Notes - Design - Colour & Vision

- Dr Nick Hayward

A brief intro to colour and vision in interface and application design.

Contents

Intro If we consider the notion of colour perception in humans, we quickly realise that, inherently, it has both strengths and weaknesses. Many of these are naturally relevant and applicable for our work as user-interface designers.

For example,

- a user's ability to recognise and readily distinguish colours is dependent upon the presentation of those colours
- a user's perception of colour is also influenced by their display (their monitor, screen, or other viewing device)
- a user's vision is naturally optimal when detecting contrasts, edges within a graphical representation, and not absolute brightness
- and, of course, some users may have some degree of colour blindness…

Colour in vision Let us now consider human vision and colour representation.

So, how does colour in vision actually work?

Essentially, the retina at the back of the human eye, the surface used by the eye for focusing images, has two types of light receptor cells. These are known as **rods** and **cones**.

The rods detect light levels, but not colours themselves, and the cones detect colours.

There are three types of cones, which are sensitive to red, green, and blue light. In a parallel with technology, this is often compared to video cameras or monitors, which detect the broad spectrum of colours through subtle combinations of red, green, and blue pixels.

For example, this is a representative image of the human eye with the important part, the retina, at the back.

Notice the three types of cones, and the single type of rod.

The Human Eye (source: DoveMed)

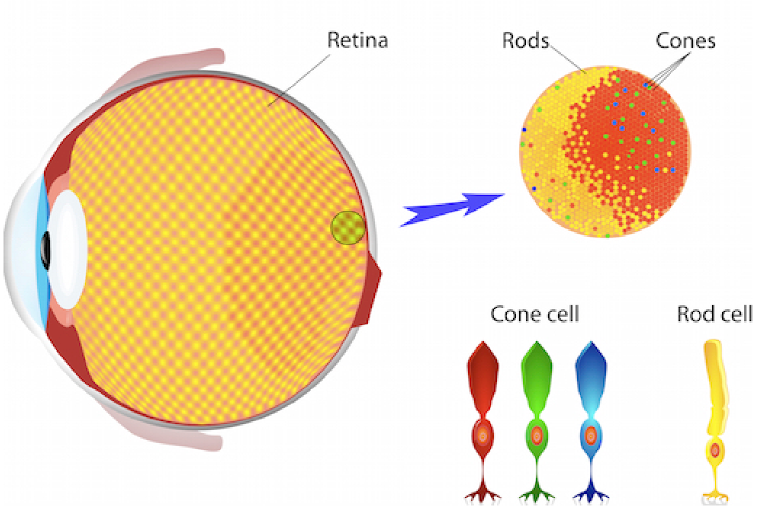

Figure 1: Human Eye

Working environment However, this is only part of the overall picture for us, as user-interface designers. In particular, as alluded to earlier, we also need to consider the influence of modern working and living spaces upon human vision.

The rods in the retina are sensitive to the environment's overall brightness, and the three types of cones are sensitive to the different frequencies of light.

When we consider this nature of vision, we also need to be aware the impact ambient light and brightness, for example modern flourescent strip lights, actually have on how brightness is interpreted by the eye.

With such bright artificial lights, we actually hardly use our rods. They are really designed to function optimally at low levels of light, effectively navigating low-light environments. It's only in very dark environmental surroundings where our rods are fully employed, such as in candlelight, a dark building at night, and so on.

Under bright artificial lights, our rods become maxed-out. They provide no real useful information, and our vision becomes reliant upon input from our cones.

Another representative image of the human eye.

Cones differ from rods in that they are designed to function best at higher light levels, and are responsible for colour vision.

The Human Eye (source: Verilux)

