BY **MIKE WOOD**

# Color confusion – the rainbow isn't always correct

IN ENTERTAINMENT LIGHTING we spend a lot of our time dealing with color. We worry about whether it sets the right mood, whether it is distracting, what it does to the performer's faces, and how bright it is. We are familiar with how color can draw attention, how it can hide detail when we want it to, and how it can distract the viewer. Such deception and persuasion are inherent parts of the craft of lighting dramatic events.

What might not be quite so clear is that these same attributes that we use and take advantage of might be causing problems in other fields. In particular, the overuse or poor use of color in scientific charts and illustrations can mislead the viewer or provide inadvertent emphasis where none was intended, in particular, the ubiquitous "rainbow color map," which is so simple to generate in Excel and thus seen everywhere, is derided and ostracized by the scientific community. Kenneth Moreland in a 2016 paper for the Society for Imaging Science and Technology states, "*. . . the rainbow map is terrible, and emphatically reviled.*" Why such strong feelings?

Moreland goes on to describe three main problems with the rainbow map when used to represent data or as scientific visualizations:

> *The first problem is that the rainbow colors do not follow any natural perceived ordering. Although the order of the hues can be learned, there is no innate sense of higher or lower.*
>
> *The second problem is that the perceptual changes in the rainbow colors are not uniform. The colors appear to change much faster in the yellow region than the green region. This can both obfuscate the data with artifacts that are not in the data and hide important features that are in the data.*
>
> *The third problem with the rainbow color map is that it is sensitive to deficiencies in vision. Although normal human vision can distinguish all of the rainbow's colors, roughly 5% of the population has deficiencies in distinguishing these colors (usually between green and red). These viewers will misinterpret much of the color map.*

**Figure 1 – The reviled rainbow map**

An example helps to show these problems, particularly if you use familiar objects where you know what they should look like. **Figure 2**, from a 2020 paper in *Nature Communications*, does just that.

"…the rainbow map is terrible, and emphatically reviled"

The original data here is the center **image a**: black and white photograph of the Earth, an apple, and Marie Curie. **Image b** maps the brightness levels to a rainbow color map. In theory there's nothing wrong with this, but the distortion causes us to make all kinds of, likely incorrect, assumptions about the resultant data. It would be very easy, seeing the Earth colored like that, to assume there was something specific about the red areas. Too hot? High elevation? What about the apple? What's important about the red? Do those colors mean anything? It isn't that using color at all leads us to wrong conclusions, it's our specific assumption that

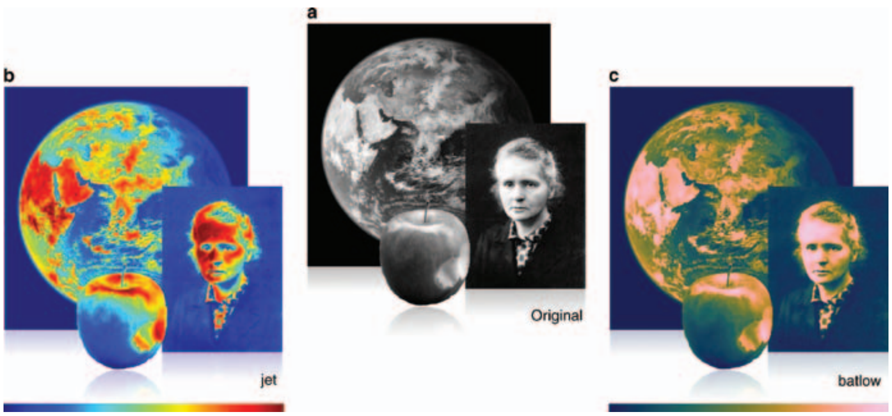


**Figure 2 – Good and bad color maps**

a rainbow color map must *mean* something. In contrast, **image c** shows a scientifically derived color map where the colors are carefully chosen. Different brightness areas still have widely differing colors and are easily distinguished, but we don't jump to conclusions in the same way as we did with the rainbow. The colors are harmonious, and comparable in brightness, so none of them take priority and leap out at us, as the red does with the rainbow.

