Synesthesia:

Where does Color Exist?

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Where does color exist? As a property of light in "red wavelengths," as a neural calculation by retinal photoreceptors, or as a calculation in the brain? The perceptual couplings of synesthesia, along with color constancy and colored shadows, suggest that color is not a property of objects: In order to be biologically useful within our environment of ever–changing illumination, the brain must assign stable colors to surfaces. Color exists only within the silent darkness of an individual skull.

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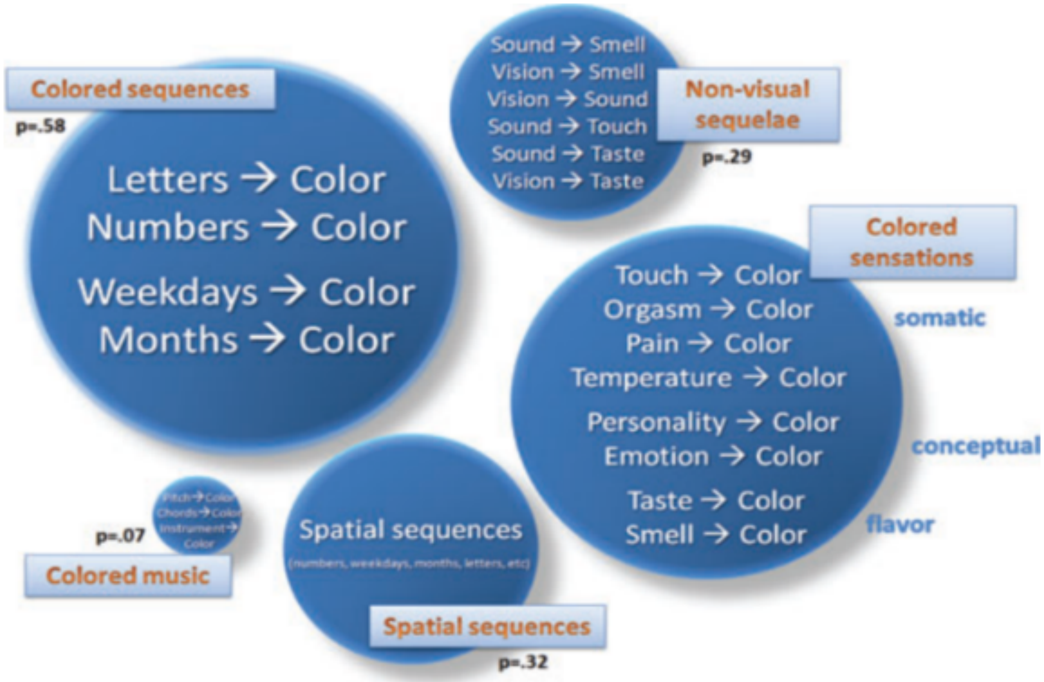
The Journal asked me to comment on synesthesia and the question, "Do colors exist and do they belong to the real world?".

First, a definition: Sharing a root with *an*–esthesia ("no sensation"), *syn*–esthesia means "joined" or "coupled sensation". Synesthesia is not a neurological disorder but rather a perceptual trait like having perfect pitch or the ability to taste phenylthiocarbamide (PTC) as bitter while the majority taste nothing. Four percent of the population (~1 in 23 individuals) carry the genes for it. It runs strongly in families as an autosomal dominant trait (Vladimir Nabokov's family is a famous example) but it is not expressed with 100% fidelity. This leaves a smaller number of 1 in 90 exhibiting some kind of overt synesthesia.

Unlike zombies, a synesthete does not replace one sense for another but rather adds qualia to the original, or inciting, sensation. Thus, a synesthete may not only *hear* my voice, music, or an ambient sound but additionally *see* it, *taste* it, or *feel* it as a physical touch. The most common manifestations are perceiving days of the week as colored, followed by seeing letters and numerals as colored whether printed or spoken[1]. Figure 1, representing 19,000 individuals, illustrates that certain varieties cluster. If you have one type of synesthesia, you then have a 50% chance of having a second, third, or fourth type[2].

[1] For further examples see R. Cytowic, *Synesthesia*, MIT Essential Knowledge Series, MIT Press, Cambridge Ma. 2018.
[2] Figure 1. If graphemes are experienced as colored (upper left circle), then a synesthete will likely see other rote sequences as colored, too, but not combinations from other clusters. The fact that experience clusters like this tells us that synesthesia is not a singular thing but should be thought of as an umbrella term for outwardly evident couplings that result from a number of inward neurological mechanisms.



