BY MIKE WOOD

Lightness—
The Helmholtz-Kohlrausch effect

DON'T BE PUT OFF by the strange name of this issue's article. The Helmholtz-Kohlrausch (HK) effect might sound esoteric, but it's a human eye behavioral effect with colored lighting that you are undoubtedly already familiar with, if perhaps not under its formal name. This effect refers to the human eye (or entoptic) phenomenon that colored light appears brighter to us than white light of the same luminance. This is particularly relevant to the entertainment industry, as it is most obvious when using colored lights. Although it still comes into play with colored pigments and printing, the effect in those cases is less pronounced. In this journal, I can only show you pigments—not light—and, even worse, those pigments are made up of dots of only cyan, magenta, yellow, and black ink, so please suspend your disbelief a little and imagine the effect magnified as you read. I also strongly suggest looking at the online version of this article, as the images will be displayed on your monitor and behave more like lights than the ink pigments in the printed copy. *You can access* Protocol *issues on-line at http://plasa.me/protocol or through the iPhone or iPad App at http://plasa.me/protocolapp.*

The simplest way to show the Helmholtz-Kohlrausch effect is with an illustration.

The top half of **Figure 1** shows seven differently colored patches against a grey background. I drew this in Photoshop, and every color in this figure, including the grey, has the same lightness. Is that surprising? If I use Photoshop again to convert the top image to greyscale, then I get the image at the bottom. Now every color has become the same shade of grey, confirming that the lightness of each was the same. What is even more interesting is the range of different lightness most people see when looking at this image.

Note: Not everyone will see the differences as strongly, particularly with a printed page like this. Just about everyone sees this effect with lights, but the strength of the effect varies from individual to individual. In particular, if you are red-green color-blind, then you may see very little difference.

What I see—which will agree with what most of you see—is that the red and pink patches look by far the brightest, while blue, green, and amber are less bright. Dimmest of all is the green-yellow patch, third from the left. Lights of these colors will behave in the same way as these printed examples, only even more so. Red and pink lights will always look much brighter to the eye than a green or yellow light of the same luminance. The effect will vary from person to person, and will also be affected by the lighting and colors of surrounding objects in your vision. The effect is most extreme when viewed in a darkened space with no surrounding lighting—just exactly what we get in a theatre!

Figure 2 shows another example.

Both illustrations in **Figure 2** show a background color—one red one blue—with a range of different-brightness yellow squares on top. Which of the yellow squares looks the same brightness to you as the underlying color? To me, looking at this on my computer monitor as I write the article, it looks as if the bottom right yellow square matches the red background in brightness, while the bottom left patch matches the blue.

