Vision Questions

1) When fixating just to the side of a star, it looks brighter than when it is fixated directly. This phenomenon is known as 'averted vision' (Barrett, 1977). When looking directly at the star, the light from it that enters the eye focuses on the fovea, at what is considered 0 degrees of retinal eccentricity. When fixating to the side of the star, the light from it enters the eye at a slightly different angle and focuses on the retina with some eccentricity, which is to say that it focuses to the side of the fovea. The fovea is adapted for high visual acuity colour vision, meaning that it has a high density of almost exclusively cone receptors (up to 180,000 cones mm^{-2}, no rods in the foveola), whereas when considering parts of the retina that are slightly to the side (nasal) of the fovea, the number of cones drops dramatically, and instead there are many more rod receptors (~3,000 cones mm^{-2}, ~70,000 rods mm^{-2}) (Jonas, Schneider and Naumann, 1992; Purves et al., 2004: 244). Rod receptors provide monochromatic information and function to detecting differing levels of brightness. Rods are approximately 100 times more sensitive to light individually than cones, and this increased sensitivity is compounded by the convergence of many rods onto rod bipolar cells and bipolar cells to amacrine cells, compared to cones, which contact a single midget ganglion cell. This, for rods, increases perceived brightness/sensitivity at the expense of visual acuity (Purves et al., 2004: 242-244).
As a result, looking slightly to the side of the star means that light is focused onto primarily rods rather than cones, which have increased sensitivity to the light. This is amplified by the convergence of multiple rods and rod bipolar cells, which ultimately results in the star looking brighter than when fixated directly.

2) In a rural setting, many more stars are visible than compared to an urban environment, they also appear brighter. The main reason behind this is that cities tend to have both more pollution and more light pollution than rural environments. Pollution, in the form of gas and dust emitted by cars and industrial processes among other things, acts as a partial barrier in between the stars and observers on Earth. It reflects some of the light from the star so that it does not reach the observer, effectively lowering the star's luminance. Light pollution affects the visibility in a different way that interacts with existing particulate pollution: the light from buildings and streetlights etc is reflected by particles in the environment, the amount reflected increasing with more pollution. This reflection of light makes the night sky effectively brighter for observers in cities than in rural areas. The stars must be brighter than the background by a certain threshold in order to be seen, as otherwise they are lost in the 'noise', and so fewer stars are visible in cities than away from them. This threshold is controlled by dark adaptation, and even very low levels of background illuminance cause cause photopigment bleaching, which raises the relative threshold required for discrimination (Normann and Werblin, 1974; Plainis, Murray and Charman, 2005).
Pollution lowers the effective brightness of the stars, while light pollution raises the background luminance and reduces observers' dark adaptation and thus increases the threshold.

3) When looking in a mirror and looking from one eye to the other, one does not see the movement of the eyes. Saccadic suppression appears to be the main factor involved in this. Saccadic suppression is the inhibition of visual information during and shortly preceding the rapid jumps between optical fixations known as saccades, wherein it is assumed the world is approximately stationary unless there is a sufficient stimulus at the end of the saccade to suggest otherwise (Deubel, Schneider and Bridgeman, 1996). As such, the greatest suppression occurs when the angular movement of the stimulus is less than 3 times that of the eye (Bridgeman, Hendry and

Stark, 1975). The mechanism behind this appears to be primarily neural rather than optical (Riggs, Merton and Morton, 1974), with the efferent signal to move the eyes acting as a trigger (Yarrow et al., 2004) for inhibiting activity in the superficial layers of the superior colliculus (which receives visual signals from the eyes) via GABAergic neurons in the intermediate premotor layer (Phongphanphanee et al., 2011).

From looking at one eye in the mirror, one's eyes change to fixating on the other in one saccade, during which time the activity of the neurons in the superficial layer of the superior colliculus have their activity mediated by those in the intermediate premotor layer, such that visual movements less than 3 times the angular movement of the eyes are suppressed. As the apparent movement in the mirror is less than this, and there are no sudden, major changes in the visual world during the saccade, the eyes are not seen to move.

