and (outside the laboratory) uncommon viewing conditions" (sect. 3.1.1, last para.). By specifying a canonical illuminant, CIE-C coordinates overcome the first objection. Because they are mathematically equivalent to reflectance-type, they are no better or worse relative to similarity relations. Similarly, they can be extended to productances. The laboratory conditions objection is unfounded in any case. Of course, the CIE color matching functions were determined under special viewing conditions; nonetheless, given the standard matching functions, determining the tristimulus values of a given reflectance under a canonical illuminant is a matter of straightforward calculation.

Whether the physical property to be associated with color in a physicalist approach is B&H's reflectance-type or a 3-parameter illumination-independent specification such as CIE-C, there remains a significant gap between the property and the precision with which the visual system can determine it.

Do metamers matter?

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Abstract: Metamerism is a rather common feature of objects. The authors see it as problematic because they are concerned with a special case: metamerism in standard conditions. Such metamerism does not, however, pose a problem for color realists. There is an apparent problem in cases of metameric light sources, but to see such metamers as problematic is to fail to answer Berkeley's challenge.

What makes the existence of metamers problematic for the color realist? According to Bryne & Hilbert (B&H), two objects are metamers insofar as they have different reflectances yet "match in [apparent] color under a given illuminant" (target article, sect. 3.1.1, para. 1). Metamers, claim B&H, are rare. But at least for this definition, this is false. Walk into any room full of objects and turn down the lights. Long before the "given illuminant" is too low for us to see at all, all the objects will match in hue. Similarly, in the parking lot, under low-pressure sodium lights, all cars appear to have the same color. And then there is the notorious case of metameric socks: The navy blue and black ones form metameric pairs in the early morning light of my bedroom. Metamerism, or what one might call common metamerism, can result from either of two facts: Our ability to accommodate to changes in illumination is less than perfect, and, under some illuminants, no mechanism could preserve color constancy.

Such a wide variability of causes of identical color appearances seems intolerable, so the standard way color realists define colors is by their appearance under just one illuminant – standard conditions. Objective red is the SSR of those objects that appear red to normal observers under standard conditions – daylight, for example, or perhaps white light. The only troublesome metamers are then the sets objects of quite different reflectances that are indistinguishable to normal observers in standard conditions. Such metamers could be distinguished by their appearance if only we had different color systems, most notably if we had more than three cones. Fortunately, standard-condition metamers are very rare in nature, so the problem of such uncommon metamers is perhaps not a practical one.

The problem is that the same determinate color can be identified with any number of different metameric SSRs, and the choice between them is arbitrary. B&H's proposed solution is to take determinate colors to be reflectance *types* rather than reflectances. A fully determinate shade of red is, in fact, a perceptual equivalence class of reflectances, those that a normal human trichromat cannot distinguish in standard conditions. Colors are fully objective; color types, both determinate and determinable, are anthropocentric.

But is a solution needed? Suppose the color sophisticates at Toyota develop a new paint, Metameric Blue. In daylight, Metameric Blue appears just the same as another Toyota color, Mundane Blue. At sunset, Metameric Blue cars take on a sophisticated silver-blue tint. In Toyota brochures, Metameric Blue and Mundane Blue are listed as two standard color choices. How else would one list them? Moreover, if standard condition metamers became widespread, we would carefully check our potential new cars, laptops, and cellular phones under the appropriate illuminants before we chose them

The moral of the story: If what counts as a determinate color is a matter of which SSRs are indistinguishable to a normal observer, then indistinguishability under standard conditions is the wrong criterion. If we can distinguish one SSR from another under at least one illuminant, we have two determinate colors. This goes for determinables as well: To be red is not just to look a certain way in standard conditions. It is to look the right way (red!) across a range of conditions. The cosmetics industry has long known this. A red lipstick which, in candlelight, looks slightly orange is really an orangey red, even if the difference between it and one that appears pure red in candlelight is below JND under standard conditions. That's why cosmetics' counters have those silly mirrors. Statistically, white light gives us the best chance of discriminating between the SSRs of objects. But there will be pairs of SSRs that are only distinguishable if we skew the SPD of the illuminant so as to increase the signal-to-noise ratio in the relevant part(s) of the spectrum. The proper solution to the problem of metamers – common and uncommon – is thus to simply accept that the same color will have different appearances in different conditions. For something to be blue, it must look just the way blue things ought to look in green light, blue light, white light, and, indeed, no light at all.