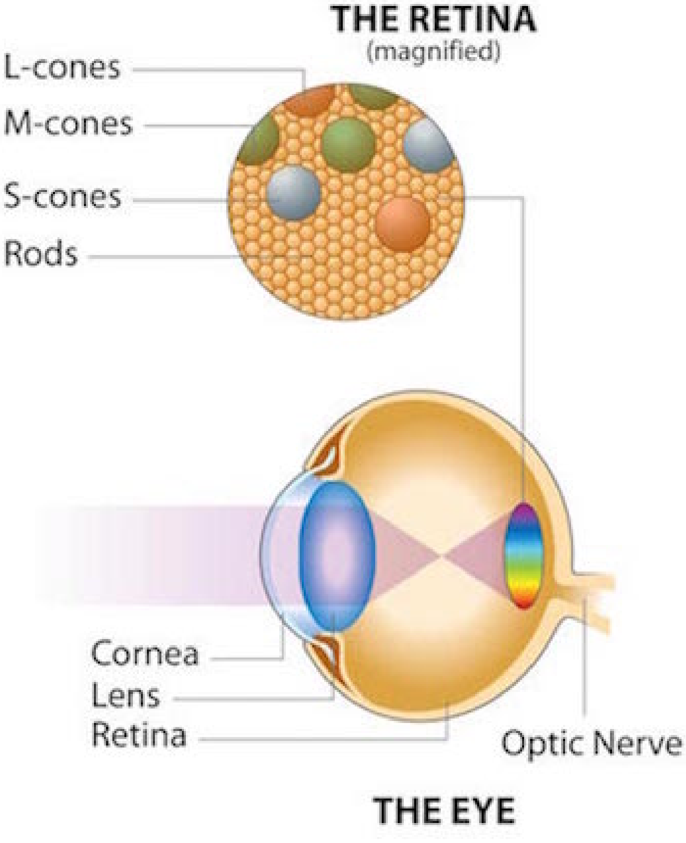

Figure 2: Human Eye

Human eye and vision We categorise the three types of cones as follows,

- S-cone = short-wavelength sensitivity
  - s-cones are sensitive to light over almost the entire range of visible light. However, they are most sensitive to the middle (i.e. yellow) and low (i.e. red) frequencies
- M-cone = middle-wavelength sensitivity
  - m-cones are less sensitive than s-cones, and are sensitive to light ranging from high-frequency blues through the middle frequency yellows and oranges
- L-cone = long-wavelength sensitivity
  - L-cones are far less sensitive than either s or m cones, and are most sensitive to light at the upper end of the visible light spectrum, from violets through blues. As a consequence, our eyes are much less sensitive to blues and violets than other colours.

Each type of cone is also sensitive to a broader range of light frequencies than might be expected by the traditional comparison with RGB. Each type will often overlap considerably with regard to sensitivity ranges.

So, how does the brain combine these disparate cone signals thereby allowing us to see our normal broad range of colours.

Well, the brain works on the principle of *subtraction*.

In the visual cortex at the back of our brain, neurons subtract signals coming along the optic nerves from the S and M-cones. This produces a red-green *difference* signal channel.

Other neurons in the visual cortex subtract signals from the L and S-cones, which yields yellow-blue *difference* signal channel.

Then, a third group of neurons in the visual cortex adds the signals coming from the S and M-cones to produce an overall black-white, or luminance, signal channel.

These three channels are known as *colour-opponent channels*.

Sensitivity One of the effects of this varied subtraction in the brain is that our vision is now much more sensitive to differences in colour and brightness. In effect, we are more sensitive to contrasting colours and edges than to absolute brightness levels.

This sensitivity to contrast rather than absolute brightness in our visual system turns out to be an advantage. For example, as hunter gatherers we were able to more easily discern our prey in varied lighting. In effect, hunting was possible in early morning cloud and high noon sunshine and glare.

In a similar vein, our sensitivity to colour contrasts rather than absolute colours allows us to discern the colour of an object in bright light or shade.

Optical illusions The grey square optical illusion, designed in 1995 by Edward Adelson, a Professor at MIT, shows a checkered board with light and dark grey squares.

The illusion relies on the premise that the square labelled **A** appears to be darker than the square labelled **B**. This assumption inherently relies on a 2D plane of a 3D projection. The illusion is that both squares are, in fact, the same colour from the shown perspective (i.e. the 2D plane).