4)   When looking in the mirror at one eye, immediately after closing the other (CE), the first eye's (OE) pupil can be seen to dilate. After a minute, opening CE results in OE's pupil constricting, while the CE has a dilated eye. Looking through CE results temporarily in a brighter-looking world than when looking through OE. Perceived brightness is negligibly different when a stimulus is viewed monocularly rather than binocularly (Stevens, 1967) and so, as the internal representation of brightness is binocularly summative (Blake, Sloane and Fox, 1981), brightness must be compensated for when viewed monocularly. This compensation occurs optically in part, as is visible from the dilated pupil. There is also what Gibson (1937) describes as an adaptation with negative after-effect: the now-raised apparent brightness tends towards the neutral, as demonstrated both in vivo (Valeton and van Norren, 1983) and in vitro (Hood and Birch, 1993a, 1993b), via a multiplicative gain reduction, response compression, and, at high illumination levels, photopigment bleaching (Lennie, 2003: 229). When CE is uncovered and the adaptation is no longer necessary, the pupil constricts, less light enters OE and the brightness level appears lower. CE receives more light when opened, and so for the remaining time that it is dark adapted with a dilated pupil, the world appears brighter. Closing one eye causes both to dark adapt by dilating the pupil, as the light entering CE nears 0, and the light entering OE (before adaptation) is half of the brightness of the binocular view. Once adapted, OE maintains the apparent brightness of binocular view, however the photosensors 'normalise' (Howard, 2002:85, 126) to a dimmer state, thus, when CE opens, it both lets in more light and senses it more strongly than the 'adapted' and smaller-pupilled OE.

5) Threading a needle while looking at an angle perpendicular to the thread is much more difficult with one eye open than with two. This is in large part because more, and more powerful, depth cues are available with two eyes open than with one, particularly considering the distance from the eyes at which one threads a needle, and the small size of the target hole. The primary monocular cues involved are the retinal image angle (both absolute and relative between the needle and thread); accommodation, detection of the change in power of the eye's lens; and interposition when the threading does not succeed - either the needle or the thread occludes the other. When using both eyes, all of these monocular cues are still available but convergence, the detection of the extent to which the eyes point inwards; and the more powerful binocular disparity, which monitors the difference in retinal angle of stimuli between the two eyes also aid in the perception of depth. While with two eyes the needle eye and thread can be matched in depth accurately and precisely using all of the depth cues available, such that the challenge becomes primarily dexterity-based rather than vision-based; with just one eye, the resolution/threshold of depth is larger than the needle thickness, and so attempts to thread it are effectively guesswork within a certain range.

The following 3 questions have a similar basis in theory, and so some general statements can be made. Each will be further addressed in its own question.

Howard (2002: 84-85, 126) states that a number of sensory modalities have antagonistic/oppositely tuned detectors, such that one fires more when the stimulus is greater, and less when the stimulus is smaller, and the inverse is true for the other detector. As such, a "bipolar sensory continuum" (Howard, 2002:126) is formed, with a central point between the two extremes, where the opposite detectors are firing equally, known as the norm (Howard, 2002: 84). Within these opponent systems, adaptations occur such that the perceived stimulus is brought towards the norm when observed for an extended period of time. Much of this form of automatic gain control is thought to take place for at least some forms of stimulus in the striate cortex (V1) (Hammond, Mouat and Smith, 1985) and the lateral geniculate nucleus (LGN) (for visual signals) by a combination of summation of neural signals/synaptic currents and division by "the pooled activity of a large number of other simple cells" as found/determined by the cell membrane conductance (Carandini and Heeger, 1994). This is similar to a simple averaging function. This "shunting inhibition" (Carandini, Heeger and Movshon, 1997) has the effect of response normalisation, and appears to have the purpose of a calibration or error-correction mechanism (Andrews, 1964). This calibration persists, after the stimulus is removed, for a short period, typically on the scale of one minute, although some effects last much longer. During this time, the visual area that has been recalibrated appears to be showing the opposite of the effect of the stimulus (Howard, 2002: 85).

