The myth of unique hues*

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Abstract

The paper examines the notion, widespread in the contemporary color science, that there are certain hues, specifically focal red, yellow, green and blue (RYGB), that are unique or privileged in human prelinguistic color perception, all other hues chromatic hues being perceptually composed of these. I successively consider and reject all motivations that have been provided for this opinion; namely linguistic (unique hues as referents of necessary and sufficient color descriptors), "phenomenological" (unique hues as phenomenologically pure color experiences), and some minor or historical motivations. I conclude that, contrary to the standard opinion, there is no solid reason to claim that the RYGB hues are unique among colors in a sense that would allow for direct neurophysiological explanation. The notion also has no relevance for the construction of perceptual color spaces and is not defensible as an explanatory principle with respect to the existing crosslinguistic patterns of color categorization.

Keywords: unique hues; color; red, yellow, green, blue; color naming; categorization; opponency

1 Introduction

It is a common notion in the contemporary color science that there are certain hues, labeled "unique hues", that are perceptually unlike all other hues. Namely, these hues are phenomenally pure or unmixed and all other chromatic hues can be described in their terms since they are perceptually composed of two of them in a specific proportion. It is typically claimed that there are 4 such unique hues: pure (or focal) red, yellow, green, and blue.

The modern idea of 4 unique hues in perception dates back to the 19th century Prague and Leipzig physiologist Ewald Hering. Hering (1878, 1964 in

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English) coined his theory of color perception in terms of red-green and yellow-blue opponent mechanisms, in disagreement with the contemporary trichromatic theory by Young and Helmholtz (cf. Baylor, 1995). His ideas were revived in the influential opponent-process theory of color developed in the 1950s by the psychophysicists L. M. Hurvich and D. Jameson (1957). The opponent-process theory describes perceived color as a combined output of three psychophysical channels organized in an opponent fashion: red-green, yellow-blue, and an achromatic black-white channel. These three channels had been identified on the basis of the assumed phenomenal uniqueness of the respective colors, which was also confirmed by the subjects' consistent performance in experiments. Hurvich and Jameson's psychophysical findings then gained strong support from physiologists who described certain patterns of opponent color-coding (that is, activation of a neural channel by one color and inhibition of the same channel by another) in post-receptoral neurophysiological processing. (Valois et al., 1966; Valois and Valois, 1975.) The physiological primacy of four (or 6, including also white and black[1]) unique hues was subsequently adopted as a powerful explanatory principle in color categorization (or color naming) research (Hardin, 1988; Kay and McDaniel, 1978; in a more restrained form Kay and Maffi, 1999, and even Kay et al., 2009).

However, it turned out that the response patterns observed in the neurophysiological channels of color processing do not fit to the three primary perceptual oppositions that had been examined by psychophysicists. Despite continual efforts in neurophysiology, there is a wide consensus in the present-day color science that we are still lacking a plausible physiological explanation for the existence of four perceptually unique hues interrelated in a double-opponent way. (Cf. Broackes, 2011; Dedrick, 1998; Jameson and D'Andrade, 1997; Jameson, 2010; Krauskopf et al., 1986; Mollon, 1995, 2009; Saunders and van Brakel, 1997a; Wuerger and Parkes, 2011.)

The rhetorical situation is remarkable. The past deconstruction of the proposed link between the physiological and the perceptual has led almost everyone in the field to the following conclusion: further neurophysiological research is needed in order to bridge the epistemic gap between the observed neural fundament of color perception ("cardinal axes" given by color-coding preferences of neurons in the visual pathway), on one hand, and the well-known fact of there being four unique hues characterizing human color perception, namely (pure) red, yellow, green and blue (hereafter, RYGB), on the other hand. The latter, intuitively rather plausible description of the perceptual phenomena, surviving without a change from Hering's times, is taken for granted. That places the burden of connecting the perceptual and the physiological fully on neurophysiology. The perceptual primacy of RYGB is a common unquestioned assumption in the neurophysiological studies of color as well as in the literature on color categorization (naming) in languages of the world. (Cf. Broackes, 2011; Dedrick, 1998; Jameson, 1997; Kay and Maffi, 1999; Mollon, 1995, 2009; Panorgias et al., 2010;

[1]Since Hering and throughout the discussion, black and white have kept an ambivalent status, usually mentioned in connection with the assumed achromatic perceptual channel but omitted from the list of unique hues.

Stoughton and Conway, 2008; van Laar, 1997; Kay et al., 2009; Wuerger and Parkes, 2011.) Broackes (2011) calls the four perceptually unique hues "striking phenomena to be explained". Valberg (2001) titles them "an old problem for a new generation". According to Mollon, a leading neurophysiologist, "the special phenomenal status of the four pure hues is perhaps the chief unsolved mystery of colour science" (Mollon, 1995, p. 146; cf. also Mollon, 2009).