As well as our expectation that colors must mean something, as they do in traffic signals, for example, the rainbow coloring suffers from large perceived brightness differences from one color to another. The three primary colors, red, green, and blue, appear brighter than the secondary cyan, yellow, and magenta. They even appear brighter than white! I've discussed this effect before way back in my *Protocol* article of

Figure 3 – All possible RGB colors

Summer 2012. It's exemplified by **Figure 3**.

This shows all possible colors that can be produced by an RGB display (or CMYK printing if you are reading this in a physical copy of *Protocol*). The colors go left to right from red to magenta to blue and then all the way back to red again via green, while lightness goes from black to white. Clearly, the brightest part of this image *must* be the white portion at the top, in the case of an RGB monitor, that's where all three colors are on at full power, or, in the case of a print copy, that's the white paper reflecting all light back. However, our eyes and brain don't see it that way. Instead, we see the perceptually brightest point as a horizontal line across the center where all colors are

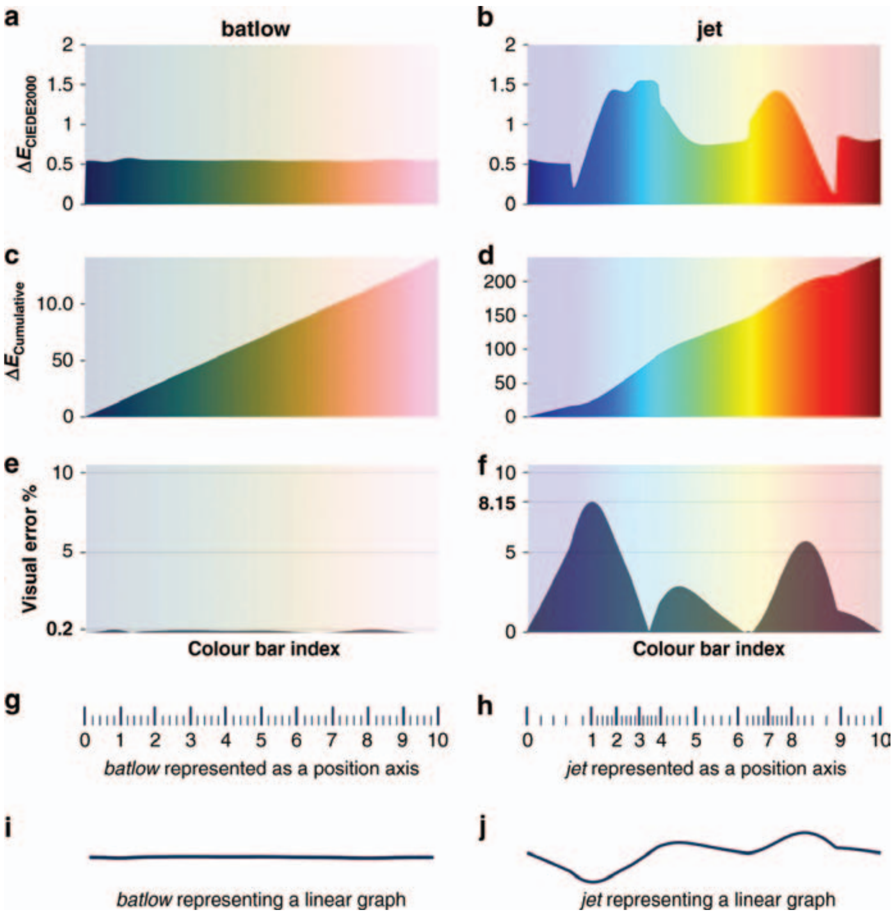


Figure 4 – Colors without bias

fully saturated. In fact, you likely see an ethereal and imaginary horizontal bright line at that point. We also see, as mentioned above, that the full red looks brightest of all.

