BY MIKE WOOD

Our ageing eyes

MY TOPIC THIS MONTH is one that might be a little sensitive, but it's one we all experience, ageing. In particular how ageing affects our eyes and how this might be an issue on stage with narrow-band LED-based lighting.

It's no secret that, as our eyes age, the lens moves away from its young pristine clarity towards something that is yellower and somewhat translucent as yellow pigments accumulate in the lens. (It's also partly due to an increased pigmentation of the yellow spot at the center of the retina, but that effect is less than the changes in the lens). These days the fix for cataracts is to replace the entire lens, but that's a relatively recent innovation. It also isn't a procedure that everyone needs. For most people the yellowing and impairment to vision is little enough that they just live with it. In fact, the changes come on so slowly over many years, that you likely have very little appreciation of them. I know that, as far as I'm concerned, it looks like nothing has changed. However, at the age of 63, it's certain that lens yellowing must have occurred, and I don't see things in the way I did 30 years ago.

> "What can we do about the specifications of the eyes in our audience?"

A paper published last month in *Optics Express* written by Aurelien David, Dane Sahlhoff, and Michael Wisser from Soraa digs into this issue, in particular, how this yellowing interacts with the light from LED sources. This paper covers a lot of ground, but the area that caught my attention relates to white light LED sources, specifically those that use a violet or blue pump LED and red and green phosphors. They tested the vision of 64 subjects ranging in age from 18 to 64 and measured their perception of a range of violet + phosphor LEDs against broad band white light sources.

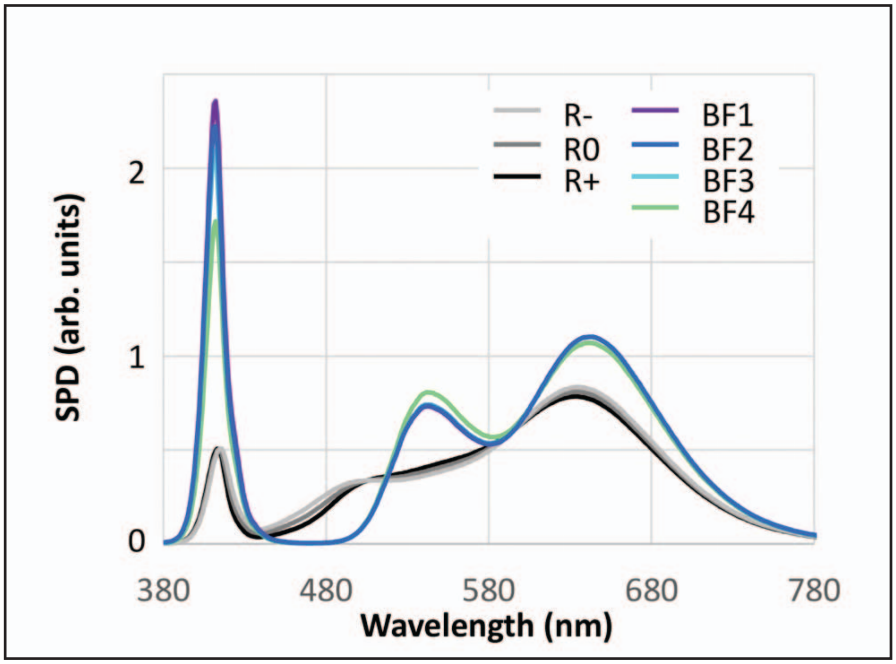

Figure 1 – Four test sources

Figure 1 shows the four test sources, BF1-BF4, they all have approximately the same correlated color temperature, and the same red and green phosphors, but vary along the pink/green axis as the amount of the violet pump LED that is allowed to escape changes.

Figure 2 shows the spots on the wall. Note that, in this case, the camera has adjusted its white balance to match BF3. This is not necessarily reality (whatever that is), and how it is seen by the human eye is likely to be different! The participants were then asked to match these whites for green/pink tint to three wide-band standard reference white sources (shown as the three curves R1, R0, and R+ in **Figure 1**).

