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Class: 36211 Perception & Cognition  
Title of Coursework: What is the basis of our ability  
to perceive either colour or  
form?  
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I affirm that this essay is my own work, and does not  
include any unacknowledged material taken from  
another source.

Signed:

Date:

Colour can be defined as 'the property of objects that depends on the light that they reflect' (Encarta, 2003). This essay will examine the basis of our ability to perceive colour, covering the nature of colour as an aspect of light, theories of the way in which human eyes separate the colours within visible light, and the way in which our eyes and brains manipulate that perceived colour to obtain information about our environment.

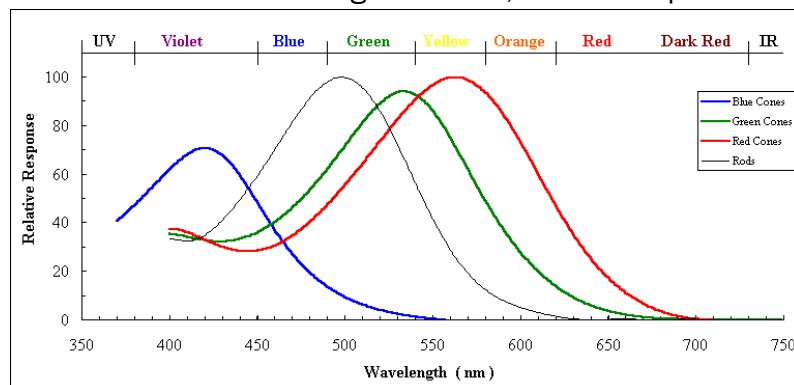
James Clerk Maxwell, a Scots physicist and mathematician of the nineteenth century, attempted to mathematically formalise the relationship between electricity and magnetism as proposed by his predecessor Michael Faraday. In doing so, he found that a whole range of energies were so related, not least of which was visible light (Bodanis, 2000). Light occupies a very small portion of Maxwell's electromagnetic spectrum, between approximately  $4$  and  $7 \times 10^{-11}$  metres (Encarta, 2003).

Daylight, or any 'white' light, is made up of a mixture of frequencies of electromagnetic radiation. We see these frequencies as colours. Isaac Newton's seven colours of the rainbow: red; orange; yellow; green; blue; indigo; violet, correspond to different wavelengths of light, red having the longest wavelength and violet the shortest. In fact, the colours of the rainbow, or colours produced by experimental refraction of daylight, blend into one another with no distinct boundaries (Encarta, 2003).<sup>1</sup>

Perception can be defined as 'any of the neurological processes of acquiring and mentally interpreting information from the senses' (Encarta, 2003). The acquisition of sensory information about colour starts with the eyes, in the retina and proceeds to the brain.

The retinas of human eyes have two types of light-sensitive cells: rod cells and cone cells, which are sensitive to narrow ranges of frequency. Rod cells are fairly evenly distributed across the retina, and are sensitive to low levels of light, but because they do not discriminate between different frequencies, they do not 'see in colour' (Bruce, Green & Georgeson, 1996).

Cone cells are distributed mainly around the centre of the retina, in particular an area called the fovea which is entirely cones and no rods. Cones cells are not as sensitive to low levels of light as rods, but do respond to three different, narrow



wavelengths: three different wavelengths of light (see figure 1), (Bruce, Green & Georgeson, 1996).

Figure 1. Cone cell sensitivities (University of New Mexico, 2004)

<sup>1</sup> Newton was a both a religious man and a believer in numerology. It has been argued that he actually counted six colours in the spectrum, but that the number six has malign implications to numerologists, unlike seven, the number of days in the week and a significant number in Judeo-Christian religion, so Newton included indigo, a very exotic colour for the time (Westfall, 1983).

What humans call visible light is an anthropocentric concept, based on the capabilities of human eyes. Pit vipers can 'see' infra-red images (although they have to use separate sensory organs – the lenses of their eyes are opaque to infra-red radiation), and the eyes of some insects and birds have cells which are sensitive to ultra-violet (Bruce, Green & Georgeson, 1996). If birds can perceive different levels of reflected ultra-violet, does that mean they can see the bits of skin that sunbathers have missed with their sunblock, in the same way that we can see the different colours of their suntan?

Similarly, other animals have fewer types of cone cells or no cones at all. Table 1 shows colour perception abilities of various animals based on the architecture of their eyes.

Table 1.