Still, there are the metameric pairs of psychophysics – those produced by triplets of light sources – that are genuinely indiscriminable. Here, there are no alternate illuminants to distinguish them, so we have pairs of quite different SPDs being classed as the same determinate color by normal observers after all.

Is this a problem for the objectivity of colors? Only if real colors are tied to apparent colors in a way that no other objective property is. Apparent colors are connected to real ones, according to B&H, because of the way the question of realism is posed. If all of our perceptual judgments of color turned out to be false, there would be no real colors. Should someone claim that physical properties of kind C are colors, but all our color judgments were false about those properties, the person would be changing the subject. But these points are perfectly general: They are not confined to "secondary" properties or even to perceptual ones. If a person claimed that being in debt was a certain kind of property humans can have, property D, but *none* of our judgments of indebtedness turned out to be true for his theory, he would be changing the subject. He would not be talking about indebtedness. And if there was *nothing* in the world that made a large portion of debt judgments true, indebtedness would be an "illusion." This is what happened to phlogiston, and to say that phlogiston turned out to be oxygen is indeed to change the subject.

That some, or even most, of our perceptual judgments of color turn out to be true is thus a minimal condition of color realism. Such a minimal condition is also true, for example, of the property of shape. But for a shape to be determinate is not for it to be indistinguishable to normal human observers under some (or even all) conditions. That every actual shape is determinate (i.e., of a fully determinate type, as B&H point out) is a basic fact about the world. It is not a fact about our perceptual acuity. Shapes go all the way down to, for example, waveforms of light. There is nothing at all puzzling about differences in shape that we cannot perceive, or perhaps even detect, with our best instruments. This is what it means for a property to be truly objective: It is independent of observers; or recognition-transcendent, as we philosophers like to say.

Thus, if colors are objective like shapes, and if indeed they are

SSRs, then determinate colors are just determinate SSRs. In tying determinate colors to what normal perceivers can distinguish, B&H have, in their own words "failed to answer what we might call *Berkeley's Challenge,* namely, to explain why perceivers should be mentioned in the story about the nature of color, but not in the story about shape" (sect. 2.2, last para.).

Parallels between hearing and seeing support physicalism

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Abstract: There are 2,000 hair cells in the cochlea, but only three cones in the retina. This disparity can be understood in terms of the differences between the physical characteristics of the auditory signal (discrete excitations and resonances requiring many narrowly tuned receptors) and those of the visual signal (smooth daylight excitations and reflectances requiring only a few broadly tuned receptors). We argue that this match supports the physicalism of color and timbre.

The correspondences between the perceptual properties of hearing and seeing are not simply one to one, but one to many. Consider color: the intuitively obvious correspondence would be color to pitch. Each "pure" color and "pure" pitch can be associated with a single wavelength, and it seems natural to associate colors with pitches and vice versa. Moreover, although there are not complementary pitches or metamers, there are pitch intervals (octaves and fifths) that have unique perceptual relationships leading to the circle of fifths and spiral representations of pitch height (frequency) and pitch chroma (octaves) (see Shepard 1982).[1] However, we believe that a richer correspondence exists between visual color and auditory timbre.[2] Here color and timbre belong to objects. Color and timbre constancy allow perceivers to break the sensory world into coherent objects in spite of variations due to surface illumination or due to excitation frequency and intensity. Without source timbre, there would be no connections among sounds. We are using the term timbre in a nontraditional way. By the ANSI (American National Standards Institute) definition, timbre is that quality that distinguishes two sounds at the same pitch and loudness, and therefore, each sound-producing object produces a set of timbres across pitch and loudness. Yet, timbre must necessarily be a property of the source (e.g., a flute, a Barbra Streisand) that allows the listener to segment the varying acoustic signals into stable sources.

