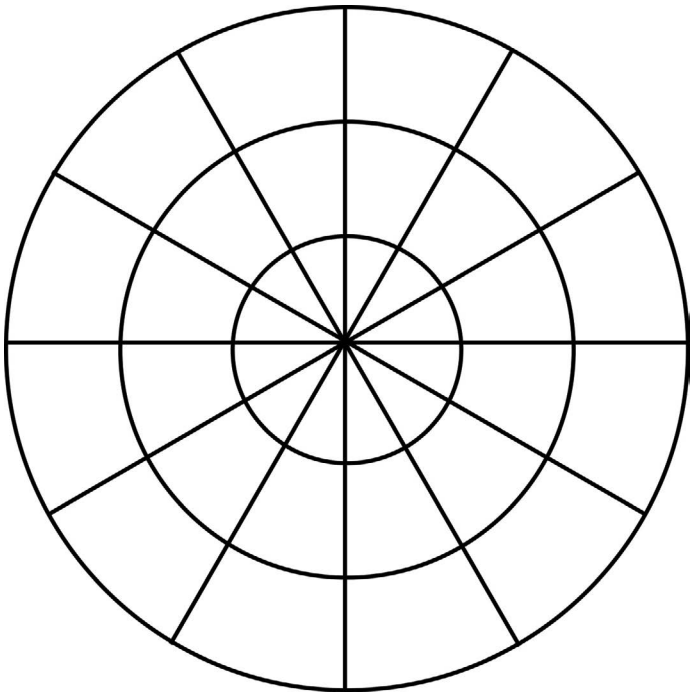
Eye diagram

Visual Field Map

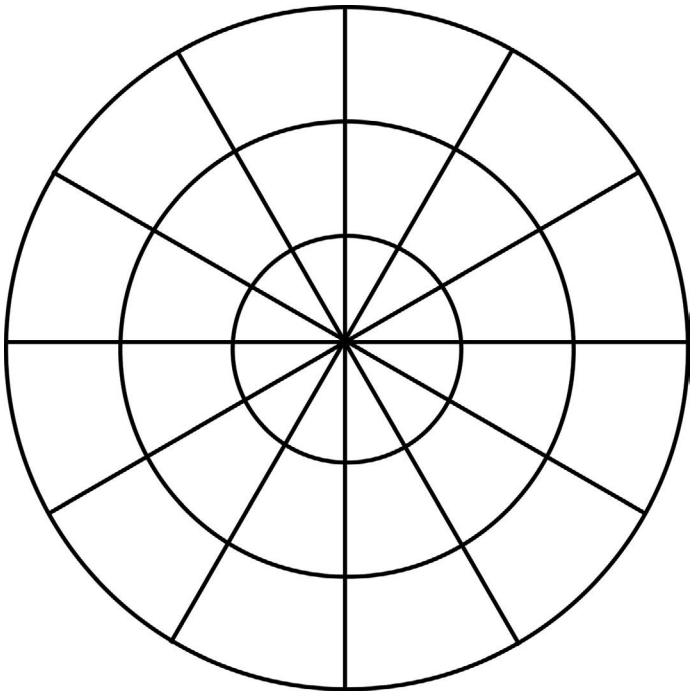
Student

Date:

Name:



Right eye



Left eye

The Mammalian Eye

Student

The eye is one of the most important sense organs in the human body. It helps the nervous system gather information about the external _ _ _ _ _ _ _ _ _ _ _ in order for it to respond adequately and maintain homeostasis. The wall of the eye is composed of three main layers. The outer layer is called the _ _ _ _ _ _, it is a strong white coat that protects the eye. The middle layer is called the _ _ _ _ _ _ _, it is dark in colour because it contains blood vessels that supply the eye with nutrients and oxygen. The innermost layer is called the _ _ _ _ _ _, it contains photoreceptors called rods and cones that are important in the production of sight.