<b>Animals</b>	<b>The colours they see</b>
Spiders (jumping spiders)	Ultraviolet and green
Insects (bees)	Ultraviolet, blue and yellow
Crustaceans (crayfish)	blue and red
Cephalopods (octopi and squids)	blue only
Fish	Most just see two colours
Amphibians (frogs)	Most see some colour
Reptiles (snakes)	Some colour and infrared
Birds	Five to seven colours
Mammals (cats)	Two colours but weakly
Mammals (dogs)	Two colours but weakly
Mammals (squirrel)	blues and yellows
Mammals (primates-apes and chimps)	Same as humans
Mammals (African monkeys)	Same as humans
Mammals (South American monkeys)	Can't see red well

Source: Arizona State University (<http://askabiologist.asu.edu/research/seecolor/atable.html>)

The receptor cells in the retina can distinguish between different frequencies of light, but how do the eye and the brain interpret their output? As usual in psychology, there are opposing theories about exactly what happens to information from the eye. Ian E. Gordon writes that 'few psychologists know them all; no teaching department includes more than a small subset in its perception courses' (Gordon, 2001), but this essay will cover the two basic arguments regarding the output of the retina, and the two basic arguments about how the brain interprets it.

The Young-Helmholtz theory states that each colour receptor measures the amount of light of its own particular wavelength, and the relative values produced by each of the three types of receptor are compared or mixed to provide information about the colour of an object (Eysenck & Keane, 2000).

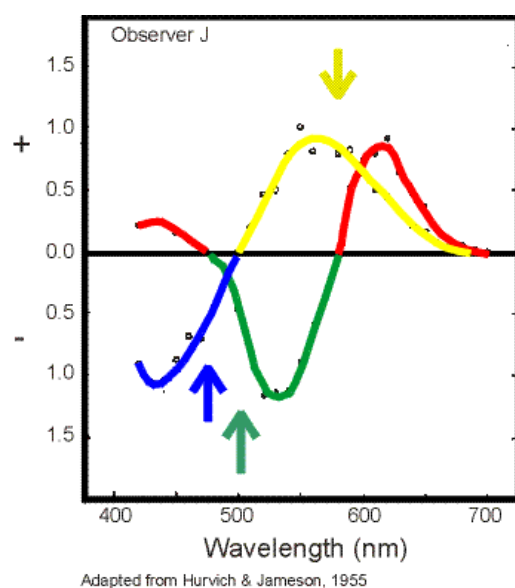
There are problems with this theory. If you look at a coloured square on a computer monitor for thirty seconds and then close your eyes, you will see an image of a square of a different residual colour. This phenomenon is known as an afterimage, and it occurs with blue and yellow, and green and red. The Young-Helmholtz theory does not explain this apparent opposition of colours (see <http://psychology.ucalgary.ca/pace/VA-Lab/colourperceptionweb/theories.htm>).

Another problem with this theory is that microphotospectroscopy has revealed that the sensitivities of the cone cells do not match up with all of the frequencies of the primary colours of light (Gordon, 2001). The colour we see as red has a wavelength of between  $6.2$  and  $7.8 \times 10^{-11}$  metres (US Byte.com). MacNichol (1964) and Dartnall, Bowmaker and Mollon (1983) showed that the peak absorption of long-wavelength cone cells is around  $5.6 \times 10^{-11}$  metres: significantly shorter than the wavelength of red light (Gordon, 2001). This would tend to contradict the Young-Helmholtz theory that we see red light directly with red 'flavoured' cone cells.

According to opponent-process theory, the processing of visual information starts before it leaves the eye: cells which detect differences between adjacent receptor cells are located within the retina itself (Bruce, Green & Georgeson, 1996). Rod cells are compared for differences between dark and light in a concentric circle pattern: is the centre of the circle significantly brighter than the surrounding ring of receptors, or is the centre of the circle significantly darker than the surrounding ring? There are two types of ganglion cells, one triggered by brighter centres, one triggered by brighter surrounding rings (Bruce, Green & Georgeson, 1996).

Cone cells are compared in a similar way for differences between red and green and blue and yellow, again with one ganglion cell triggering 'red centre - green ring', and another triggering 'green centre - red ring' and so on (Bruce, Green & Georgeson, 1996). This is certainly supported by the way colour blindness works: some people are red-green colour blind; others are blue-yellow colour blind. Other ganglion cells compare the output of all three types of cone cell to produce an achromatic, or light and dark, channel. De Valois & De Valois (1975) found physiological evidence in monkeys to support the existence of these opponent cells (Eysenck & Keane, 2000).

There are also problems with this theory. If the retina does nothing but distinguish red from green, blue from yellow and light from dark, our colour vision would resemble a broken Windows computer that will only run in sixteen colours. There must be more subtle distinctions being made.



