The functional organisation of the visual system

The aim of this essay is to describe the organisation of the visual system in relation to its specific functions. In order to perform essential functions, the visual system is faced with many computational problems needing to be solved in order to maintain effective visual perception. This essay aims to describe one such computational problem the visual system must solve; colour constancy. If light coming down from the sky changes colour, the perceived colour of objects should also change, however this is not the case. The nervous system is highly involved in the process of maintaining effective colour constancy and this essay aims to look into how colour constancy is achieved in the nervous system. The first part of this essay will outline the functional organisation of the visual system, focusing on the general anatomical organisation, the retina, lateral geniculate nucleus (LGN), organisation of the cortex and parallel and hierarchal processing. Focus will then be on the chosen computational problem of colour constancy and the importance of the visual system maintaining successful constancy of colour. The next issue will be to assess how colour constancy is achieved within the human nervous system, focusing on the functional specialisation of the cortex, cone receptors and retinal involvement in attempt to understand how colour constancy is maintained in the nervous system.

The visual system is part of the central nervous system and includes the eyes, connecting pathways to the visual cortex and different parts of the brain that collectively allow for sight. The visual system must convert patterns of light that fall onto the retina into perception. Initial visual processing takes place within the retina, with the preliminary aim to convert information about luminance into information about contrast (Kuffler, 1953).

All in all the visual system works by the rule of relative qualities, i. e the luminance of an object in relation the luminance of its surrounds. These relative qualities and comparisons take place within the retina.

The retina contains two kinds of photoreceptors (rods and cones) that absorb light and send signals to bipolar cells, which are connected to ganglion cells that send information to the LGN. The LGN has six layers; four parvo-cellular layers and two magno-cellular layers. Ventral to each of these layers is a thin kinocellular layer. Parvo-cellular cells and kinocellular cells play a role in colour vision. Therefore, initial colour vision takes place within the retina, with cone photoreceptors being specialised for colour processing. It has been found that there are three types of cone receptors within the retina which are sensitive to different wavelengths of light; short wave length light (blue light), medium wavelength light (green light) and long wavelength light (red light). Colour detection is perceived largely by the relative activation of the short, medium and long wavelength cones. The trichromatic theory of colour vision proposed by Young-Helmholtz (1800/1867) is a predominant theory into colour perception. Cone cell receptors contain light-sensitive photo pigments which allow them to respond to light and create colour vision. Young-Helmholtz theory proposed that we have one cone type most sensitive to short wavelength light (blue), one most sensitive to medium wavelength light (yellow/green) and finally one most sensitive to long wavelength light (red). It is the relative activation of each cone type that results in the perception of colour. Another dominant theory into colour processing has come from Hering’s (1878) opponent processing theory. Hering argued that there are three types of opponent processes within the

visual system that account for colour perception. One opponent process results in the perception of red at one extreme and green at the other extreme. Another type results in perception of yellow at one extreme and blue at the other. The final opponent process results in perception of black at one extreme and white at the other. Hering argued that it is the ratio of activation along these opponent processes that accounts for colour perception.

Opponent cells have been found within the LGN, which provides functional evidence for the involvement of the LGN in colour vision. There are red/green colour coded cells and yellow/blue colour coded cells within the LGN which are essential for colour processing and colour constancy. However in essence the function of the LGN is to pass signals from the retina to the cortex rather than to process them.

Another important functional part of the visual system is the visual cortex, which contains cells that respond to wavelengths coming from an object in relation or comparison to wavelengths coming from surrounding objects. This comparison is essential in the analysis of colour. The visual cortex contains many layers of cells, with colour, form, movement and disparity being dealt with by separate groups of cells. It is divided into sub-layers; IVA, IVB, IVCÎ± and IVCÎ². Cells in the parvo-cellular layers of the LGN, dealing with colour, project to layers IVCÎ² and IVA, thus showing the functional organisation of the cortex.

In the secondary visual cortex (V2), cells dealing with colour, form and disparity are also kept separate. V2 processes properties such as colour and

brightness. V4 deals particularly with colour and form. The visual cortex is organised into a columnar form. The similar properties of the cells within the cortical column are most likely due to the arrangement of anatomical connections. There have been found to be columns dominant for colour and orientation of edges. According to Zeki (1977) within area V4 there are separate columns for red, green and blue perception. Thus showing the visual cortex is organised on the basis of functions.