As light enters the eye, it is _ _ _ _ _ _ _ _ _ (bent) towards the pupil by a curved structure called the _ _ _ _ _ _. Just behind this structure is a clear fluid called _ _ _ _ _ _ _ _ _ _ _ _ _, through which light will pass to reach the lens. It is the job of the lens to focus light on the retina. In order to do this the shape of the lens changes according to the _ _ _ _ _ _ _ _ of the object from the eye. The shape is controlled mainly by the _ _ _ _ _ _ _ muscles and the _ _ _ _ _ _ _ _ _ _ ligaments. Besides distance, the eye also has to adjust according to the amount of light entering the eye. The _ _ _ _ controls the amount of light entering the pupil. Besides a colourful pigment, the iris is composed of two layers of muscles called _ _ _ _ _ _ _ _ and _ _ _ _ _ _ muscles. In bright light, the circular muscles _ _ _ _ _ _ _ _ and the radial muscles _ _ _ _ _, causing _ _ _ _ _ _ _ _ _ _ _ of the pupil, in order to reduce the amount of light entering the eye. In dim light the opposite occurs – the pupil _ _ _ _ _ _ _ to let more light enter.

As light passes through the eyeball, it travels through a jelly like substance called _ _ _ _ _ _ _ _ humour which maintains the _ _ _ _ _ of the eyeball. Eventually light reaches the retina where it stimulates the photoreceptors to send impulses through the _ _ _ _ _ nerve towards the occipital lobe of the brain to be interpreted. The retina has an area that is saturated with cones to see colour and fine details, this is called the _ _ _ _ _. Where the optic nerve enters the eyeball there is an area that does not contain any photoreceptors. It is referred to as the _ _ _ _ _ _ _ _ _.

Missing words: environment, sclera, choroid, retina, refracted, cornea, aqueous humour, distance, ciliary, suspensory, iris, circular, radial, contract, relax, contraction, dilates, vitreous humour, shape, optic, fovea, blind spot.

The Mammalian Eye

Student

The eye is one of the most important sense organs in the human body. It helps the nervous system gather information about the external _ _ _ _ _ _ _ _ _ _ _ in order for it to respond adequately and maintain homeostasis. The wall of the eye is composed of three main layers. The outer layer is called the _ _ _ _ _ _, it is a strong white coat that protects the eye. The middle layer is called the _ _ _ _ _ _ _, it is dark in colour because it contains blood vessels that supply the eye with nutrients and oxygen. The innermost layer is called the _ _ _ _ _ _, it contains photoreceptors called rods and cones that are important in the production of sight.

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The Mammalian Eye
Answers

Teacher

The eye is one of the most important sense organs in the human body. It helps the nervous system gather information about the external **environment** in order for it to respond adequately and maintain homeostasis. The wall of the eye is composed of three main layers. The outer layer is called the **sclera**, it is a strong white coat that protects the eye. The middle layer is called the **choroid**, it is dark in colour because it contains blood vessels that supply the eye with nutrients and oxygen. The innermost layer is called the **retina**, it contains photoreceptors called rods and cones that are important in the production of sight.

As light enters the eye, it is **refracted** (bent) towards the pupil by a curved structure called the **cornea**. Just behind this structure is a clear fluid called **aqueous humour**, through which light will pass to reach the lens. It is the job of the lens to focus light on the retina. In order to do this the shape of the lens changes according to the **distance** of the object from the eye. The shape is controlled mainly by the **ciliary** muscles and the **suspensory** ligaments. Besides distance, the eye also has to adjust according to the amount of light entering the eye. The **iris** controls the amount of light entering the pupil. Besides a colourful pigment, the iris is composed of two layers of muscles called **circular** and **radial** muscles. In bright light, the circular muscles **contract** and the radial muscles **relax**, causing **contraction** of the pupil, in order to reduce the amount of light entering the eye. In dim light the opposite occurs – the pupil **dilates** to let more light enter.

As light passes through the eyeball, it travels through a jelly like substance called **vitreous** humour which maintains the **shape** of the eyeball. Eventually light reaches the retina where it stimulates the photoreceptors to send impulses through the **optic** nerve towards the occipital lobe of the brain to be interpreted. The retina has an area that is saturated with cones to see colour and fine details, this is called the **fovea**. Where the optic nerve enters the eyeball there is an area that does not contain any photoreceptors. It is referred to as the **blind spot**.

Bleaching Sequencing

Student

Cut out the statements and put them in the correct order

Sodium ions build up outside the membrane causing hyperpolarisation of the rod cell.