Hurvich (1981) argues that the colour perception process is in fact a synthesis of both the above theories. If the receptor cells for different frequencies are feeding both excitatory and inhibitory signals to opponent cells, the difference between the output of the red-green opponent cells and the blue-yellow opponent cells can produce a more accurate representation of colour, whilst the combined output of all the cones feeds an achromatic channel with luminance, or brightness, information (Eysenck & Keane, 2000).

Figure 2: The Chromatic valence curves of human colour vision (York University, 2004).

Figure 2 shows the comparative outputs from the blue-yellow and red-green opponent cells to the spectrum of visible light. The two valences obtained for any given frequency are almost like map coordinates; unique to that position. This theory satisfies the way we can see a large variety of colours, but also how after-images occur.

The big issue in visual perception in general, not specifically in relation to colour, is between empiricism and nativism. Empiricism argues that our senses report raw data which our intellect then has to assemble into meaningful constructs. Nativists argue that our perception is directly driven by objects, and that no abstraction is necessary.

Empiricism is grounded in the origins of modern science, in thinkers like Locke and Kant, with concepts like the *tabula rasa* mind, and the *a priori* object that exists only in the mind. The empirical view would tend to imply a lot of learning to use sensory data, for instance the images projected onto our retinas are upside-down. Does our haptic interaction with objects we see teach us that not only are they objects, but that we need to invert their images to make sense of them? (Gordon, 2001).

James Gibson disagreed. Gibson saw vision as having developed as a tool for identifying food, a means of self-preservation, of identifying a suitable mate, and as such it is direct perception of objects themselves and not deductive reasoning to arrive at an idea of an object (Gibson, 1950). Gibson's background as a military psychologist in World War II showed him that perception is based on the environment and objects in that environment, not just abstractions of objects (Gordon, 2001). Many nativist theories are identified as Gibsonian theories.

Although this argument is more about form than colour, it does have implications for colour. If we see an object of a particular colour, it is different from seeing a pattern of colours from which we deduce an object. This has implications for the theory of colour constancy.

Colour constancy means that we tend to see objects as being the same colour regardless of changes in the lighting. Film makers and photographers are almost obsessed with the colour of ambient and artificial light sources. They measure it on a scale called colour temperature. Incandescent light is generally more yellow than natural light, which tends to be more blue than incandescent.

If you were to follow someone out of a building, out of incandescent light and into natural light, you do not see them disappear only to be replaced by someone similar, only of a different colour. The change in colour of the same person is accommodated quite naturally by the brain (Eysenck & Keane, 2000).

This phenomenon even extends to objects which are actually the same colour, they are just lit differently. In Land's (1977) experiment with two coloured 'Mondrian' pictures which were lit differently, one coloured panel of each picture was actually reflecting the same colour wavelengths as the other. Until the rest of both pictures were masked off, the participants saw the two panels as different colours. In isolation, the two panels looked the same (Eysenck & Keane, 2000).

If Gibson was correct, then the opponent-process theory takes on a new light. The directly-perceiving eye is looking for objects, for forms, and they tend to have edges, outlines, different colours from their environment. The opponent-process cells are set up to notice changes within the centre of the field of vision, where green changes to red, or light to dark, where the edge of an object lies rather than the gradual change in colour due to a texture gradient, like the ground or the sky.

The area of the brain which seems to start the processing of colour information is part of the cortex known as V4. The information about colour from this area of the brain complements the rest of the visual stimuli: motion; depth; position, to give us a more complete view of our environment than animals with less complex eyes (Kolb & Whishaw, 2003). Area V4 has been compared to a mail room or railway marshalling yard, where information is sorted and organised for its onward journey.

Engel, Koenig & Kreiter (1992) theorised that colour information from area V4, along with information about form and motion from the other visual centres (Kolb & Whishaw, 2003) is married together through synchronised bursts of visual information, known as oscillation-binding theory (Eysenck & Keane, 2000). Tovée (1996) disputes this, saying that there is less of a problem with binding information together since most of it comes from the cone cells in the fovea anyway, with the rest of the visual field being 'filled in' by a higher mental function (Eysenck & Keane, 2000).

This essay has examined the basis of our ability to perceive colour. It seems most likely that a synthesis of the Young-Helmholtz and opponent-process theories, as proposed by Hurvich, is an accurate description of the way the retina collects colour information and, at least as far as colour is concerned, the Gibsonian model of direct perception best supports phenomena like colour constancy, and may even help to explain the basis of opponent-process theory. Although less is known about the brain processes surrounding colour perception, there is lively debate about the exact nature of colour perception beyond the eye and occipital lobe.

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