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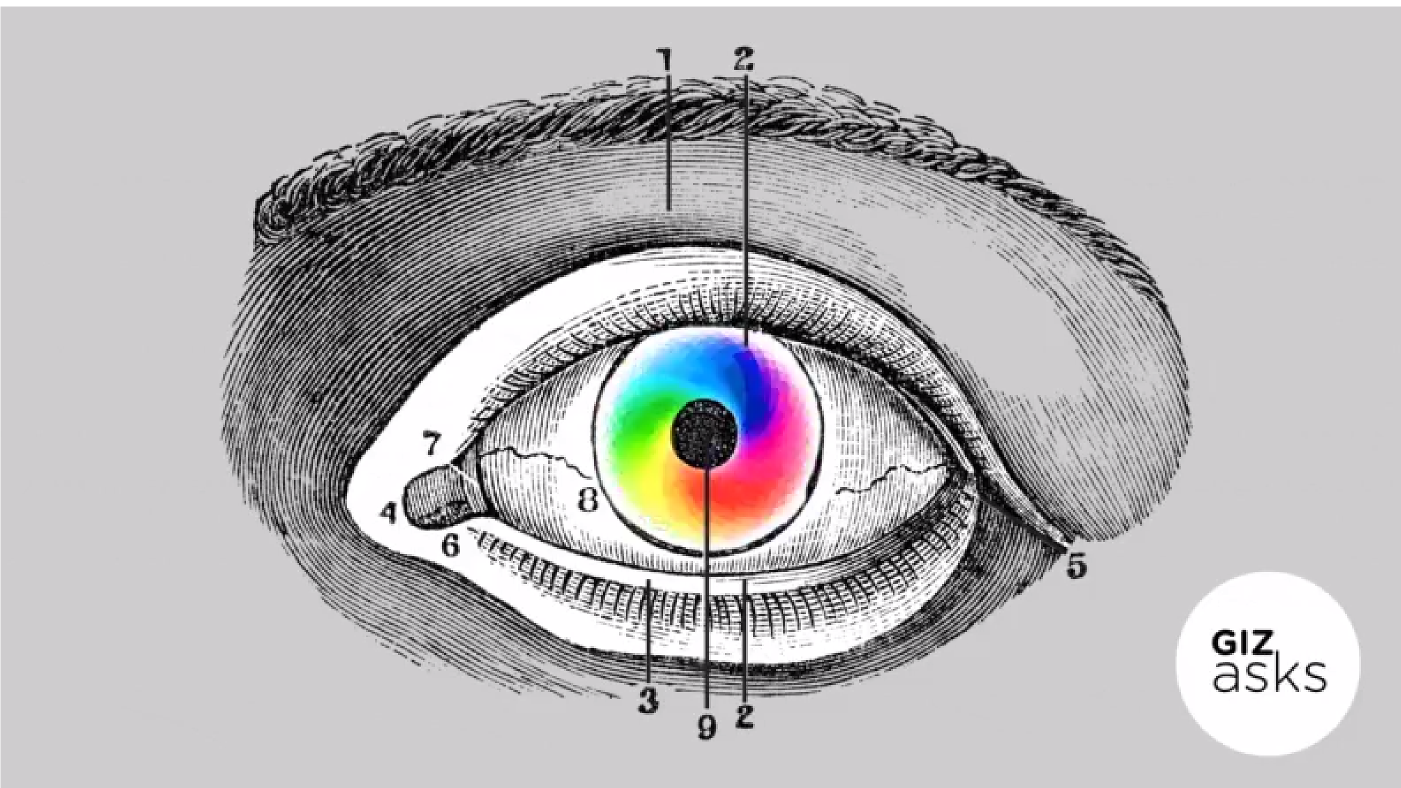
GIZ ASKS

Will There Ever Be New Colors That We Can See?