In the dark, sodium ions move into the rod cell via non-specific cation channels and are actively pumped back out causing slight depolarisation.

This means no inhibitory neurotransmitter can be released from the rod cell at the synapse with the bipolar neurons.

Rhodopsin is split into its component parts – retinal and opsin.

The presence of opsin causes cation channels in the rod cell membrane to close.

This does not affect the sodium pump, which remains active.

This causes continual glutamate release and prevents bipolar cells depolarising.

Action potential passes to ganglion cells which send impulses along the optic nerve to the brain.

Bipolar neurons respond with depolarisation (inhibitory effect of the firing rod cell has been removed).

When light reaches the back of the retina it is absorbed by rhodopsin in the outer segment of rod cells.

Bleaching sequencing
Answers

Teacher

Cut out the statements and put them in the correct order

In the dark, sodium ions move into the rod cell via non-specific cation channels and are actively pumped back out causing slight depolarisation.

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This means no inhibitory neurotransmitter can be released from the rod cell at the synapse with the bipolar neurons.

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Action potential passes to ganglion cells which send impluses along the optic nerve to the brain

Wordsearch

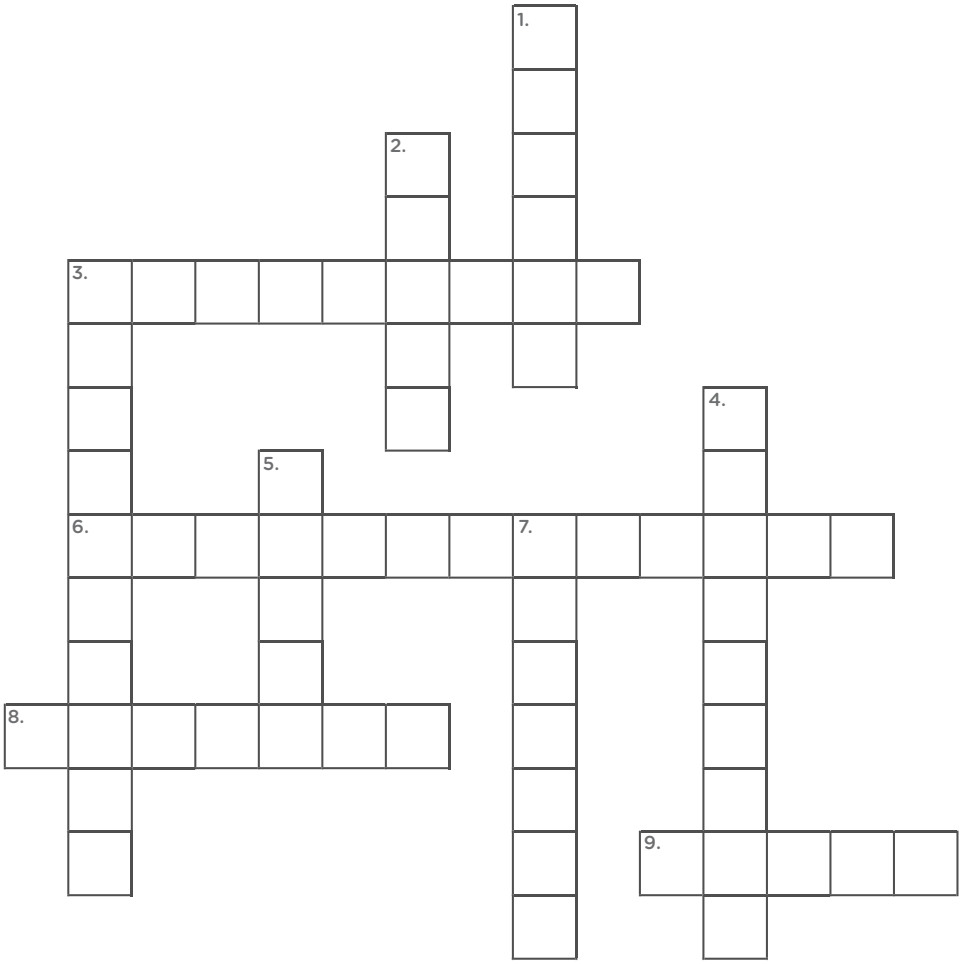
Student

S C R Y E G D N I L B R U O L O C X S W
G F Z S T N E M G I P O T O H P D T N U
V I T R E O U S H U M O U R L I N W O L