Figure 1 – Equal lightness

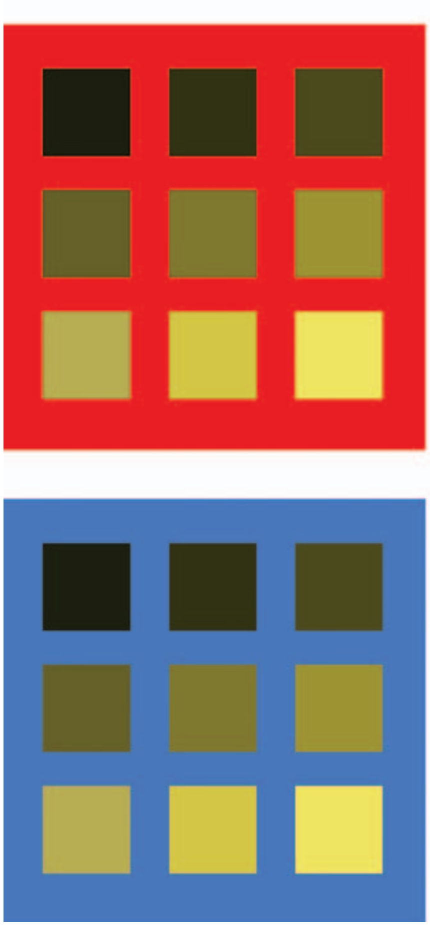

Figure 2 – Lightness comparison

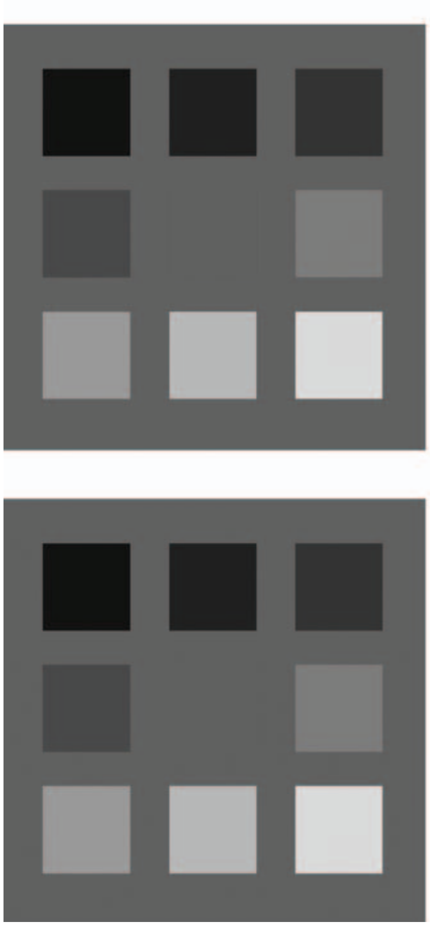

Figure 3 – Grey scale version of Figure 2

This may well look different to you, seeing this in a printed journal. In fact, the patch that is the same lightness is the centre patch of the middle row in both cases. If I convert the colors to greyscale as in **Figure 3**, you can see that is the case. The background has a lightness of 50%, and the patches start at 10% in the top left, and increase by 10% for each step. Thus, the bottom right patch, which looked the same to me, is, in fact, 90% lightness; that's almost twice the actual brightness of the background!

Note: *If you want to try this yourself in Photoshop, use the Lab color mode to define your colors. The 'L' in Lab stands for lightness, and Photoshop uses the CIE definition of lightness to calculate this value. The CIE Lightness value does not take into account the Helmholtz-Kohlrausch effect.*

I'm sure you see how important this effect is to us as lighting users. It is not a small effect of purely academic interest. When one light can look twice as bright as another, just because the color is different, then we need to know about it! The effect gets stronger as the saturation of color increases. Our eyes perceive and interpret increasing saturation as part of the color's luminance, as well as its chroma. Saturated colors really do pop.

Even though the effect is minimal at some colors—specifically, those around green and yellow— it is still true that a colored light of any hue will always appear brighter than a white light of the same luminance. Think about what that means on a stage: If we put a gel in a light, then it is quite possible that the resultant beam actually looks brighter to the eye than the original white, even though we have filtered out some of the original light. Try this with a piece of saturated pink or magenta gel and you can see it for yourself. It also clearly explains why yellow gel colors always look dimmer than blues, even though the transmission may be very similar.

Just how significant is this effect? **Figure 4** attempts to illustrate some data on how it varies color by color. The x axis of this chart shows all visible colors, including the extra-spectral mixed colors between blue and red, the magentas and pinks. The y axis shows the brightness that a white light would have to be relative to the colored light to appear to be the same brightness. The first thing to notice is that all colors, without exception, appear brighter than white, even if only by a very small amount. The greens and green-yellow area show the smallest increase. At the other extreme, reds, pinks, magentas, and blues show as much as a 2 to 2.5 increase over an equivalent white light.

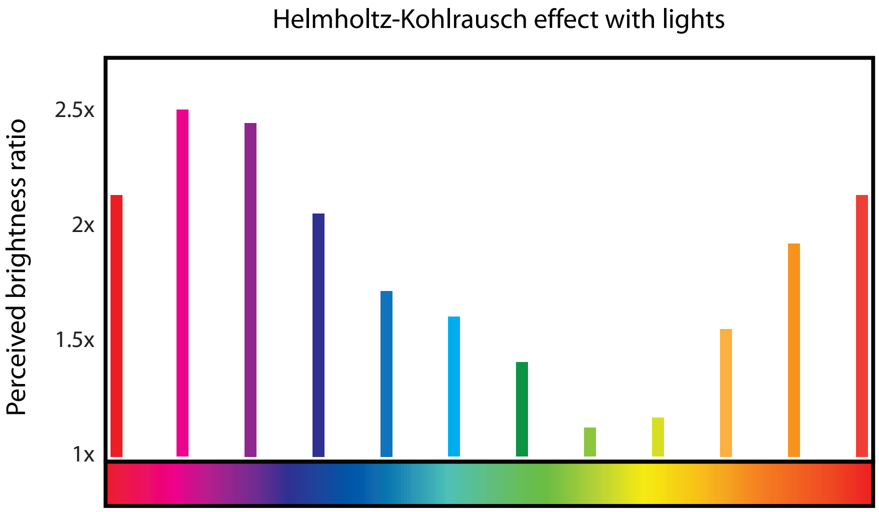

Figure 4 – Magnitude of HK effect with fully saturated monochromatic lights

Note: These values are just one set of approximations, as opinions on the magnitude of this effect vary from observer to observer. We must never forget that we are talking about a completely subjective topic as much related to psychology as to physics. It is very difficult for us to compare the brightness of two different colors while ignoring the color itself. Various techniques, including strobing and flickering, have been used by researchers, but it's still not an exact science. All human vision theory, by its very nature of using the human eye and brain as our detector, must be subjective and statistical in nature.