6) After viewing the spiral stimulus (special4k4 [YouTube], 2010) for over 30 seconds, the checkered pattern shown afterwards appeared to rotate in the middle and contract at the outside, opposite to the motion of the initial spiral. (Howard, 2002:84) states that stationarity is the norm for motion, and so any continuous motion that is fixated upon for an extended period of time will be normalised. Visual signals pass through the LGN and V1 before reaching the middle temporal visual area (MT+/V5 - associated with motion perception) which has been demonstrated in vivo with humans to be "part of the neural network underlying motion adaptation" (Antal et al., 2004). Both this and the waterfall after-effect appear to occur due to the neural adaptation of the opponent mechanisms based on activity in several cortical sites, including V1 and V5+/MT (Anstis, Verstraten and Mather, 1998).

7) a) After looking at the lines tilted up to the left for a minute, the horizontal lines appear to tilt up to right.

b) After looking at the lines tilted with the tops to the left of vertical for 2 minutes with one eye, the vertical lines appear to tilt with the tops to the right of vertical when observed with the other eye.

There appears to be an orientation norm at both horizontal and vertical (Howard, 2002: 84; Morant, and Mistovich, 1960), as the two conditions (a) and (b) counter-rotate towards these respectively. This is corroborated in the literature by Gibson and Radner (1937) and Campbell and Maffei (1971). The fact that the effect in (b) occurred when observing the vertical lines with an eye that had not directly observed the tilted lines (there is a large degree of interocular transfer) suggests that the effect occurs after the signals from the 2 eyes have been merged, which corresponds well with the aforementioned theory that normalisation occurs in the LGN (after the optic chiasm), at least for orientation processes. Similar to before, this and the waterfall

effect are similar in that they both are spatial in nature, and occur from a recalibration towards a norm that leaves the perception afterward of a reversal of the initial stimulus.

8) a)   After fixating on a point within a red circle surrounded by a green ring for approximately a minute, replacement of these stimuli with a blank white screen results in an after-image of a green circle surrounded by a red ring.

b)   After fixating on a point within a blue cross overlaid onto a yellow circle with one eye for a minute, viewing a blank screen with the same eye results in the inverse, a yellow cross on blue circle after-image, however viewing the blank screen with the eye that did not see the stimulus results in no after-image. The after-image was stronger than with red-green stimuli.

The fact that an inverse after-image is formed suggests that there is some normalisation occurring, which Howard (2002:84) suggests occurs on red-green and blue-yellow spectra, where grey is the norm for both. The colours map to short- (blue), medium- (green) and long- (red) wavelength receiving cones (referred to by their colour for clarity), where yellow is formed by the addition of red and green. Because there is no interocular transfer, it seems likely that this adaptation occurs before the images from the two eyes are fused. The literature indeed suggests that a pre-processing stage occurs in which the trichromatic information from the cones is filtered into 4 dimensions in order to create 2 bipolar sensory continua, which are later combined to give full colour representations (Chatterjee and Callaway, 2003). Howard (2002: 126) states that the creation of the opponent system "occurs in the retina to produce ganglion-cell receptive fields with opponent centres and surrounds". Takahashi, Ejima and Akita (1985) the additional strength of yellow-blue adaptation to changes at 2 sites - the cone receptor site and the opponent site - as opposed to just 1 for red-green stimuli - the cone receptor site.

9)   A piece of card was used to cover an asymptomatic emmetrope's left eye, while they fixated on the researcher's left eye, with the distance between eyes being between 30cm and 50cm. After holding this for approximately 30 seconds, the card was moved over to the participant's right eye for another 30 seconds. During the transition the previously covered left eye was observed to move nasally/inwards and its pupil dilated. This inward movement shows the resting position of the eye was slightly exophoric. Covering the eye prevented it from self-correcting its location using the binocular fusion mechanism (Von Noorden, 1996), allowing it to move to a 'neutral' resting position. Sethi (1986) has suggested that this is an oculomotor normalisation adaptation to the convergence required for near fixation similar in concept to the questions above. Literature on the 'cover test' using a similar protocol (Barnard and Thomson, 1995) found a mean exophoria of 1.6 degrees at a fixation distance of 40cm for asymptomatic emmetropes, with the same scale and direction of heterophoria as the participant. The dilation of the pupil likely occurred for a similar reason as in question 4, in that it is compensating for only using one eye by letting more light in. Interestingly, this occurred regardless of whether the covered eye was open or closed - the cover did not occlude a large amount of light, merely interrupt the eye and the intended focal point - it would appear that a controlling factor in pupil size is to which eye the person is attending, rather than simply the intensity of light that enters it.

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