A S N C I T A M O R H C I R T E O A I T
Z E I O S M T A P E T U M K M N V C S R
C N O P I R C T K I H R L A N O N C I A
I S P T R H H K G L G C G S A I O O V V
L I R I I O O S S G I I Y W I T I M C I
I T A C A D R B D R L T V T D C S M I O
A I E N I O O K O Y D A U O A I I O P L
R V N E P P I U R Y E M D P C R V D O E
Y I S R O S D O V T S O I S R T R A C T
M T M V Y I S G Q I I R L D I S A T S P
U Y J E M N C M X U R H A N C N L I O L
S B J P E U Y Z W C A C T I C O U O E I
C S P P S C L E R A L I I L O C C N R P
L W S A N I T E R B O D O B R O O J E U
E U R K D L E N S Z P Q N K N N N W T P
S R O T P E C E R O T O H P E E I G S R
F E R U O M U H S U O E U Q A S B Q T H

iris
pupil
lens
cornea
sclera
choroid
ciliary muscle
suspensory ligaments
aqueous humour
vitreous humour
retina
photoreceptor
rods
cones
optic nerve
blind spot
tapetum
circadian
ultraviolet
polarised light
sensitivity
acuity
dilation
constriction
accommodation
myopia
binocular vision
stereoscopic vision
colour blind
photopigments
rhodopsin
trichromatic
dichromatic
near point

Crossword

Student



Across

3. A pigment that detects light

6. Being able to focus on objects which are at different distances from you

8. The muscle that changes the shape of the lens

9. These receptor cells detect colour

Down

1. You have this if you cannot focus on objects in the distance

2. It allows you to see everything but there is nothing there

3. The change in the direction of light when it enters the eye

4. Where the nerves and blood vessels enter the eye

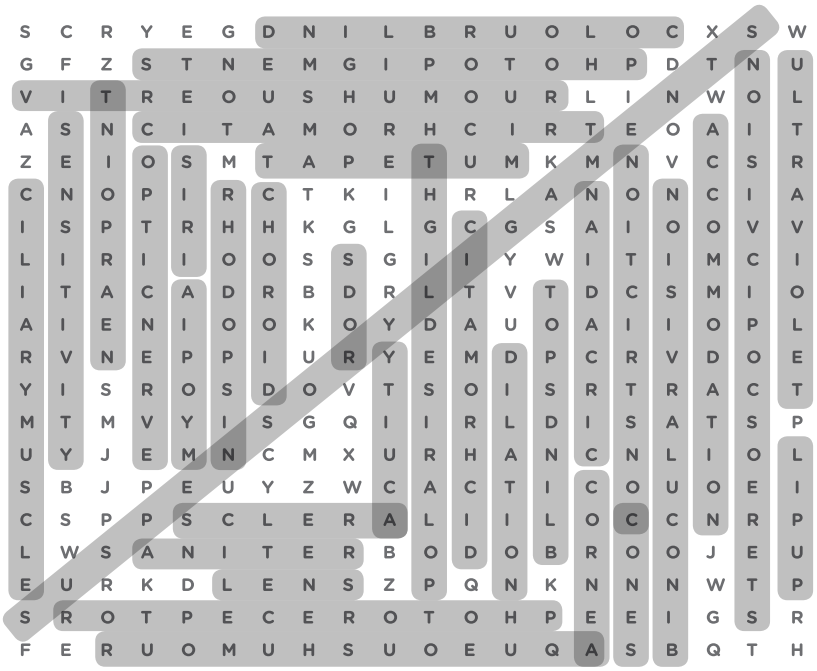
5. The greatest concentration of receptor cells are found here