" . . . yellow gel colors always look dimmer than blues . . . "

The recent increase in the use of additive color mixing in stage and studios with LEDs brings up another oddity of this effect, which can be extremely confusing if we don't realize what's going on. Let's imagine we are using an LED unit with red, green, and blue emitters. Let's also assume for the sake of simplicity, that each color, when used on its own, produces 1,000 lux on our stage. Now we bring up the red on its own and view the effect on stage, then we switch to green on its own and take a look at that. Finally, we bring up both red and green to mix a yellow. What will we see? If, for example, we measured the green at 1,000 lux and the red at 1,000 lux, we know that the mix of the two together will be 2,000 lux and should look twice as bright as the individual colors. In reality, yes, the light meter tells us we have 2,000 lux in the resultant yellow color, but our eye tells us that it doesn't actually appear to be much, if any, brighter than the individual colors. If we now mix all three colors—red, green, and blue—to make a white, we have the same problem. We might have 3,000 lux on stage but, to our eyes, the mixed white hardly looks any brighter than the red did on its own. It gets even more confusing if you are looking at the same stage with video cameras. The cameras don't exhibit this effect—thus, on camera, the colors will look dimmer and the white will look brighter as indeed, they all really are.

I have one final example for you, which you must view on a monitor to see properly. Please take a look at the online version of *Protocol* to view it. **Figure 5** shows three columns of colored patches as used in computer monitors. The left patch is a fully saturated color in the six primary and secondary colors, red, green, blue, cyan, magenta, and yellow. The centre column is the grey patch that has the true same lightness as the saturated target patch. Finally, the third column contains patches of the original color, which, perceptually match the lightness of the grey patch when adjusted by a human observer. Each patch has its RGB values below it.

For example, in the top row, the red patch on the right, which has a red value of 162, looks the same brightness to us as the grey patch next to it. Thus we see a patch of 162 red as if it were as bright as one with a value of 255. (Allowing for the display gamma, that's again a difference of nearly 2:1). As shown with the previous experiments, we see

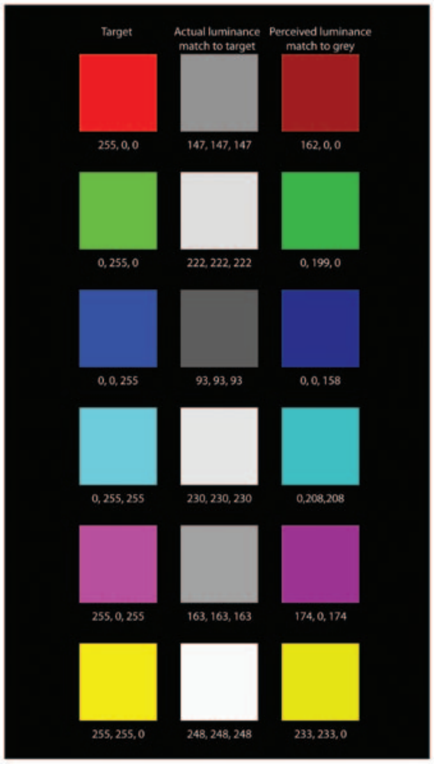

Figure 5 – Computer monitor HK effect

" . . .colored light appears brighter to us than white light of the same luminance . . . "

the least difference with green and yellow, and the largest with red and magenta.

The relevance of the HK effect to entertainment lighting is clear. We commonly use saturated colors on stage that are often actually rather dim. We probably get away with that because of the HK effect in the viewer's eyes, which makes those deep saturated colors look brighter than they really are. We also prefer deep reds, pinks, and blues, which produce the highest HK effect to greens which have the lowest—so, everything is in our favor!

Note: In previous Protocol *articles I've discussed how the standard CIE photopic curve underestimates the amount of deep blue light we can see, which is one reason why Congo Blue appears much brighter than its 2% transmission figure would suggest. The HK effect adds even more to that. Not only does the eye see more of that blue light than our meter tells us, we also perceive it as brighter than it actually is!*

I'd love to see some experimentation on a stage with deeply saturated colors to see what values for HK effect we get in those circumstances, both with gels and with LEDs. Perhaps someone could take this on as a research thesis? ■

Reference: ***Figure 5*** *data taken from:* The Perceptual Amplification of Color for a Common Computer Monitor: Helmholtz-Kohlrausch at Work on the Desktop Computer. *J. Michael Sanchez (Xerox Corp.) and Mark D. Fairchild (RIT Munsell Lab)*

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