This can be proven using a number of different methods, including

- manually verifying the image's colour with an image tool, for example the Gimp, Photoshop &c.
- by connecting squares A and B with a rectangle of the same colour
- by isolating the squares, and removing the surrounding context, we can remove the illusion from the image

Grey square optical illusion - Edward H. Adelson (source: Wikipedia)

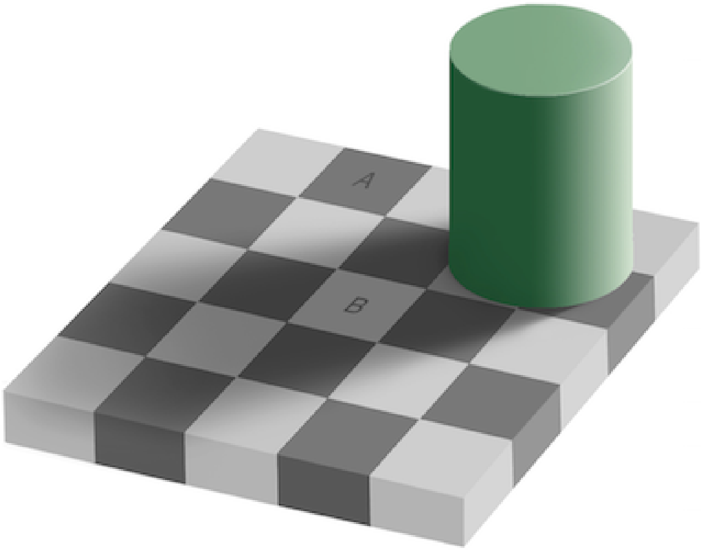

Figure 3: Grey Square Illusion

By adding a rectangle of the same colour as square A and B, we show the connection between the similar squares in question.

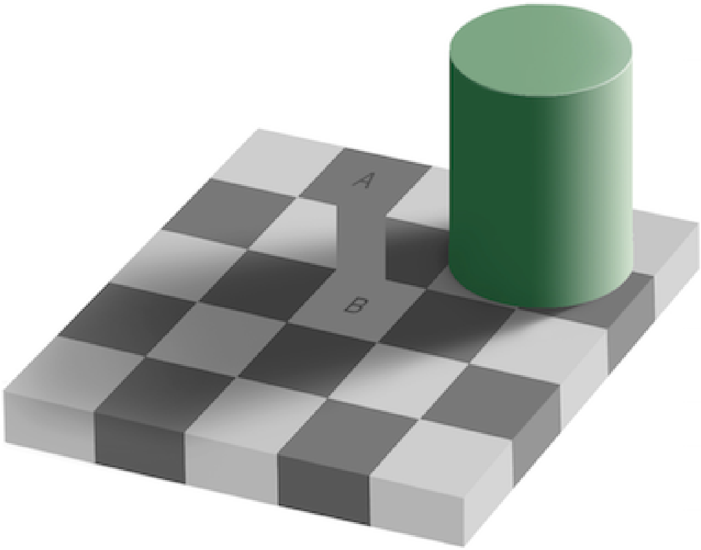

Figure 4: Grey Square Illusion

Grey square optical illusion - Edward H. Adelson (source: Wikipedia)

shade and shadow The more we look at this illusion, and the image, video &c. on the 2D plane, the more we will struggle to understand why the two colours are, in fact, the same. It's not until we realise the effect of the shade on the brain's perception of colour will it start to make sense.

Our brain is effectively compensating for the shadow and adjusting the colour of square B. Our eyes will see the squares as the same grey colour, but our brain adapts this perception to match what we think is actually the real representation of the colours and the B square.

Another example of this usage is *chiaroscuro*, commonly found in art and photography.

For example,

Figure 5: Supper at Emmaus, Caravaggio

Supper at Emmaus, Caravaggio. Further details

colour presentation As seen in the grey square optical illusion, our ability to discriminate colours is very much dependent upon how those colours are presented.

Our ability to discern differences between colours is also limited. The very nature of the mechanics of our visual system results in three known presentation factors, which affect our ability to distinguish between colours.

We may see this effect in the following image,

Colour Presentation (source: National Geographic - Modified)

For example, such presentation factors include:

- Colour patch size - as objects get smaller or thinner, it becomes harder to discern their colour. Text is often naturally thin, so its exact colour can be quite hard to determine. Consider black and navy, for example.
- Paleness - as colours become paler, the harder it becomes to differentiate similar tones.
- Separation - the more separated colour blocks become, the harder it becomes to determine their colours. This is particularly true if the user requires eye motion to move from one colour block to the other.

Each of the colours in the previous image is a different shade, however it's difficult to quickly discern the differences.

A few things to avoid in images and graphics

- try to avoid overly pale colours, in particular pale colours juxtaposed to each other. The difference between such colours will be particularly difficult for a user to see.
- avoid paler colours for smaller blocks or zones. They will often simply be lost in the noise of larger zones and blocks
- think carefully about your chosen colours for charts, graphs, infographics etc

Colour blindness Another issue for discerning colours, and for interactive designing from our perspective, is whether our chosen colours can also be distinguished by users with common types of colour blindness.