We instinctively work with this when lighting a stage, perhaps without knowing why, and adjust lighting levels to account for these effects. However, it isn't so obvious when working with illustrations and charts on a computer screen or on paper. So, how should we deal with using color without inadvertently adding emphasis when it isn't desired, as when using a full rainbow shading? Perhaps surprisingly, quite a lot of research has gone into developing color maps that don't have these biases.

**Figure 4** shows the perceptual lightness using the CIEDE2000 color difference formula for two color schemes. On the right is the infamous rainbow that Excel will give you, while on the left is the Batlow color scheme used as an example in **Figure 2**. The top curves, **a** and **b**, show the perceived brightness of each step along the color scale, while curves **c** and **d** show the cumulative lightness difference, and curves **e** and **f** show the visual error or bias that the viewer is subject to. The bias inherent in the rainbow is obvious while the Batlow is flat all the way across, that is, all the colors used in Batlow have the same perceived brightness so don't induce bias.

Does this mean we are restricted to using fairly bland colors, or a single hue? No, not at all. **Figure 5** shows three further examples (all from the ColorBrewer website at https://colorbrewer2.org) in this case for map coloring of US counties.

The left example uses shades of a single color, the middle shades of two colors, while the right example uses eight completely different colors but deliberately excluding the standard rainbow colors. Although

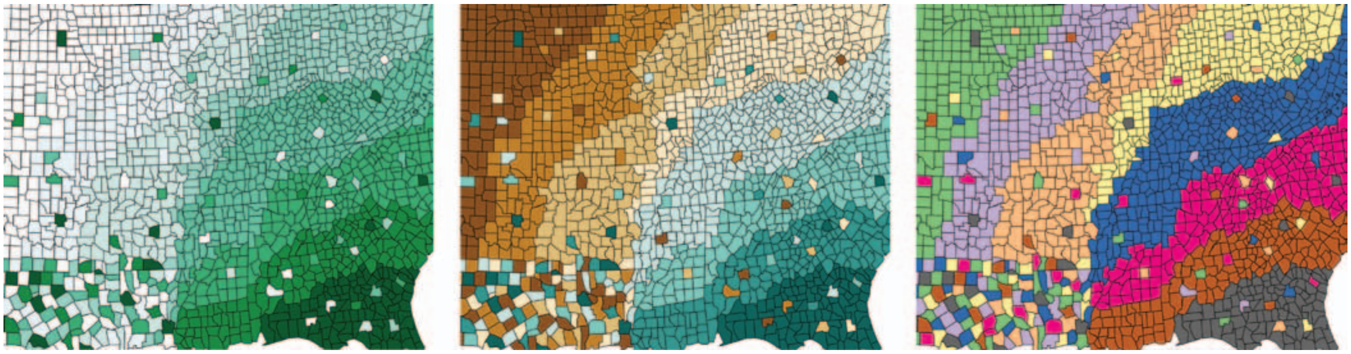

Figure 5 – Example color schemes

these are all bright colors, they don't trigger the automatic bias that we see with red, green, and blue. There is no reason to think that the lavender area is any more or less significant than the pale yellow; they are simply distinct and different.

Is there a lesson in this for stage lighting? Do we experience the same visual biases with saturated primary colors? Should we be avoiding them unless we actually want those biases? I suspect the answer to all three questions is yes, but that we already handle this on an unconscious level. It might be interesting to see which are the most popular theatrical colors and see if the theory bears out in practice. ■

**Mike Wood** runs Mike Wood Consulting LLC, which provides consulting support to companies within the entertainment industry on product design, technology strategy, R&D, standards, and Intellectual Property. A 40-year veteran of the entertainment technology industry, Mike is a past President of ESTA and Co-Chair of the Technical Standards Council. Mike can be reached at mike@mikewoodconsulting.com.

## Reference:

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