The results show solid correlation with age. The older the participant, the greener

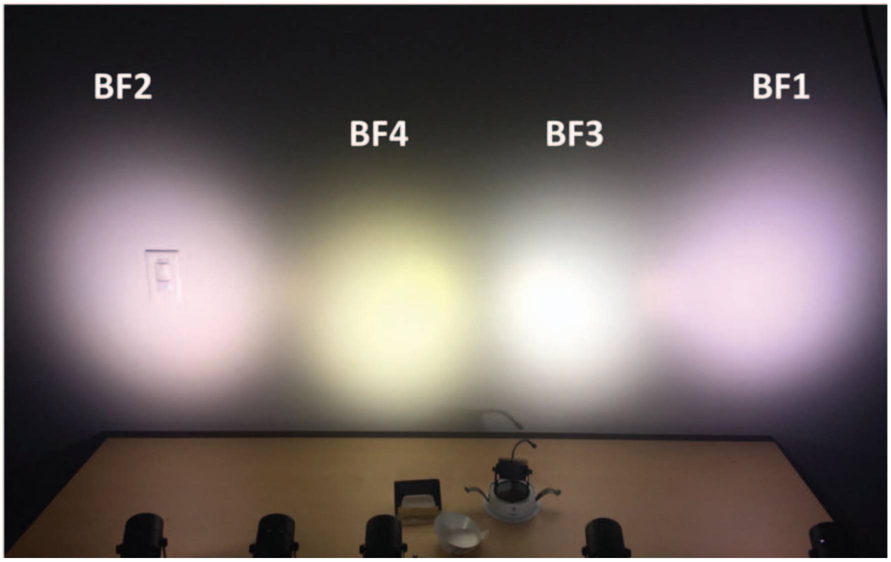

Figure 2 – White spots on wall

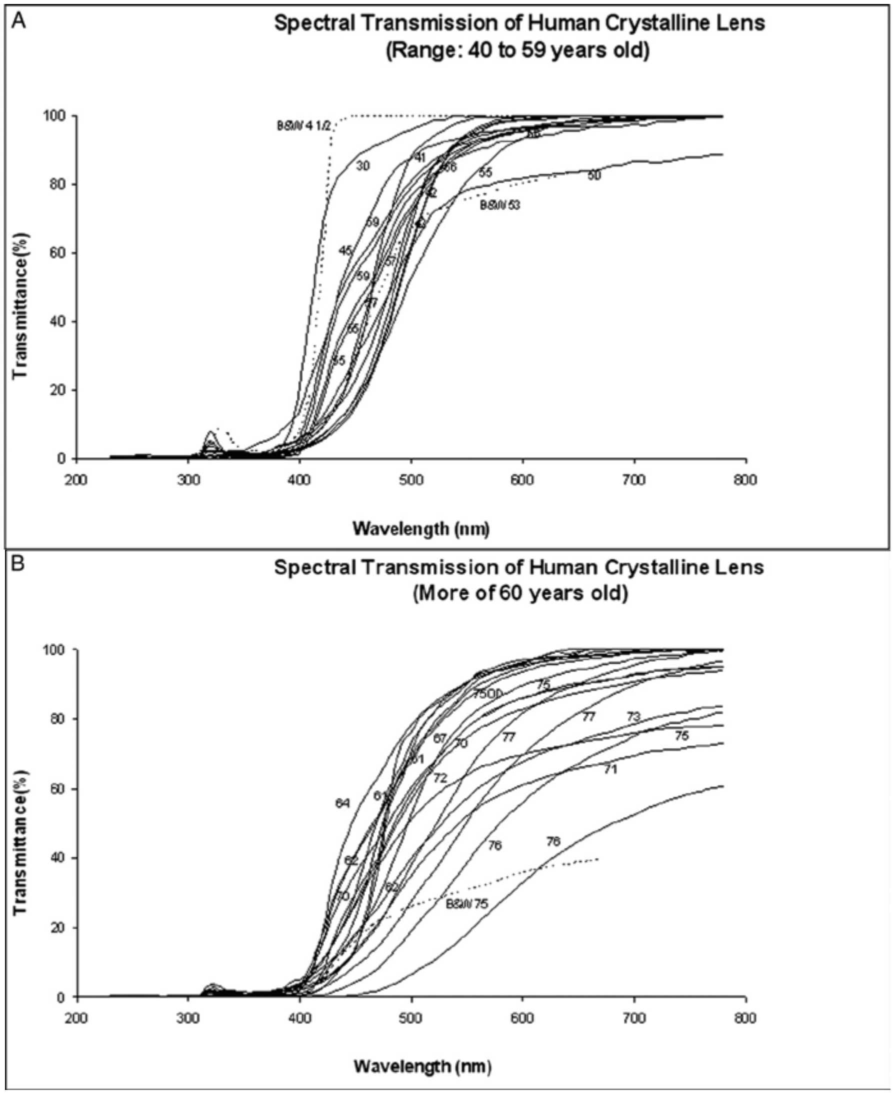

Figure 3 – Human lens spectral transmission

becomes the perceived color. This is what you might expect from ageing lenses, but the effect is magnified in this case because of the narrow-band emitters being used. The older participants will see much less of the violet pump emitter than the younger eyes which dramatically skews the net color they see from the mix. This still happens with broadband sources such as the sun or incandescent lights, but the effect is much less pronounced. The current switch to narrow band LED light sources exacerbates the problem. This trend was very pronounced in the Soraa test, with some lamp scores shifting by nearly the full pink-green experimental scale from the youngest to the oldest age group. In other words, what the youngest saw as matching the pinkest reference source, the oldest saw as matching the greenest! Older people have a lower sensitivity to short-wavelength radiation, causing them to perceive less of the violet peak needed for chromaticity balancing and therefore report greener tints. The range of difference or perception with age was up to 9 MacAdam ellipses —that is way more color shift than we would accept for light sources in most specifications, but what can we do about the specifications of the eyes in our audience?

> **“You can never have full and complete knowledge of what your audience is seeing.”**

Figure 3 shows the results of a study published in 2012 in *Investigative Ophthalmology and Visual Science* showing how the spectral transmission of the human eye lens varies as we get older. **Graph A** shows subjects with ages varying from 40 to 59, against a 30-year-old's eye (the dashed curve) as reference. **Graph B** shows the continuing degradation in subjects older than 60.

If you plot this same data on the familiar 1931 CIE chart, you get the result shown in **Figure 4**. The increasing yellowness with age