Colour blindness does not infer an inability to see colours, for example a monochrome type of vision, but a defect with one or more of our colour subtraction channels. This naturally makes it difficult to distinguish certain pairs of colours.

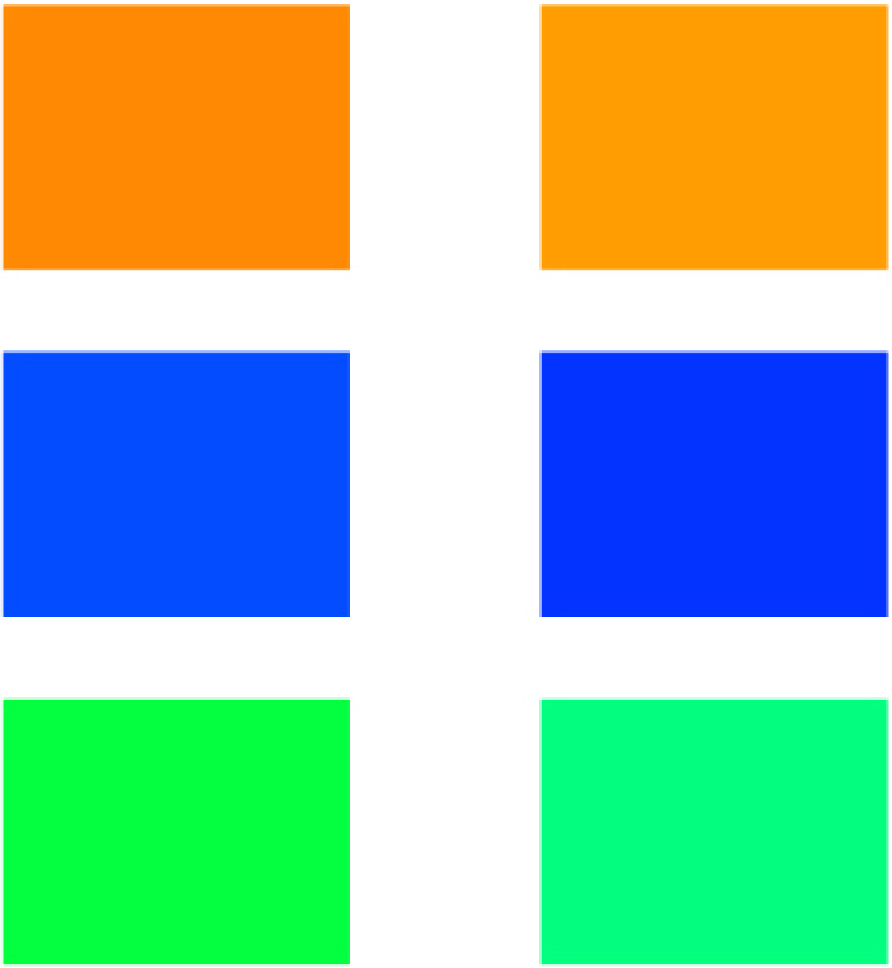

Figure 6: Colour blocks

It is believed that approximately 8% of men, and just under 0.5% of women, have a deficit in colour perception. (cit: Wolfmaier, 1999)

The most common form of colour blindness is lack of perception of red-green. Other types are far less common.

For example, this is an image depicting normal human colour vision on the left, and colour perception for a human with red-green colour blindness on the right. Colour is still visible for a person suffering from colour blindness, but the brain's perception of colour is altered.

Key

- left = normal human colour vision
- right = human Red-Green colour blindness

Figure 7: Colour Blindness

Colour Blindness - Red-Green (source: Ask a Mathematician / Ask a Physicist)

colour differentiation and impact So, how does this impact upon our work as interface designers.

If we consider data visualisation, for example, we often use colour to differentiate quantity, scale, percentages, and so on. For a person with red-green colour blindness, this would impact their ability to discern such data differentiation solely based upon colour.

We could rectify this issue in at least two respects, either by modifying our colours to match those perceived by red-green colour blindness or offer supporting data and explanation for the visualisation.

