BM-3252 MEDICAL PHYSICS

UNIT-1

1.2 LIMITS OF VISION AND COLOR VISION AN OVERVIEW

Limits of Vision

Visual Acuity

- If the angle between two light rays passing through the optical centre is too small, we will not be able to distinguish between them with respect to location.
- The minimum angle at which resolution is just possible is called the visual angle, and the inverse of the visual angle, measured in minutes of arc, is our visual acuity.
- The most commonly applied test of visual acuity has been the Snellen chart. One version of this chart consists of a series of 11 rows of letters, progressively smaller from the top.
- When it is viewed from a distance of 20 ft the letters on the eighth line are just distinguishable by a person of good vision: the distinguishing characteristics of the letters on this line form a visual angle of 1 min of arc at 20 ft.
- A person with 20/20 vision can read the letters of the eighth line at 20 ft. The lines above the eighth are marked with greater distances, again at which they are just discernible by the person with good vision.
- A person with 20/40 vision can read at 20 ft the line (in fact the fifth) that with good vision is readable at 40 ft.
- Note that the visual acuity expressed as a ratio is dimensionless, and the distances could equally well be expressed in metres or any other unit.
- Many Snellen charts are now marked in metres and 6/6 vision (recorded at 6 m) is the equivalent of 20/20 when measured in feet. There are alternative tests, based for example on patterns of lines or grids of squares.
- The Snellen chart, in particular, is quite crude because some letters are distinguishable just by their general shape, and are therefore easier to read than others.
- Under ideal conditions a person with excellent vision might achieve a visual acuity of two, implying that their visual angle of resolution is 0.5 min.
- For the normal eye the optical centre is about 17 mm in front of the retina, and the cones are 2 μm apart.
- This implies that the maximum visual angle is about 0.4 min, and the upper

bound on visual acuity is 2.5.

- There is an order of magnitude reduction in visual acuity at 10° of arc from the fovea. The brain appears to be able to compensate for this by scanning the scene in front of us and building up a high-resolution image within the brain.

Visual Sensitivity

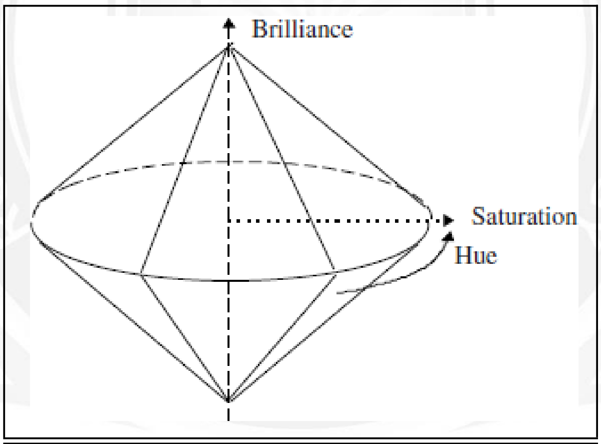
- The rods are much more sensitive than the cones. In terms of luminance, the cones do not function below about 0.001 cd m^{-2}, and our vision is entirely dependent on the rods.
- The optimal sensitivity of the rods is to light at a wavelength of about 510 nm. Hecht directed light at this wavelength at an area of high rod concentration (away from the fovea).
- He demonstrated that, for a number of observers, the average threshold was about 100 photons arriving at the cornea.
- He further calculated that only about 48% of these would arrive at the retina: 4% would be reflected at the cornea, 50% of those remaining would be absorbed in the media within the eye.
- Of the 48% getting through, 20% would be absorbed by the rhodopsin to create a visual stimulus (the remainder would either have been absorbed by the neural components before reaching the photoreceptors or would miss the rods entirely and be absorbed by the black pigment behind). In total then, only about 10% of the light arriving at the retina, or about ten photons, actually generates the visual stimulus.

Color Vision

- Colour is a psychophysical property of light, in that it is associated with visual perception.
- The two attributes of a light wave that governs the perception is its wavelength and the intensity.
- When light is mixed together, the spectral composition of the resulting combination is considered to be important.
- This effectively gives three parameters that is used to describe a colour. The duration of exposure to the light and time of exposure to the stimulus might also be important.
- Putting aside the time element, the remaining three parameters have been represented by Munsell as a double cone.