7. The iris does this in dim light

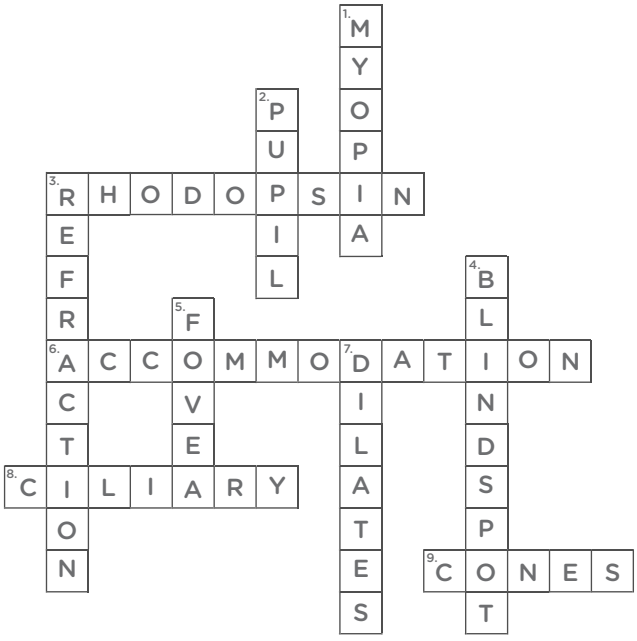
Answers

Teacher

Word search | page 74



Crossword | page 75



Glossary

Student

Accommodation
The ability to focus objects which are at different distances from the eye.

Acuity
The ability to see two distinct points.

Aqueous humour
Transparent semi-liquid fluid behind the cornea that maintains the shape of the eye and cushions the iris and lens.

Binocular vision
Vision that uses two eyes to create a single image.

Bipolar cells
Connect photoreceptor cells to retinal ganglion cells.

Blind spot
Area where nerves and blood vessels enter and exit the eye. No photoreceptors are found here so light focused here cannot be seen.

Choroid layer
Middle layer of the eye that contains blood vessels and nutrients for the eye.

Ciliary muscle
Changes the shape of the lens for fine focusing.

Circadian rhythm
A repeating cycle of biological and behavioural changes that repeat every 24 hours.

Colour blind
Is the inability or decreased ability to see colour, or perceive colour differences and is also known as colour vision deficiency.

Cones
Cone cells are photoreceptors found in the retina. They contain pigments that respond to different wavelengths of light and enable us to see in colour. Concave – curves inwards like the inner surface of a sphere.

Concave
Curves inwards like the outer surface of a sphere.

Convex
Curves outwards like the outer surface of a sphere.

Cornea
Bends light towards the pupil.

Glossary

Student

Dichromatic
Having only two types of colour receptor pigment. Individuals who are dichromatic often display what is known as red-green colour blindness and lack the receptor for medium wavelength light.

Dilation
Expanding in size.

Fovea centralis
The main focal point on the retina where there is a high concentration of receptor cells for seeing fine detail.

Iris
Circular muscle that controls the size of the pupil, also contains coloured pigment.

Lens
A transparent biconvex structure that adjusts its thickness to enable fine focusing of light on the retina.

Myopia
The inability to focus on objects in the distance, also known as short-sightedness.

Near point
The closest point that the eye can focus on accurately.

Optic nerve
Nerve that receives impulses from the retina and carries them to the brain.

Photopigments
Pigments that undergo a physical or chemical change when they absorb light causing photoreceptor cells to trigger a signal that is sent to the brain.

Photoreceptor
Cells in the retina that detect light.

Polarised light
Light that oscillates in one orientation.

Pupil
The opening found at the front of the eye that is formed by the surrounding iris and lets light enter the eye.

Refraction
The change in direction of a wave when it enters a medium that changes its speed.

Retina
Inner layer of the eye that contains light-sensitive cells which detect light .

Glossary

Student

Retinal ganglion cells
Are connected to bipolar cells and combine image signals detected by rod and cone cells.

Rhodopsin
Visual pigment molecule made of a protein – opsin – and a compound made from vitamin A, called retinal, that changes shape when it absorbs light.

Rods
Photoreceptor cells spread out over the retina that have good sensitivity and detect light even in low light conditions.

Sclera
Tough protective white outer layer of the eye.

Stereoscopic vision
The ability to judge depth by combining two slightly different images from each eye into a single perception.

Suspensory ligaments
Attaches the ciliary muscle to the lens.

Tapetum
Reflective layer found behind the retina in the back of the eye of many vertebrates that improves vision at night or in low light environments.

Trichromatic
Having all three types of the colour receptor pigment.

Ultraviolet (UV)
Light with wavelengths between 400 and 100nm.

