Guidelines for Colour-Blind Friendly Data

Introduction to Colour Blindness

Colour blindness effects 4-5% of the total population, with a higher propensity for males. Different types exist with the most common categorization based on the affected cone types (prefix: Prot-, Deutero-, Trita- for RGB respectively) and severity (suffix: -nomaly and -nopia for partial/total loss, respectively). Red and green affected types are by far the most common. Blue colour blindness and monochromatic vision are significantly rarer.

In science, it is common to use colour to help distinguish data, e.g. to link to datasets in line graphs, highlight different regions in microscopy, or identify atom types in molecular models. However, if colorblindness is not considered, then it can make data indistinguishable to a significant fraction of the population.

Table 1. *Types and prevalence of colour blindnesses, with estimated distribution of UCL's ~66,000 staff and students. (a) Data from www.color-blindness.com, (b) palettes from wikipedia.org/wiki/Color_blindness,*

Type	Male[a]	Female[a]	# at UCL	Estimated Vision[b]
Normal Vision	91.89%	99.48%	63151	
Deuteranomaly	5.00%	0.35%	1766	
Protanomaly	1.00%	0.10%	363	
Protanopia	1.08%	0.03%	366	
Deuteranopia	1.01%	0.02%	340	
Tritanopia	0.01%		7	
Tritanomaly	0.01%		7	
Achromatopsia	<< 0.01%		1	

Colour-blind Software

Most simply, consider using a colour-blindness simulator which can convert your images to a representation of a colour-blind individual's vision. Options include:
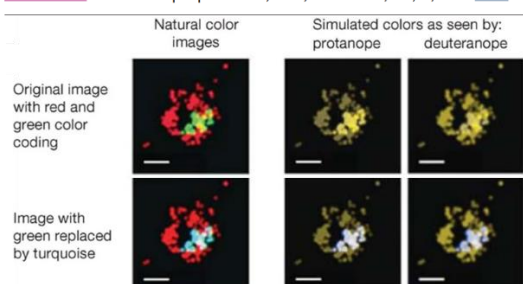
- www.color-blindness.com/coblis-color-blindness-simulator/ which uploads image files. Use *Protanopia* and *Deuteranopia* filters to simulate the most extreme versions of common colour blindness.
- Chromatic Vision Simulator (Kazunori Asada) an app available on Android/iOS which provides a P/D/T filter for cameras.

By quickly using these tools, you can see if your data is distinguishable for the colourblind, allowing similar ones to be changed. In chemistry, some colours are "set", notably the CPK colouring of atoms (O red, N blue, H white, etc), but different shades of the same colour can have dramatically different contrasts for those with colour blindness. It is useful to use these tools to tweak the colours e.g. using vermillion instead of red for oxygen atoms to increase contrast while remaining near the traditional hues.
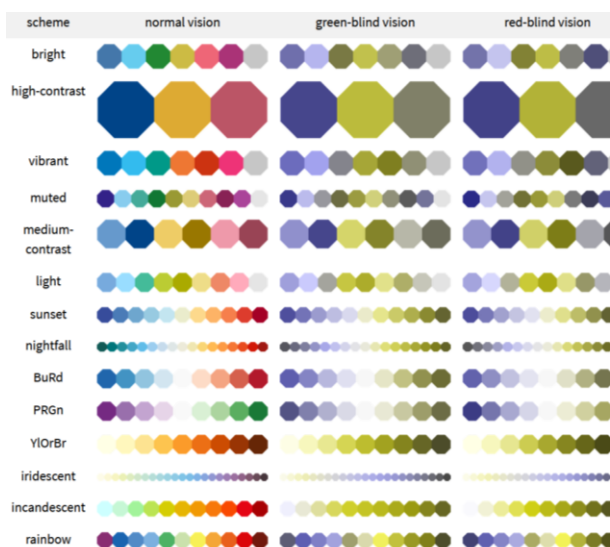
High Contrast Palettes

One simple route to avoiding confusing data is by using premade colour palettes. Several options exist, including options by Bang Wong (*Nat. Methods,* 2011, **8** (6), 441) and a wide selection from Paul Tol (personal.sron.nl/~pault/) including rainbow-mimic palettes with ≤23 colours. You should use RGB or CMKY values to allow completely accurate reproduction of colours.


Figure 1. (Top) Bang Wong Palette with RGB and CMYK values (Bottom) Demo data

Figure 2. Summary of Paul Tol Palettes, RGB/CMYK avialble at personal.sron.nl/~pault/

Variety in Type

For line or scatter graphs, contrast can be provided via changing the line (solid/dash/dot/dash-dot/etc) and symbol type (● ■ x ▲, solid and hollow), respectively. It is particularly recommended to combine colourblind friendly palettes with line/symbol types to maximise readability.
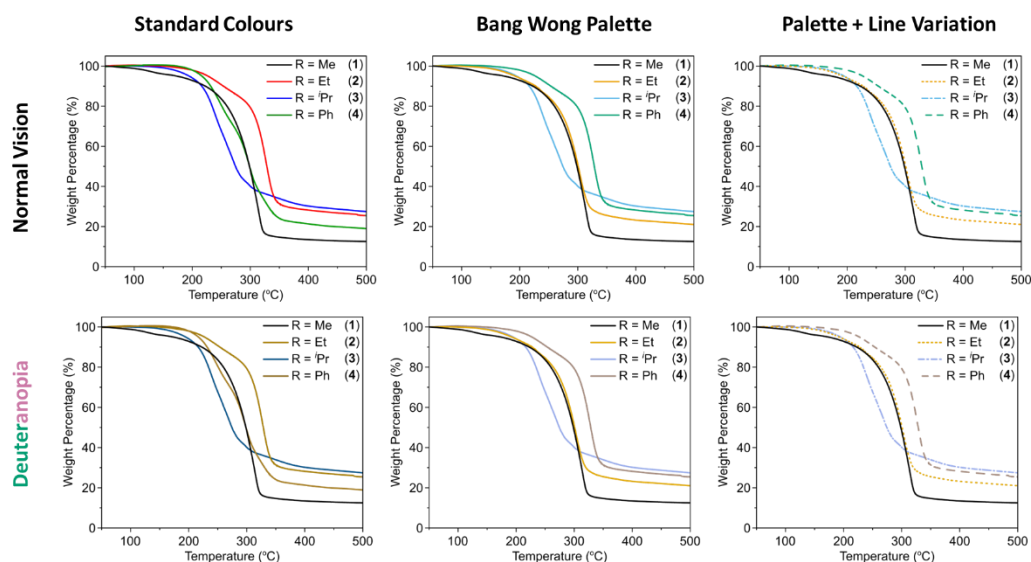
Figure 3. *Line graphs using OriginPro colours (Black, Red, Blue, Olive), the Bang Wong Palette with/without line variation for normal/deuteranopia vision. Note samples 2/4 are indistinguishable with default colours. Original data from S. Douglas et al., ChemPlusChem, 2023, 88, e2022004 (which used the Bang Wong palette).*