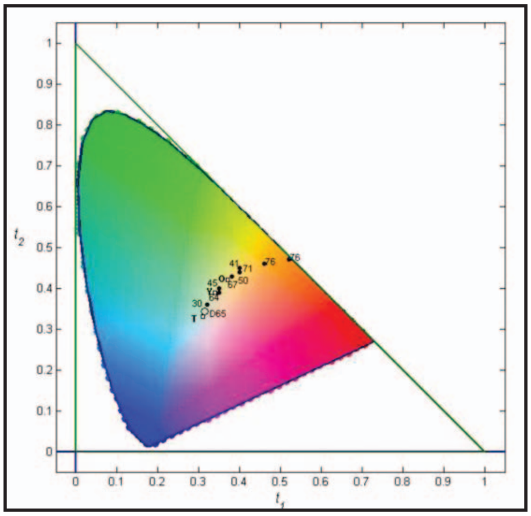

Figure 4 – Human lens color shift

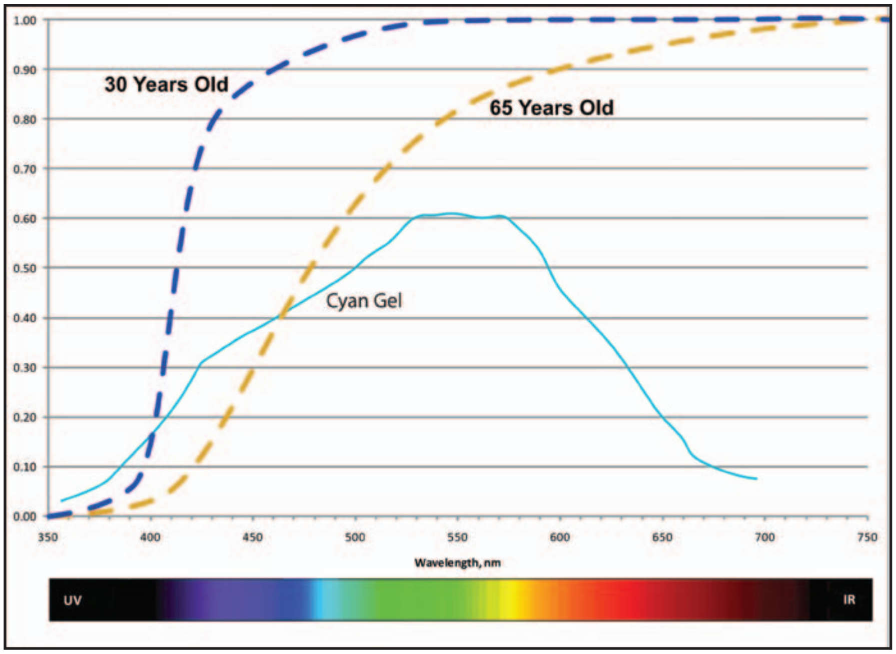

Figure 5 – Gel and broadband light source

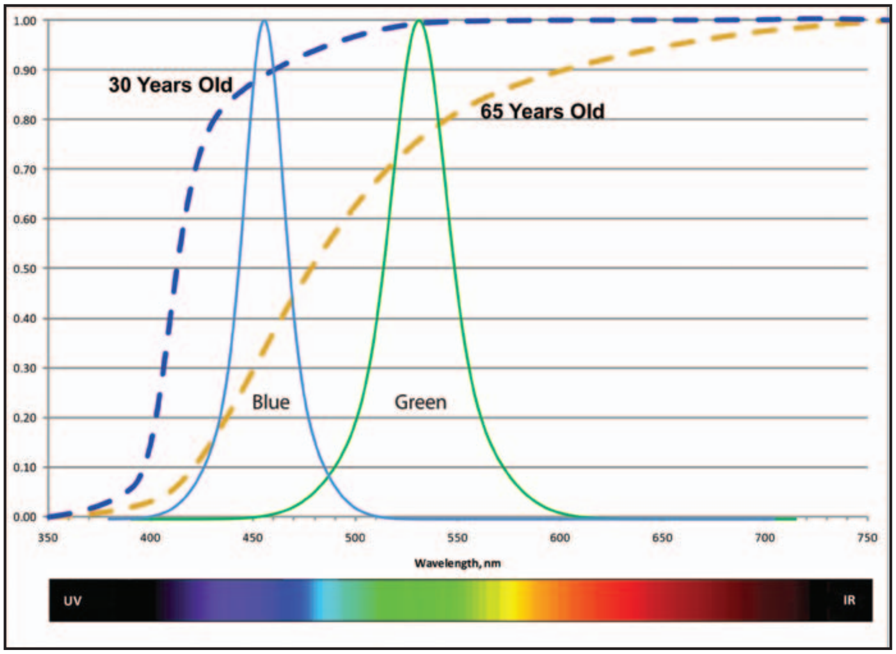

Figure 6 – Narrow band LED additive light source

effectively moves the white point from, in this case, a 6,500 K daylight at age 30 out to almost a fully saturated amber by the time you are in your mid 70s.