With respect to visual qualia, synesthetes never see pictorial images, but rather generic shapes such as lines, crosshatchings, circular forms, spirals, and tunnels. Imagine something like fireworks: a configuration arises, moves, scintillates a bit, and then fades unless the stimulus persists to replenish the photisms. A strong emotional charge is often present, too, as it is in the case of fireworks.

Explaining color has been an historical challenge for philosophers. It has likewise been a challenge for scientists. While the Young and Helmholtz theories predominated for many years, neither could account for the perceptual phenomena of color constancy or colored shadows. That is, a sheet of paper will continue to look white, an apple red, and a banana yellow despite wide variations in light intensity and wavelength composition coming from tungsten, fluorescent, LED, or daylight sources. This is color constancy: to the eye, measurably different stimuli look the same. We can demonstrate colored shadows by lighting an object with a colored light, say a red one. The shadow cast looks black as we expect it to. But when white light is added, the shadow suddenly turns green even though there is nothing but white light falling on it. With a yellow light and white light the shadow looks blue, and so on. Where, then, do the colors come from?

If the three retinal photoreceptors acted like spectrophotometers (as intensity meters with peaks in three different parts of the spectrum) then an object's color would be obliged to change dramatically as the quality of illumination changed. Moving objects would be especially confusing and color would have little biological utility given that the composition and intensity of daylight changes moment to moment depending on the sun's angle, shadows, cloud cover, and the amount of water vapor and particulate matter in the air. The fact that colors remain constant indicates that our photoreceptors do not operate this way. The redness so evident in daylight film exposed to incandescent light never bothers us when we step indoors to tungsten–lit rooms. Our nervous system does not perceive the extra red because it does not depend on the flux of radiant energy reaching the eye to determine color. So what does it depend on?

The Retinex theory, promulgated by optical scientist Edwin Land, inventor of Polaroid, seemed to explain these two puzzles and answer the question of whether color exists in the real world or only in perceiving minds. Land published his experiments starting in 1955 and refined the theory with collaborator John McCann into the 2000's. His work had the flavor of Gestalt psychology in that it relied more on demonstration than logical argument. He showed that differently colored rectangles lit to send the *same* information to the brain, still registered as *different* colors despite the fact that the only information reaching your eye that you know of is the wavelength composition of the light coming from a given area. Land's demonstrations flummoxed those who contended that physical wavelength determines color perception. It wasn't until 1989 that V4, the unique color area in the human brain, was discovered thanks largely to Samir Zeki at University College, London and his decades of electrode penetration studies in macaque visual cortex. Zeki's experimental designs relied explicitly on Land's Retinex framework.

What V4 does is compute a ratio between a given point and all surrounding points, and then assign a color to a surface. Color has enormous utility compared to its biological cost because it assigns stable features in an otherwise constantly changing visual world. To answer the original question above, color most assuredly exists but not in the external world. One often hears that something looks red because it reflects more red wavelengths. But there is no such thing as "red wavelengths". Even Newton when explicating his prism experiments said, "There are no colors in the rays". Colors exist only in a perceiving mind, within the silent darkness of an individual's skull.

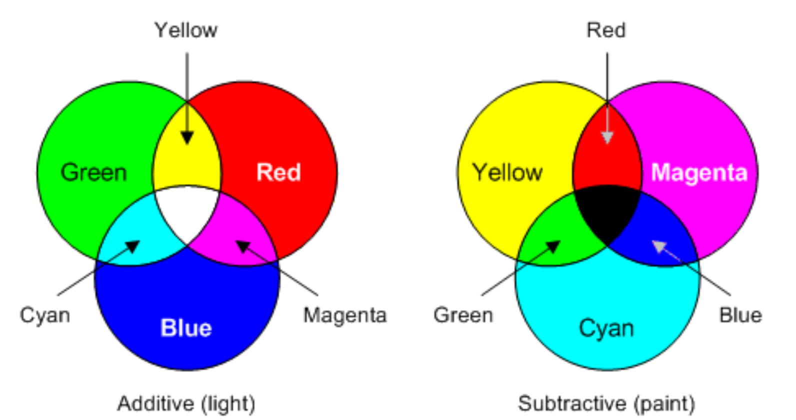
Why does color figure so prominently in synesthesia? Perhaps because vision constitutes 85% of the brain's inputs and the color system operates at a low resolution compared to other aspects of vision such as form, contrast, spatial location, stereopsis, and movement. Video 1 illustrates the separation of color from form: despite the boundary, the brain makes the color flow into the line. Similarly, when early engravers tinted black–and–white prints they understood that they could run outside the lines without worry (figure 2)[3]. The "watercolor effect" allows colors to bleed beyond boundary lines because the color network has fewer cells and a greater receptive field. Loosely applied color appears to conform to high–contrast outlines even though actually it does not.