One factor that has been made clear is that different features of a visual stimulus are dealt with in parallel processes within the visual system. The features of colour are kept separate through at least three levels of processing; V1, V2 and V4. However it has been found that within these parallel processes, hierarchal processing occurs. Dew (1984), has provided clear evidence for a hierarchy of cells types within the colour system. Photoreceptors join onto opponent colour cells which respond to some wavelengths and not to others.

The visual system is functionally organised to overcome many computational problems, one of which is colour constancy. Colour constancy is a “ tendency for a surface or object to appear to have the same colour when there is a change in wavelength contained in the illuminant.” (Eysenk, 5th edition). The phenomenon of colour constancy indicates that colour vision does not depend only on the wave length of reflected light. The problem involved in colour constancy is to assign colour to a scene in the ambient light (spectral reflectance) (Maloney, 1985). Spectral reflectance is the percentage of light at each wavelength a specific surface reflects. As the illuminant power varies, the light reaching the eye also varies. However the percentage of

light a surface reflects (due to its physical properties) does not change. The function of colour constancy is to discount the illuminant and recover information about surface spectral reflectance. Marr (1982) claimed that there must be an extra level of perception and processing. Light is reflected off objects with a fixed percentage of energy at each wavelength (surface spectral reflectance) and some of it enters the eye of the observer where is it selectively absorbed by cone receptors.

The maintenance of colour constancy is achieved in the nervous system in various ways. The functional specialisation of the cortex is one way in which colour constancy is achieved. Zeki (1992, 1993) argued that different parts of the cortex have different and specialised functions. V1 and V2 have been found to have inputs in early stages of visual perception. Both cortical areas contain specialised cells responsive to colour and form which process these properties and relay signals to specialised visual areas, (Zeki, 1992, p47). V3 and V3A have been found to be responsive to form and shape but have no input in colour processing. V4 however has been found to be responsive to colour and combines connections from temporal and parietal cortex, (Baizer, Underleider and Desimone, 1991). Zeki’s critical assumption was that colour and motion are processed in anatomically distinct parts of the visual cortex. Lueck et al (1989) have provided supporting experimental evidence of the anatomically distinct processing of colour. They presented coloured or grey squares to observers. PET scans showed 13% more blood flow within area V4 when presented with coloured stimuli, other areas were found to be unaffected. On the other hand Wade, Bewer, Rieger and Wandell (2002) used FMRI and found areas V1 and V2 were also actively involved in colour

perception. Zeki (1983) has provided evidence for the involvement of V4 in promoting colour constancy. Zeki found that within monkeys, certain cells in area V4 responded strongly to a red patch in a multicoloured display illuminated predominantly by red light. These cells did not respond when the red patch was replaced by green, white or blue patches, even though the dominant reflected wavelength was red. Therefore these cells respond to the actual colour rather than the wavelength reflected from it and has a role in the process of colour constancy. Lesions in area V4 have been found to impair colour constancy while other aspects of colour vision are unaffected, (Heywood and Cowey 1999). The cortical area of V4 has argued to be able to distinguish differences between surface colour and colour of the illuminant thus being important in achieving colour constancy.

Land (1977) retinex theory argues that both the retina and the cortex are involved in visual processing. The basic assumption of this theory is that we decide the colour of a surface by comparing its ability to reflect short, medium and long wavelengths against adjacent surfaces. When comparisons cannot be made, colour constancy does not occur. The three types of photoreceptors in the retina absorb light; each level of activation within each cone receptor is compared to that of others. Kraft and Brainard (1999) conducted a visual experiment in a box which included a tube wrapped in tin foil, a pyramid and a cube as well as a Mondrian stimulus. When all objects were visible, colour constancy was high (83%), even with changes in illumination. Progressively removing the cues decreased colour constancy. The most important factor in maintaining colour constancy was local contrast, involving the comparison of retinal cone responses from the target

surface with that of the immediate background. Colour constancy dropped to 53% when local contrast information was not available. Also global contrast was important; the retinal cone responses from the target surface are compared to the cone responses of the whole visual scene. When observers could not use global contrast colour constancy dropped from 53% to 39%. This therefore indicates that we need to know about lots of different stimuli in the visual scene if we are to calculate what the illuminant is like, discount it and achieve colour constancy.

Photoreceptors have therefore been shown to be heavily involved in colour constancy which provides evidence for the involvement of the nervous system. Young-Helmholtz (1800/1867) trichromatic theory of colour vision and Hering's (1878) opponent process theory outlined previously in this essay provide evidence that photoreceptor cone cells within the retina are heavily involved in colour perception and constancy. Shepard (1990) stated that the trichromacy of human colour vision is a reflection of the three phases of natural light/illumination; light-dark light, red-green light (low sun) and yellow-blue light (poor illumination and sky light). To achieve colour constancy on the basis of their surface reflectance's, the visual system must discount perceptually for the three types of variation in illumination. Shepard (1990) and Maloney and Wandell (1986) argued that trichromacy of the visual system allows for colour constancy.