I got to thinking about what this might mean in entertainment lighting. We clearly have coped with the problem when using continuous sources such as incandescent, along with continuous filters such as gels. However, what happens when those sources and gels are replaced by narrow band additive mixing? Does it make things worse? Well, yes, I think it does, considerably so!

I took the human eye data described above and replotted it against the kinds of sources that we are familiar with. **Figure 5** shows the lens transmission curves for a 30-year-old and a 65-year-old against the spectrum of a cyan gel in front of a continuous broadband white light source. The 30-year-old eye sees just about the whole of the cyan spectrum, with very little distortion. Only the very deepest violet wavelengths are reduced. However, the 65-year-old eye sees a reduction in the deep blue and some mid-blue as well. Overall this will shift the perception of the older viewer to seeing this as a more greenish cyan than the one that the 30-year-old sees. Because the curves are broad, and only the top end is reduced, the change is fairly subtle, and likely not too much of a problem. The peak of the cyan is not affected significantly at all.

However, the situation is potentially very different if you use narrow band additive mixing from LED sources, particularly if you only use three color RGB mixing. Now we get a situation more like that shown in **Figure 6**. In this case we have mixed a green and blue LED to make a cyan that matches that shown in **Figure 5**. Instead of wide bands of single colors, we have two narrow spikes, one blue and one green. There is no actual cyan light, instead our eyes take in the two spikes and the brain perceives a single cyan color somewhere in between them. The 30-year-old eye sees this as intended, with very little reduction in the blue spike. However, the 65-year-old eye now sees the blue spike dramatically reduced in intensity because of the effective yellow filter in the lens. In fact, in the hypothetical case illustrated, the blue is reduced by as much as 70%. The green, on the other hand, is only reduced by 20% or so. The net result is a significant change in the mix, and a swing in the perceived color towards the green and away from the blue. The 65-year-old viewer will be seeing a much greener cyan than the 30-year-old does.

Now consider what might be happening in a theatrical production when the lighting designer mixes the colors in their RGB additive LED light to make a cyan. In one scenario, the designer is young and mixes what they see as a mid-cyan. However, if the demographic of the audience for that show is older, then that won't be what they see. Instead they will see a much greener cyan. Well, you might say, we can't mix the lights according to our audience, we have to take a mid-position and mix to an "average" eye. Okay, but what about the lighting designer themselves? If, in this same case, the lighting designer were older, then they would add a lot more blue into the mix to subconsciously compensate for their yellowing eyes so that the cyan looks right to them. Then, a younger "average" audience would see the mix as having too much blue, more than the LD intended.

What are you going to do? Issue each member of the audience with a specifically selected pair of blue or yellow tinted sunglasses, chosen to match their age so as to bring everyone to the same point as the lighting designer? Clearly that's nonsense. We accommodate these nuances and foibles, if we even notice them. However, it perhaps makes you wonder about stressing over color mixing on lighting desks when the age of each audience member is likely to shift the perceived color more than the tolerance of the system. Particularly with simple three-color additive RGB lighting, I think this is a real issue, but it's a waste of time worrying about it too much. You can never have full and complete knowledge of what your audience is seeing. How old are they, and have they had cataract surgery, or not? Arguably if the audience is consciously noticing and thinking about these nuances in the lighting, then something more major is wrong with that show. (Although I suspect that many of you, like me, do tend to watch the lighting way too much when we go to the theatre. It's an occupational hazard that really annoys our spouses.)

It isn't all bad though. As additive color lighting gets better with broader coverage and less missing colors, then this issue diminishes again. In particular two enhancements help this problem. Use more colors of narrow-band LEDs to fill in the gaps, or use broader band, phosphor-converted LEDs. Both of these solutions are already seen in many theatrical lighting products as we know they make colors look better and improve color rendering. What they will also do, which is perhaps not so obvious, is make the colors more consistent for all the audience, no matter their age. ■

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