[3] Figure 2. The "watercolor effect" allows for loose application of color. The low-resolution of the color system makes it appear to adhere to higher-resolution linear boundaries.

Carol Steen, a well–known sculptor and painter lamented to me the inability to match her painting palette to the synesthetic colors she saw. I explained that synesthetes perceive the additive colors of light (RGB) rather than the subtractive colors of pigments (CMYK) (figure 3). For all the talk of their "gorgeous colors", synesthetes admit to seeing "weird", "ugly", or "washed out" colors that they normally would not pick. One individual with an S–cone deficiency that renders him unable to distinguish blues and purples speaks of seeing "Martian colors". That is, he sees synesthetic colors he is incapable of seeing in the real world. The reason such "unnatural" colors exist is that V4 is being stimulated via non–optical routes such as graphemes, phonemes, tastes, or sounds.

There is of course an enormous difference between the *idea* of synesthesia and the perceptual phenomenon. Pseudo–synesthetes freely engage in deliberate contrivances as in Georgia O'Keefe's paintings, "Music: Pink and Blue", Alexander Scriabin's *Prometheus,* which features a light organ and a separate stave for its notation, and Sir Arthur Bliss' "Color Symphony". By contrast true synesthetes include composer Olivier Messiaen, who invented his modes of limited transposition method specifically to convey the colors that natural sounds evoked; Wassily Kandinsky whose four types of synesthesia influenced his paintings; and Vladimir Nabokov who referenced synesthesia ad lib throughout his fiction and whose family manifested the trait over three generations (his son Dmitri wrote about his famous family in the afterword to *Wednesday is Indigo Blue*). More contemporary synesthetic artists include Billy Joel, Lady Gaga, David Hockney, and Pharrell Williams.

Efforts throughout history tried to establish a fixed correspondence between color and sound. Sir Isaac Newton was perhaps the first, Goethe took a stab at it in *Zur Farbenlehre* (*Theory of Color*, 1810), and Kandinsky most famously sought the translation key for correspondences among all the senses in *Concerning the Spiritual in Art* (1911). Alas, these efforts failed because there is no universal translation algorithm equating one sense to another. That should be apparent from the fact that synesthetic perception is idiosyncratic;

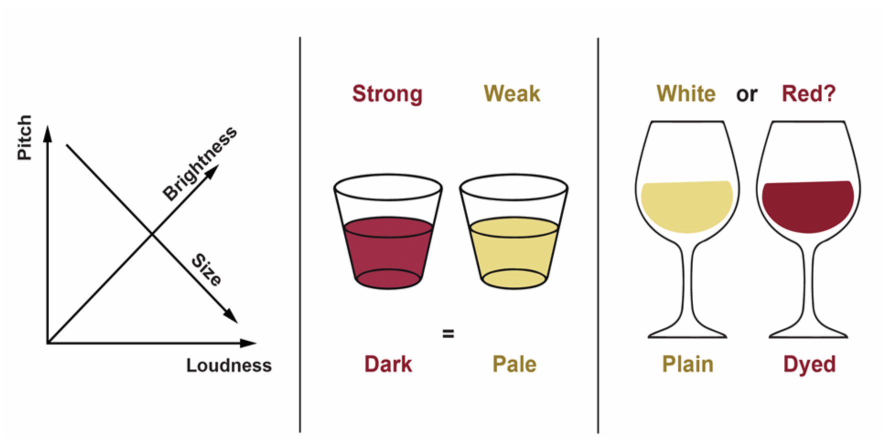


Additive and subtractive color combinations

even twins with colored hearing do not experience the same colors. It is too easy to equate visual wavelength with color and then conflate wavelength with auditory Hertz. Sound frequency does have a point–to–point correspondence along the inner ear's basilar membrane as well as along Heschl's transverse temporal gyrus (i.e., it is tonotopically organized). But neither wavelength nor perceived color has a similar kind of one–to–one representation in the retina or anywhere else in the visual system.