Vitreous humour
Transparent jelly-like substance which fills the eyeball and maintains its shape.

Curriculum Links

Teacher

Year 3 - Light

- Recognise that light from the sun can be dangerous and that there are ways to protect their eyes

Year 6 - Light

- Use the idea that light travels in straight lines to explain that objects are seen because they give out or reflect light into the eye
- Explain that we see things because light travels from light sources to our eyes or from light sources to objects and then to our eyes

Key Stage 3 Physics

Waves

- The transmission of light through materials: absorption, diffuse scattering and specular reflection at a surface
- Use of ray model to explain imaging in mirrors, the pinhole camera, the refraction of light and action of convex lens in focusing (qualitative); the human eye
- Light transferring energy from source to absorber leading to chemical and electrical effects; photo-sensitive material in the retina and in cameras

Key Stage 4 Science

How Science Works: Applications and implications of science

Pupils should be taught:

- To consider how and why decisions about science and technology are made, including those that raise ethical issues, and about the social, economic and environmental effects of such decisions.

All pupils develop their ability to relate their understanding of science to their own and others' decisions about lifestyles, and to scientific and technological developments in society.

AQA GCSE Biology and Science A

B1.2.1 The nervous system

Knowledge and understanding of the structure and functions of sense organs such as the eye and the ear are not required.

- The nervous system enables humans to react to their surroundings and coordinate their behaviour.
- Cells called receptors detect stimuli (changes in the environment).

Receptors and the stimuli they detect include:

- Receptors in the eyes that are sensitive to light

AQA GCSE Biology

Practical work to develop skills and understanding of the nervous system.

AQA GCSE Physics

P3.1.4 The eye

a) The structure of the eye

The structure of the eye is limited to:

- Retina
- Lens
- Cornea
- Pupil/iris
- Ciliary muscle
- Suspensory ligaments

b) Correction of vision using convex and concave lenses to produce an image on the retina:

- long sight, caused by the eyeball being too short, or the eye lens being unable to focus.
- short sight, caused by the eyeball being too long, or the eye lens being unable to focus.

c) Range of vision. The eye can focus on objects between the near point and the far point.

d) Comparison between the structure of the eye and the camera.

e) The power of a lens is given by: P =1/f

Additional guidance

Candidates should know the function of these named parts.

Candidates should understand how the action of the ciliary muscle causes changes in the shape of the lens, which allows the light to be focused at varying distances.

Candidates should know that the near point is approximately 25 cm and the far point is infinity.

Candidates should be aware that the film in a camera or the charge-coupled devices (CCDs) in a digital camera is the equivalent of the retina in the eye.

Candidates should know that the power of a converging lens is positive and the power of a diverging lens is negative.

P is power in dioptres, D

f is focal length in metres, m

Edexcel GCSE physics

Topic 1 Radiation in treatment and medicine

1.10 Identify the following features in a diagram of the eye – cornea, iris, pupil, lens, retina, ciliary muscles.

1.11 Demonstrate an understanding that light is focused on the retina by the action of the lens and cornea.

1.12 Recall that the average adult human eye has a near point at about 25 cm and a far point at infinity.

1.13 Explain the symptoms and causes of short sight and long sight (students will not be expected to draw scaled ray diagrams, but may be expected to interpret them).

1.14 Compare and contrast treatments for short sight and long sight, including the use of:

a) Simple lenses.

b) Contact lenses.

c) Laser correction.

(Combined lens equation is not required; students will not be expected to draw scaled ray diagrams, but may be expected to interpret them.)

Unit P1: Universal physics

Topic 2 The electromagnetic spectrum

2.6 Relate the harmful effects, to life, of excessive exposure to the frequency of the electromagneticradiation, including:

c) Ultraviolet: damage to surface cells and eyes, leading to skin cancer and eye conditions.

OCR GCSE

Gateway Science Suite Biology B
B1: Understanding Organisms Item B1d: The nervous system

Summary

Our bodies have to respond to changes that happen both inside and outside the body. The nervous system plays a major part in this. This item provides the opportunity to collect and analyse primary scientific data when investigating density of nerve endings in different skin areas and secondary data when researching reaction times in races. Theories and ideas can be tested in the investigation of binocular vision.