In conclusion it has been shown that the visual system is highly organised on a functional basis. The visual system is faced with many computational problems which it must solve. Evidence that functional specialisation of

cortical areas, cone receptors and the retina are methods for which the nervous system uses to overcome the problem of colour constancy.

Word Count: 1992.

Baizer, Ungerkeider and Desimone, (1991). In Eysenck M. And Keane M (5th edition). Cognitive Psychology, (pp. 38). Psychology Press.

Carlson, (7th edition). Physiology of Behaviour. pp184-186. Pearson Education Company.

Daw, (1984). The psychology and physiology of colour vision. Trends in Neurosciences. Pp 330-336.

E. Thompson (first edition). Colour Vision. A study in Cognitive Science and the Philosophy of Perception. (pp80-105). New York: Routledge

Eysenck M. & Keane M (2005). Cognitive Psychology, 5th edition p. 33-54. Psychology Press.

Eysenck M. And Keane M. Cognitive Psychology, 5th edition p. 49. Psychology Press.

Gross, R, (2005) Psychology the science of mind and behaviour, (5th edition) p. 89-91. Hodder Arnold.

Hering (1878). In Eysenck M. And Keane M (5th edition). Cognitive Psychology. pp 50. Psychology Press.

Hering (1878). In Gross, R, Psychology the science of mind and behaviour, 5th edition p. 89

Heywood and Cowey, (1999). In Eysenck M. And Keane M (5th edition). Cognitive

Psychology, pp. 53. Psychology Press.

Kraft and Brainard, (1999). In Eysenck M. And Keane M (5th edition). Cognitive Psychology, (pp. 53). Psychology Press.

Kuffler, S. W. (1953). Discharge patterns and functional organisation of mammalian retina. Journal of Neuropsychology, 16, pp37-68.

Land (1977). In Thompson. E, (first edition). Colour Vision. A study in Cognitive Science and the Philosophy of Perception. (pp81-90). New York: Routledge.

Land, (1977, 1982). In E. Thompson (first edition). Colour Vision. A study in Cognitive Science and the Philosophy of Perception. (pp81-86). New York: Routledge.

Land (1977). In Eysenck M. And Keane M (5th edition). Cognitive Psychology, (pp. 52-53). Psychology Press.

Luek et al. (1989). In Eysenck M. And Keane M (5th edition). Cognitive Psychology, (pp 39). Psychology Press.

Maloney, (1985). In E. Thompson (first edition). Colour Vision. A study in Cognitive Science and the Philosophy of Perception. pp43. New York: Routledge.

Maloney, (1985). In Thompson. E, (first edition). Colour Vision. A study in Cognitive Science

and the Philosophy of Perception. pp81. New York: Routledge.

Maloney and Wandell (1986), In Thompson. E, (first edition). Colour Vision. A study in Cognitive Science and the Philosophy of Perception. pp194-195. New York: Routledge.

Marr, (1982). In E. Thompson (first edition). Colour Vision. A study in Cognitive Science and the Philosophy of Perception. (pp42) New York: Routledge.

Shepard, (1990). In Thompson. E, (first edition). Colour Vision. A study in Cognitive Science and the Philosophy of Perception. (pp190-195). New York: Routledge.

Snowden, Thompson and Troscianko, (2006). Basic Vision, an introduction to visual perception. (pp159-163). Oxford: University Press.

Wade, Brewer, Rieger and Wandell, (2002). In Eysenck M. And Keane M (5th edition). Cognitive Psychology, (pp 39). Psychology Press.

West, G. (1979). Colour Perception and Limits of Colour Constancy. Journal of Mathematical Biology. 8, 47-53.

Young-Helmholtz (1800/1867). In Gross, R, (2005). Psychology the science of mind and behaviour, 5th edition p. 90. Hodder Arnold.

Zeki (1992, 1993). In Eysenck M. And Keane M (5th edition). Cognitive Psychology, pp. 37-42. Psychology Press.

Zeki (1983). In Eysenck M. And Keane M (5th edition). Cognitive Psychology, pp. 53. Psychology Press.

Zeki, (1977). Colour Coding in the Superior temporal sulcus of the rhesus monkey visual

cortex. Proceeding of the Royal Society of London. Series B. Biological Sciences. Pp195-223.