There do exist, however, regular and orderly psychophysical correspondences among certain sensory dimensions (figure 3)[4]. For instance, both synesthetes and non–synesthetes say that higher tones are smaller than low ones, and that louder ones are brighter than soft ones. Even smell maps to lightness and intensity as both chefs and psychologists know. Both say that dark liquids taste and smell stronger than their equivalent pale versions while the unsuspecting say that white wine surreptitiously colored red, smells and tastes like red wine. And of course Mom was right when she scolded that your eyes were bigger than your stomach. We do eat with our eyes. "This *looks* delicious", we say, never the future-oriented, "This is *going to taste* great".

Skeptics often accuse synesthetes as "merely remembering" past associations from



refrigerator magnets, making it up to get attention, or else suffering from residual hallucinations from prior drug use. Aside from all the failed attempts to prove that synesthesia is a learned association, standard psychometric tests confirm that synesthesia is indeed perceptual. For example, if I project a numeral into your peripheral vision while

[4] Figure 3. Lawful, orderly correspondences exist among sensory dimensions. See text.

instructing you to look straight ahead, you can still make it out. But if I then surround it with other numerals it becomes invisible, a phenomenon called masking. Synesthetes likewise can't make out the masked digit but will say things like, "It must be '7' because I see green". Similarly, if I show you a matrix of 5's in which I've embedded a hidden figure made of mirror–image '2's, it will take a while to search and find it. But synesthetes who see 5's as differently colored from 2's quickly pick out the embedded form.

Experiments like these tell us that synesthetic coupling happens early in perception, perhaps before one is even aware of a stimulus at all. This has obvious relevance to the study of consciousness, as well as to orthodox notions of modularity and functionalism. Jeffrey Gray argued that synesthesia was the death of functionalism. Against the claim that "qualia are the functions (input–transformations–behavior) by which they are supported, and nothing more," stand the incompatible conditions of (a) 1 function → 2 qualia and (b) 2 functions → 1 quale. Synesthesia constitutes incompatibility (a) [1].

People frequently ask whether synesthetes aren't overwhelmed by their extra perceptions. The answer is a definitive no. They love their experience. To be without the trait would be as odious as a non-synesthete going blind. As to whether they get confused, imagine a blind friend commiserating, "Oh you poor thing! Everywhere you look you're always seeing something. Doesn't it drive you crazy to always have to see everything?". Of course not. Seeing the normal texture of reality. Synesthetes simply have a different texture of reality than most of us.

Synesthesia is normally one-directional: sound to sight, but not the reverse. In the small proportion of individuals in whom it *is* bidirectional, it tends to overwhelm them. A British music teacher who underwent extensive testing to verify her bidirectionality lived a relatively quiet life in the country. For a BBC documentary she gamely agreed to walk about Piccadilly Circus at night. The "screaming" color sounds of the neon lights quickly made her ill, and she asked to be taken away.

I'll close with the assertion that all of us are synesthetic, except that in 96 percent of us these common cross-couplings do not arise to consciousness. Aside from the corresponding dimensions of sensation mentioned above, we all lip read, which explains why even bad ventriloquists convince an audience that the dummy is talking. Cinema likewise persuades us that dialogue emanates from an actor's mouth on screen rather than the surrounding speakers. And the louder the surrounding environment gets the more we have to *look at* a person to see what they are saying. Metaphor (which by definition reveals the similar in the dissimilar) illustrates counterintuitively that it is not poetic or a highly abstracted trope of language, but rather a physically concrete experience that antedates language. Without synesthesia, metaphors like "loud tie" or "warm color" would be incomprehensible. Perceptual similarities such as "dark is also strong" yield to synesthetic equivalences, such as "I know it's 2 because it's white". These then evolve into spatial metaphors, such as "Good is up, bad is down," or ontological metaphors like "Ideas are light". Language elaborates the latter into phrases like "Brilliant!" "That was a bright idea", or "I see what you're saying".

And thus we have a continuum in which synesthesia is closer to concrete sensory experience than to the abstractions of language and high-order thinkng:

Perception → Synesthesia → Metaphor → Language