By Daniel Kolitz | 5/06/19 8:15AM | Comments (39)



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When brain chips break big, and commercial tech giants start sifting our thoughts and swapping cherished memories for subscription wine box ads, there will be plenty of reasons to be skeptical. But if this future is inevitable, we might as well dwell on the good stuff. New colors, for instance: for years we've been saddled with the same old spectrum, but the right skull implant might conceivably reveal a whole new one, its colors indescribable until we see them, and name them.

technological or otherwise—that we might, sometime in the future, escape the ROYGBIV paradigm? For this week's Giz Asks, we spoke with a number of color scientists to find out.

Mark Fairchild

Professor of Color Science and Director of the Munsell Color Science Laboratory at Rochester Institute of Technology

> The answer really depends on how you define "we." If "we" means current human beings, then the answer is a fairly definite "no." If we allow for future evolution, then it is possible that humans might develop different types of color sensors in their visual systems and new types of processing to allow them to experience new color perceptions.
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> The key here is that the definition of color, in a technical sense, relies on human perception. Color is a human perception. Therefore, while new techniques for producing stimuli that evoke color sensations will certainly be developed (e.g. today's televisions easily produce stimuli that the televisions of my childhood could not muster), color is ultimately a perception and limited to the capabilities of the human visual system. Short of evolutionary changes in human perception, we aren't likely to see any new colors. However, our attention might be drawn to perceptions that previously went unnoticed.

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Interestingly, we can perceive colors that are often considered physically impossible. For example, a single wavelength of light is typically considered the most highly saturated (colorful) stimulus that we can perceive. But let's suppose we take a wavelength that appears saturated green under normal circumstances. If we spend some time first viewing a strong reddish stimulus (closing your eyes and facing a strong light source can do the trick), we will adapt to the reddish light and thus become relatively more sensitive to green light. If we then view the green wavelength of light again, it will appear to be an even more saturated (colorful) green—which is something that is sometimes thought to be physically impossible. Color depends not only on the physical stimulus, but on the state of adaptation of our visual system (what we've seen previously) and even our psychological expectations (but that's a much more complex story). Thus, there is really nothing new under the sun that our visual systems can perceive and that we haven't already perceived, although attention might have been lacking. Therefore, there are no new colors waiting to be discovered for us to perceive in the future.

Of course, the above only applies to colors perceived through the perception of light through our visual system. We can also perceive colors through non-visual means such as hallucinations, dreams, and our imagination. I won't be so quick to rule out new color perceptions from these non-visual stimuli, but it is difficult to imagine. Give it a try.

Robert Johnston

Assistant Professor, Biology, Johns Hopkins University, whose research focuses on human retinal organoids, among other things

> Light is electromagnetic radiation that is emitted at different wavelengths. These different wavelengths determine the nature of color. People see wavelengths from about 390 to 700 nm. This is the "visible spectrum," including red, orange, yellow, green, cyan, blue, and violet. We have three cone photoreceptors that detect red, green and blue light. Sensation by combinations of these cones allows us to see the colors of the visible spectrum.
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> There are wavelengths of light outside of the visible spectrum, for example ultraviolet and infrared. We know of several species that have opsin proteins that enable cones to see UV light. There are two ways that humans could one day also see UV light. The technology already exists to put DNA encoding opsin proteins into people. The lab of Jay and Maureen Neitz injected a virus that contained this DNA into the eye of a color blind monkey. By supplying the opsin for red color vision, they gave the monkey full color vision. We could use this same technology to put UV opsin into humans, giving them the ability to see UV light.
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> My lab, the Johnston Lab, works on a different technology that could give a person the ability to see UV light. We are differentiating human stem cells into mini retinas, called "organoids". Many groups are working to transplant these organoids into people. We could reprogram the cone cells to sense UV light and then transplant the cells themselves.
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> The cone cells that sense color are also the cells that let us see well during the day time. The main goal of this research is to restore vision to those have lost the use of these important cells. Though we are focused on helping those with retinal

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Susan Farnand

Assistant Professor, Color Science, Rochester Institute of Technology

> The answer is, in all likelihood, no. Color is a perception. We can expand the wavelength range of the radiation that we can detect. Night vision goggles, for example, allow us to detect near infrared radiation, but do not provide a new color. To generate a new color, we would have to modify the way our brains interpret the detected radiation. Given the complexities of the visual system, the chance of success is quite low and the risk of permanent damage is extremely high. This kind of rewiring of the brain for the sake of seeing a new color seems prohibitive.
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> There is considerable research being conducted to understand the visual pathways from the retina into and throughout the brain. A substantial portion of the brain (a third or more) is involved with making sense of the input from the visual system. Sorting this all out is quite complicated.