- The vertical axis represents the intensity of the colour. The circumferential coordinate represents the hue: it is dependent on the wavelength, and is what we would normally think of as the determinant of colour.
- The horizontal axes define the saturation of the colour, and reflect the spectral composition.
- At the outer extreme the light is of only one pure colour, and at the inner extreme all wavelengths are present.
- The vertical axis represents brilliance, which is a property of intensity. At the bottom there is no light, and the colour is black.
- At the top all wavelengths are present at maximum intensity, and the resulting colour is white. All other points on the vertical axis represent shades of grey.

- It is less useful in predicting the outcome of combining different colours. The rules of combination are not simple.



- Pre-dating the Munsell description is the Young–Helmholtz trichromatic theory. Young originally observed that all colours could be made up from three primary ones: his chosen primaries were red, green and blue.
- He postulated that the eye contained three different types of nerve receptor, and that the brain made up composite colours by combination of signals.
- Helmholtz did not initially accept Young's theory, because he was aware that some colours could not apparently be produced from pure monochromatic (single wavelength) primaries.
- He later realized that the receptors might not be 'pure' in that they might have overlapping spectral response curves, and that this could explain the discrepancies in experimental results.

- Essentially the trichromatic theory uses the 'concentration' of three colours as a mathematical basis rather than three parameters such as brilliance, saturation and hue.
- Simple rules for the combination of colours using addition and subtraction can readily be developed on this basis.
- The choice of primaries for a trichromatic combination is arbitrary, and any three 'independent' colours will serve the purpose.
- The Young–Helmholtz theory suggests that we can write any colour, C, of intensity c as a linear sum of the three primaries,

$$cC \equiv rR + gG + bB.$$

- The intensities of the colours (c, r, g and b) can be measured in any standard photometric units, such as lumens.
- The total light flux must be the sum of the components, and so c = r + g + b it turns out that there are some colours that cannot be matched in this way.
- A saturated blue–green is one example of a colour that cannot be produced by a combination of red, green and blue light.
- What is possible, however, is to refocus the red beam so that it falls onto the original blue–green spot, and then to match the resulting colour with a combination of blue and green.

$$cC + rR \equiv gG + bB.$$

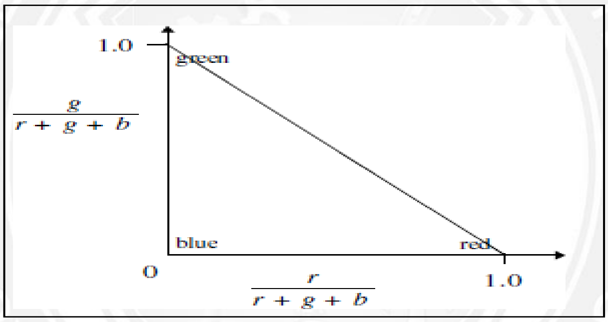
- In principle the two equations are identical, except that we have to accommodate the notion of a negative coefficient of a colour in the trichromatic equation.

Chromaticity diagrams

- Chromaticity diagrams provide a two-dimensional representation of a colour. The parameter that is sacrificed is brightness.
- It is assumed that the basic determinants of colour are the relative intensities of the three chosen primaries.
- It is assumed that one unit of colour is produced by a particular relative mixture of the primaries, irrespective of their absolute magnitudes.
- In this case a relative form of the trichromatic equation can be written;

$$C = \frac{r}{r+g+b}R + \frac{g}{r+g+b}G + \frac{b}{r+g+b}B.$$

- Changing each of the intensities by the same factor will produce the same colour. The three coefficients are not independent: any one of them can be obtained by subtracting the sum of the other two from unity.
- This means that we can choose any pair of the coefficients as the independent variables and represent the colour as a point in a single plane.
- The resulting graph is called a chromaticity diagram. All colours can be represented on this diagram, each occupying a point in the plane.
- We should recognize that some colours will not lie within the triangle shown because negative coefficients would be required to produce them.



- Straight lines on the chromaticity diagram have special properties: all colours on a straight line can be represented as a linear combination of the two monochromatic colours at its extremes.
- The monochromatic colours either side of a line through the white spot are complementary. If we stare at a red object for some time, and then look at a white piece of paper, we see a blue–green image of the object.
- This fits in with the trichromatic theory, because we would anticipate that the photochemicals associated with red vision have been 'used up', and therefore we will get a higher response to the white light from the photosensors associated with the blue and green reception.
- The triangular envelope formed by the connection with straight lines of points on a chromaticity diagram defines all of the colours that can be produced using an additive combination of the colours represented by the points.
- This has immediate application in the fields of television, cinema and colour printing.