If we accept the match between color and timbre, then we can argue that there are fundamental parallels between the production of color and the color receptors in the retina, and the production of sound and the auditory receptors (hair cells) in the cochlea. Such a parallel does not prove that color is the spectra due to the surface reflectance, or that timbre is the spectra due to the sound body resonances. But the fact that the visual and auditory sensory systems are specifically "tuned" to the different type of sensory energy for each sense does buttress both contentions and weakens the argument that sensory qualities are arbitrary constructions.

Both color and timbre are conceptualized as source/filter models, although it is the fundamental differences between both the auditory and visual sources, and filters, that are crucial to our argument. What is common to both hearing and seeing is the independent "multiplication" of the source excitation energy by the filter response. At this point we can imagine a second source/filter process: the resulting frequency spectra becomes the source and the sensitivity curve for the receptors becomes the filter. The excitation of each receptor is based on the multiplication at each frequency of the filtered source excitation by the receptor sensitivity: presumably the firing rate is a function of that sum across frequency (see Fig. 1 in the target article).

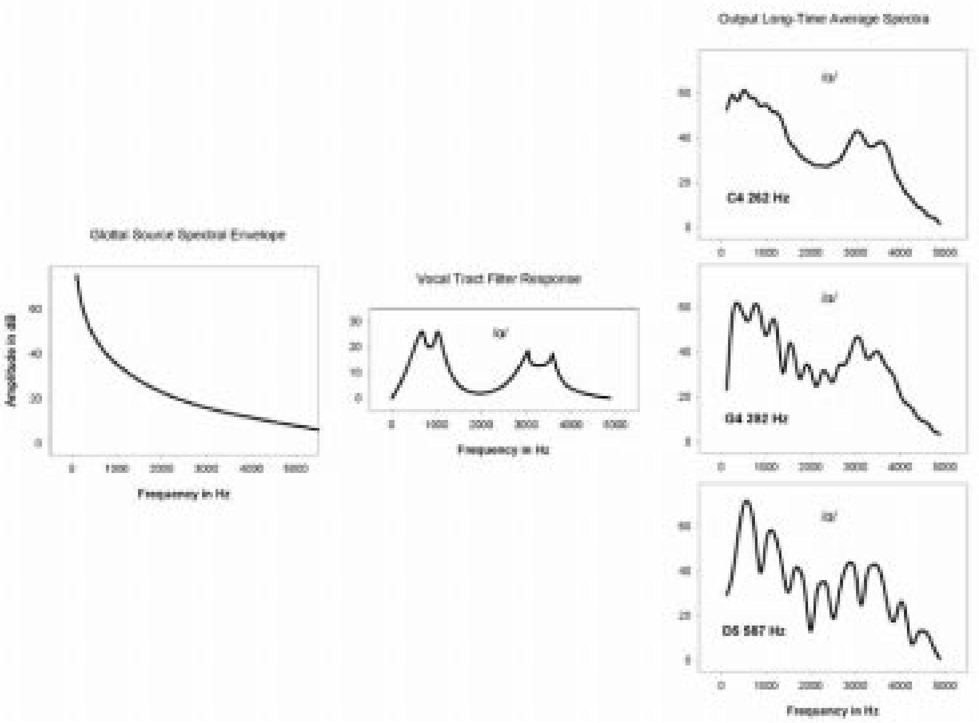

Figure 1 (Handel & Erickson). Representation of the source-filter model for the human voice. Output long-term average spectra are shown based on source frequencies of 262 Hz, 392 Hz, and 587 Hz.