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> There are cases of people who were born functionally blind due to problems with the optics of their eyes and who had these problems repaired as adults but generally had difficulty interpreting the radiation that they could then sense. These pathways are established as we learn to 'see' very early in life. If prevented from doing so—by congenital cataracts, for example—people may never 'see' normally, especially things that were not learned through touch.
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> Further, though such patients do report being able to see color, we have no real understanding of what their experience of color actually is. For that matter, we cannot be certain that your experience of blue is the same as my experience of blue. We both refer to the color of the sky as blue and we can distinguish this color from the color of a banana, which we will both call yellow. But, we do not know that your experience is the same as mine.

Bevil Conway

Head of the Unit on Sensation, Cognition, and Action at the National Eye Institute, whose work focuses on visual perception, among other things

> The answer, I think, is "Yes, of course!"
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> There are two reasons why I'm confident, but to understand these reasons, it's useful to revisit how color comes about. Color is a perceptual/cognitive process that arises because of the way our brain processes the light information that hits the retina—critically, this processing incorporates expectations and other kinds of

aren't looking at a banana right now. In practice, this means that anytime you consider the color of something, you are not only basing your color judgement on the light information hitting your eye, but also implicitly on assumptions or ideas you have about what color you think you are seeing. Because color depends on so many factors—the physical stimulus that hits the retina, and the brain processes that handle this information—there is lots of scope to "invent" new colors. Changes in technology or discoveries in our understanding of how the brain works could both give rise to "new" colors.

New technologies are emerging all the time, and with these new technologies come new possibilities to make new colors. It would be naïve to assume we had reached the technological limit already! Artist materials from ten thousand years ago, when early humans were etching graphic marks on cave walls, were restricted to natural colors derived from earth ochres and charcoal (essentially browns, reds, and blacks). Artists working back then probably couldn't imagine the invention of new colors. But history has been marked by major, unexpected, jumps in the development of new pigments—the extraction of different kinds of minerals, the invention of new chemical pigments that exploded with the industrial revolution, the invention of myriad fluorescent pigments, the development of neon lights, and lasers, and LEDs, and color filters. Each technology brought with it colors we hadn't seen before, and each was surprising. A recent example is the structural color Vantablack, which isn't a pigment at all, but a microscopic 3-dimensional structure that traps light so effectively it is essentially perfectly black. Given this track record of invention, it would be surprising if the future didn't bring with it the invention of new pigments.

"Changes in technology or discoveries in our understanding of how the brain works could both give rise to 'new' colors."

> information often comes curious hints that allow us to create new visual phenomena, or appreciate in a new way old phenomena, thus changing our visual experience. The viral image of #thedress is a great example, where new technology (social media) exposed millions of people to a quirky photograph, and uncovered a new phenomenon of a multistable color image. The scientific discovery of how the image works has changed our conception of how color works, which in turn has changed how we experience color. I would argue this has given rise to colors we have not experience before. Color afterimages, the "impossible colors" (reddish greens) that arise by stabilizing the eye, and color experiences that emerge from direct electrical perturbation of the brain, are other ways in which we have experienced new color phenomenon, not by developing new stimuli but by an understanding of how the brain processes vision.
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> And finally, there is at least one other way I imagine we will create new colors: by changing the genetics of the eye. The technology now exists to change the spectral tuning of the eye itself. This technology is not yet approved for use in humans, and there are great ethical questions that need to be addressed before it is used in humans, but it raises the distinct possibility that we could change how the eye responds to light, and invent new colors in the process.