Suggested practical and research activities to select from

Assessable learning outcomes

Foundation Tier only: low demand

Carry out an experiment to test ranges of vision using cardboard marked out in degrees or moving outstretched arms forward.

Demonstrate binocular vision by bringing pencil points together at arm's length using one then two eyes.

Describe how animals detect changes in their environment (stimuli) using receptors which generatenerve impulses.

Name and locate the main parts of the eye: cornea, iris, pupil, lens, retina, optic nerve and blind spot.

Investigate why some animals have binocular vision and others do not.

Explain the advantages and disadvantages of:

- Monocular vision: wider field of view but poorer judgement of distance.
- Binocular vision: narrower field of view but better judgement of distance.

Carry out a survey on eye defects (candidates wearing glasses/contact lens) or use second-hand data, in class or year group.

Use colour vision deficiency charts.

Describe the main problems in vision limited to long sight, short sight and red-green colour blindness.

Twenty first century science suite – Science A, Biology A

Opportunities for practical work
3.3.2 Module B2: Keeping healthy
3.5.1 Module B7: Further biology

Scotland: Curriculum for Excellence - Science

Body systems and cells

Learners ... develop informed views on the moral and ethical implications of controversial biological procedures.

Topical science

By considering current issues of science, learners increasingly develop their understanding of scientific concepts and their capacity to form informed social, moral and ethical views. They reflect upon and critically evaluate media portrayal of scientific findings.

Curriculum Links

Teacher

A-Level

AQA Biology

3.5 Unit 5 BIOL5 Control in cells and in organisms

3.5.1 Stimuli, both internal and external, are detected and lead to a response.

Receptors

Differences in sensitivity and visual acuity as explained by differences in the distribution of rods and cones and the connections they make in the optic nerve.

AQA Human Biology

3.4 Unit 4 HBIO4 Bodies and cells in and out of control
3.4.5 Drugs can affect how we perceive the world around us.

Detecting light – the eye

The structure of a human eye and its transmissive and refractive properties in focusing an image on the retina. The role of rod cells and cone cells in effecting monochromatic and trichromatic vision.

The absorption of light by rhodopsin causes a chemical change leading to the creation of a generator potential. Details of hyperpolarisation are not required. The connections between sensory cells and the neurones of the optic nerve which allow sensitivity and acuity of vision.

Perceiving – the brain

Nerve pathways from eye to brain (optic nerve, optic chiasma, lateral geniculate nucleus, visual cortex) used to illustrate lateralisation and localisation of function in the brain. Visual perception by the brain. A brief outline of 'top down' and 'bottom up' theories of visual perception

OCR AS/A Level Science

G641 Module 1: 1.1 Sensing the Environment using Electromagnetic Radiation

Remote sensing provides information about the environment to scientists. The interpretation of satellite images and other remotely sensed data is contrasted with the way the human visual system operates.

Context and exemplification

1.1.1 Emission and detection of visible and non-visible radiation; the electromagnetic spectrum:

- For example, observations of water surface waves showing reflection and refraction at plane interfaces, obstacles and gaps in barriers.
- Comparison of the health hazards of different types of radiation.

Assessable learning outcomes

Candidates should be able to:

a) Describe and explain features of wave behaviour:

- Diffraction
- Reflection
- Refraction

b) Use wave and ray diagrams to show the behaviour of light during diffraction, reflection and refraction.

d) Recall that white light is composed of a range of wavelengths of radiation.

e) Describe the nature of the receptor cells in the eye:

- Rods and cones
- The different response curves of the cone cells
- The perception of colour produced by the signals from these cells

i) Describe examples of the transfer of energy by electromagnetic radiation from a source to an absorber:

- Energy transfer from the Sun, through the vacuum of space
- Absorption by pigments such as chlorophyll
- Emission and absorption by the human body

j) Describe how light received by eyes and cameras is affected by reflection, refraction, diffraction and scattering, and the consequences for the resulting image.

k) Assess the effect of these processes on the interpretation of the received image.

l) Compare the ways in which different types of electromagnetic radiation may interact with the human body:

- Ultraviolet (absorption by the skin and resultant cell damage)
- Visible (sensed by the eye)

1.1.2 Interpreting space and satellite images

Candidates should be able to:

e) Interpret data on the sensitivities (frequency ranges, intensity ranges) of different detectors to electromagnetic radiation.