Keep in mind that it is not always possible to create a full data visualisation, for example one that easily differentiates such quantities and values, with the somewhat limited palette for red-green colour blindness.

Colour perception (source: Okabe, M & Ito, K. 2008)

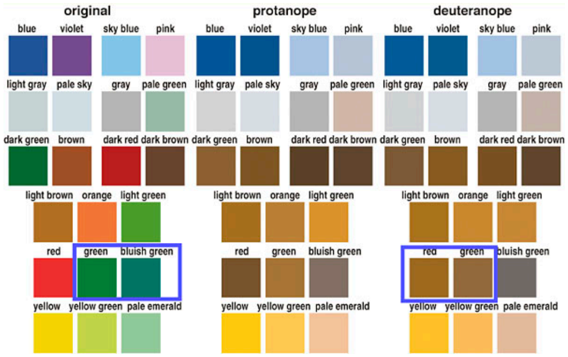

Figure 8: Colour Differention - Red/Green Blindness

Other issues to consider Other issues and factors may also influence a user's ability to differentiate and distinguish colour.

For example,

- ambient lighting will have a direct impact upon a user's display, often simply washing out the display's colours before it washes out the light and dark areas. It is often considered akin to simply switching to a greyscale display. Consider outside screens in bright sunshine, for example. This is particularly relevant when we consider the development of interfaces for mobile and wearable devices, gadgets such as cameras, GPS etc, and any other terminals where bright, direct light is a potential concern.
- the viewing angle of a user's display will also affect colour representation and interpretation. Consider some of the more recent cheaper laptops, and their reduced viewing angles, in particular when compared with better IPS displays.
- monochrome or greyscale displays can also influence our design decisions and choices. Consider the provision of a technical publication, which relies upon colour for data visualisation.
- colour variation across displays themselves is also an issue for us as designers. The simple fact that different displays use different technologies to drive their output presents issues for interface design. Some displays will offer deeper blacks, others more vibrant colour reproduction, and some will simply be produced to keep costs at a minimum.

As we've seen so far, there are many reasons why we might want to follow some basic colour guidelines and advice.

For example, the following Amazon Kindle book cannot be correctly read on monochrome devices…at least, not as the author originally intended.

- The Bible with Sources Revealed - Source: Amazon

Colour suggestions Colour choices and combinations becomes increasingly important as we begin interface design for interactive applications and systems.

Here are a few suggestions to help guide us in our design thinking and development.

- subtle colour differences may be desirable for aesthetic reasons, but it's often preferable to distinguish colours by saturation and brightness, as well as by their hue or shade. One way to test such colour variations is to view them in monochrome. If you are unable to differentiate the coloured zones, the colours may be too subtle for a user as well.
- distinctive colours help a user's visual system combine colours to form recognition. Colours that cause a strong signal (positive or negative) on one of the three colour perception channels are those colours that people will be able to distinguish with the greatest ease. These colours include black, white, red, green, yellow, and blue. Other colours will cause signals on more than one colour channel, thereby delaying our recognition of colours in our visual system.

- Obvious one really, but try to avoid colour pairs, where possible, that colour blind users will not be able to distinguish. Such pairs include dark red versus black, dark red versus dark green, blue versus purple, and light green versus white. For example, try to avoid dark reds, blues, and violets against dark colours. Instead try those colours against light yellows and greens. It's always worth trying an online colour blindness tester or simulator with your ongoing design.
- try not to rely solely on colour within your interface design. Icons, keys, notes &c. are all very useful additions to a user interface that support and reinforce the message conveyed with colour.
- Remember, colour and shade variance is not only important for colour blind users, but it may also be a consideration for users with poorer eyesight as well. Test and test again....

Resources

- Laing, R.D., Phillipson, H. & Russell Lee, A. *Interpersonal perception: a theory and a method of research* Tavistock Publications. 1966.
- Okabe, M. & Ito, K. *Color Universal Design (CUD) - How to make figures and presentations that are friendly to Colorblind people.*
  - J Fly. 2008. http://jfly.iam.u-tokyo.ac.jp/color/.
- Waloszek, G. *Vision and visual disabilities: An introduction.* SAP Design Guild. 2005. http://www.sapdesignguild.org/editions/highlight_articles_01/vision_physiology.asp
- Wolfmaier T. *Designing for the color-challenged: A challenge.* ITG Publication. 1999.