Stephen Engel

Professor, Psychology, University of Minnesota, whose research focuses on visual perception, and how experience can change it

> No and yes, depending on what we mean by color.
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> If we define color as our experience when we see a flat uniform surface in isolation—think of a Pantone color chip—then the answer is no. Our experience of color begins when three kinds of light-sensitive cells in our retina, called cone photoreceptors, respond to the spectrum of light reflected from a surface like these chips. This means that the visual input for color can be boiled down to three

measured the perceived color that many many combinations of these three levels of photoreceptor activity produce and there are not likely to be any surprise combinations that produce new colors.

On the other hand, our experience of color depends dramatically on the context in which we view things. The ability to produce neon green under normal light, for example, was invented relatively recently, and depends upon the green object looking, and sometimes actually being, brighter than objects surrounding it. Scientists have long known about these context effects on color perception, as has everyone else—they are the reason, for example, the right eye shadow can change the color of one's eyes. But the number of possible contexts is hard to determine, and knowledge of how context affects the colors we perceive is incomplete at best. This is especially true if we consider that context extends over time as well as space, and if we consider our internal context as well, sleep, drugs, etc.

So, it remains possible that people may invent new contexts that produce new color experiences. For example, viewing a certain arrangement of colors for a time, and then viewing a chip of material surrounded by just the right other stuff, could produce a color one has never seen before. I cannot say how easily such a combination could be found, but it should be discoverable in principle.

"It remains possible that people may invent new contexts that produce new color experiences."

Joseph Carroll

Professor of Ophthalmology and Director of the Advanced Ocular Imaging Program at the Medical College of Wisconsin presence of three types of cone photoreceptor in the retina (long-, middle-, and short-wavelength sensitive). Light incident on the retina is absorbed by photopigments in these cells, which initiates a processing and signaling cascade from the neurons in the retina on to the visual cortex. Importantly, light is not colored, rather color is a sensation generated at a much higher level of our visual system.

Humans who are red-green color blind are lacking either the long- or middle-wavelength sensitive cone type. The result of this is a reduction in the number of wavelength combinations that can be discriminated from about 1,000,000 to only 10,000. However, the range of wavelengths a colorblind retina can detect is pretty much the same as that of a normal trichromat. So, the light reflected off a ripe apple still reaches their retina and can be considered "seen." Moreover, they may call that sensation "red" based on a variety of learned factors. However, they may also call an apple-shaped plum "red," suggesting that the color sensations in a colorblind individual are indeed different.

If a reduction in the types of cone in a retinas reduces color vision, what about expanding color vision? Some insight into this comes from the work of Jay and Maureen Neitz at the University of Washington who added a third type of photopigment to a colorblind squirrel monkey. They showed that it was essentially possible to "cure" their colorblindness. There is no real reason why a 4th or 5th type of photopigment couldn't be added to the human retina. If the sensitivity of this new pigment is outside the range of spectral sensitivity of the long-, middle-, and short-wavelength sensitive pigments, then we would in theory be able to detect (or "see") new wavelengths–such as infrared or ultraviolet (though the human lens does normally filter out ultraviolet light). How this translates to experiencing a new color sensation may not be as straightforward, as to some extent our visual system has been trained on the properties of the images in our environment and the statistics of the light reaching the retina. If the statistics change due to a new photopigment, it's not clear how the brain would cope with that in deciding what color to associate with the new sensation. But in such an experiment, if the responses of the new photopigment is able to be

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DISCUSSION

By sing.electric

I'm surprised that none of the experts that discussed the "learned" experience of color mentioned now "new" blue is. The word for "blue" is much younger than the words for other colors in a lot of languages, and was added relatively recently.

Homer wrote of the "wine dark" sea, but never used "blue" - I don't think most people today would look at the sea and think "that's the same color as wine," but when you don't have a word for blue, you've got to come up with something.

And its not just a word, it's actual *perception*. Some cultures still don't have a word for "blue," and because of this, they don't connect the color of say, the sea with the color of the sky. They obviously are receiving the same wavelengths of light into their eyes, and in all probability, their eyes are translating those signals to the brain, but when it comes time to "interpret" those colors (as being similar to another thing, or different than another), which happens as our brains learn