- The human eye.

OCR Human Biology

Module 2: The Nervous System

In this module, the structure and function of the human nervous system is studied. The eye is used as an example of a sensory receptor and the roles of eye test and reflexes in diagnosing problems with the eye and nervous system are considered.

5.2.1 Monitoring Visual Function Context and exemplification

- The eye is used as an example of one of the many ways in which external stimuli are detected
- Health professionals can use eye responses to indicate levels of consciousness.

Assessable learning outcomes. Candidates should be able to:

a) Outline the organisation of the central nervous system and peripheral nervous system.
b) Describe, with the aid of diagrams and photographs, the structure of the eye and outline the functions of its parts.
c) Describe, with the aid of diagrams and electron micrographs, the structure of the retina (including rods, cones, bipolar cells and ganglion cells).
d) Describe, with the aid of diagrams, how a sensory receptor converts a stimulus into nerve impulses with reference to the rod cell in the retina.
e) Outline assessment of receptor activity through routine eye tests (with reference to visual acuity, colour vision and response of pupil).
f) Outline the use of blink/iris reflex tests to indicate levels of consciousness.

AQA Applied Science

A2 Unit 9: Sports Science

18.3 You need to know, understand and be able to demonstrate: occupations involving the application of science to sport.

OCR Applied Science

3.7 AS Unit G626: The physics of sport
3.7.2 Physics of the Body

Candidates' evidence will include:
II A 'Seeing in Sport' leaflet which will include the structure of the eye and how it forms an image, related to one chosen sport where good vision is of critical importance. The eyes provide much of the information used by sportsmen and women during their performance. Candidates need to examine the physical principles involved in the eye.

Candidates need to:

- Know the basic anatomy of the eye:
  - cornea
  - iris
  - ciliary muscles
  - lens
  - aqueous and vitreous humour
  - retina
  - rods and cones
  - optic nerve
- Describe the formation of a real image with a + lens and relate this to the eye.
- Describe the optical function of each of the parts of the eye listed above.
- Describe the effects of colour filters on white/day/flood light and explain how the use of coloured contact/spectacle lenses may help sports players, e.g. tennis, aviation.
- Describe how eye defects can be corrected with the use of lenses and perform calculations to determine the focal length of such lenses.

Links and Further Resources

Teacher

Scottish Primate Research Group (SPRG) field station and research centre
www.living-links.org

Seeing Colour – with 'colour blind' monkey vision simulations! Living Links Video
www.youtube.com/watch?v=yRQ17WUBrIg

Photoreceptor contraction video
www.youtube.com/watch?v=eM20d89GBYc

CLEAPSS Guide L245
Ourselves (September 2005)

CLEAPSS Guidance MRAB 1A
Health issues related to dissecting animals/animal organs

Sections 14.6 and 14.7 of the CLEAPSS laboratory handbook

Section 11.9.3 of the CLEAPSS laboratory handbook provides guidance on UV radiation.

Eye dissection videos
www.exploratorium.edu/learning_studio/cow_eye/step01.html

Further Reading

Teacher

Sheep eye dissection tutorial and a variety of worksheets
science.jburroughs.org/resources/skeleton/eye/eyetitle.html

Modelling LASIK in a school laboratory
Away from 'cookbook' experiments, Siu Ling Wong, School Science Review, March 2004, 85(312), 57–61.

There's more to light than meets the eye
Harlen, W., 2000, Primary Science Review, 64, 20–22.

Gene therapy used to successfully treat color blindness in adult monkeys
www.washington.edu/news/2009/09/15/gene-therapy-used-to-successfully-treat-color-blindness-in-adult-monkeys/

In human lenses transparency has been observed not to decrease for up to seven weeks post-mortem
www.ncbi.nlm.nih.gov/pubmed/6852143

Understanding Animal Research Teachers Zone
www.understandinganimalresearch.org.uk/teacherszone/

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Acknowledgments: Russell Foster, Shelby Temple, Roger Hardie, Hannah Buchanan-Smith, Glen Jeffery, Roy Bongaerts, Lizzie Thursby.

Design: Creative Sponge, www.creativesponge.co.uk

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