In the following, I will argue that rather than a central problem which neurophysiology should solve, the perceptual uniqueness of red, yellow, green and blue is a central chimera of the contemporary color science. Neurophysiologists have not managed to find specific mechanisms for what is called unique hues, and they will not – I bet – because there is nothing to search for; neither the focal RYGB nor any other colors are perceptually unique in the commonly acknowledged sense. My arguments do not depend on any kind of physiological evidence. I aim my criticism solely at the received wisdom concerning the phenomenal, by which the neurophysiological research has been commonly driven. I will try to demonstrate that the notion of RYGB as perceptually unique hues lives on folk intuitions and on conceptual confusion caused by the misleading powers of language (namely, on our tendency to project the existing patterns of color naming into the descriptions of color experience). I hope to show that under scrutiny, the notion falls apart. Successively, I will present and discard the reasons which have been suggested for granting the privileged status in color perception to red, yellow, green and blue. My criticism is not completely new in any of the points (in particular, cf. van Brakel, 1993; Jameson and D'Andrade, 1997; Jameson, 2010; Saunders and van Brakel, 1997a), but to my knowledge, as yet nobody has formulated a comprehensive critique of the unique hue concept which it deserves given its position in the contemporary science of color.

My point has also consequences for the question of linguistic categorization of color and its apparent cross-linguistic patterns, which have been under a lively discussion ever since Berlin and Kay (1969). (Cf., among others, Lucy, 1997; Saunders and van Brakel, 1997a; Dedrick, 1998; Kay and Maffi, 1999; Saunders, 2000; Dedrick, 2006; Regier et al., 2007; Kay et al., 2009.) Unique hues (together with white and black as "the Hering primaries") have been appealed to in attempts to explain such universal tendencies. (Cf. Jameson, 2010.) Admittedly, the Hering colors seem to have been given up as *explanans* in this field once the alleged correspondence between the physiological and the purported perceptual channels proved untenable. The recent models, such as Baronchelli et al. (2010); Jameson and Komarova (2009); Loreto et al. (2012); Regier et al. (2007), replace the central position of "the Hering primaries" with the consideration of perceptual color spaces without privileged points, such as the CIELAB color space. Still, one could, with less reductionist ambitions, take perceptual uniqueness for a plausible explanatory principle, regardless of physiology: were there such uniqueness, that is to say. Furthermore, the fact that the recent models heavily employ perceptual color spaces of various kinds makes the issue of unique hues relevant in an indirect way. Namely, the opponent organization of the assumed four unique hues is sometimes placed as a constraint on the construction of perceptually relevant color spaces, with the demand that the red-green and the yellow-blue opposition coincide with two axes of the space. (That is, for instance, the case in the Swedish NCS color order system; cf. Fairchild, 2005; Jameson and D'Andrade, 1997.) Once the notion of opponent unique hues is challenged, so should be the perceptual relevance of artificial color spaces which rest on this theoretical preconception, rather than merely on the psychophysical results regarding color similarity and difference. In the research on linguistic categorization of color, such color spaces should be avoided.

2 Some qualifications

To prevent misunderstandings, I would like to precede the discussion with a couple of qualifications.

First, I do not deny that red, yellow, green and blue are culturally and cognitively privileged colors for speakers of English, of Western languages, and of many other languages of the world. No doubt, we are used to treat RYGB as color categories par excellence. But even if the set of RYGB categories was present and salient in most or all of the world's languages – and it is in fact not –, one could still imagine multiple explanations;[2] some of them are examined in the recent color categorization models. What I reject is that the primacy be conceived as an established universal fact of prelinguistic, biologically grounded color perception, involving RYGB as perceptual components of other perceived colors, a fact that could be sensibly accounted for in neurophysiological terms (as often called for). My criticism of the unique hue concept should be read with this in mind.

Second, I take the unique hues notion to be a complex, somewhat obscure conceptual conglomerate which deserves to be challenged from several directions simultaneously. The mainstream idea of RYGB as four perceptually privileged colors involves all of the following: they, and they alone, are (1) phenomenally pure colors, which (2) are perceptually related in a double-opponent fashion, of which (3) other chromatic colors are perceptually composed, which (4) are therefore necessary and sufficient to describe all other hues, and which moreover (5) have their privileged status confirmed by other perceptual phenomena such as negative afterimages or color blindness. While some authors regard only (1) and (3) as constitutive of the notion of a color's uniqueness, let me emphasize that my criticism is aimed at the whole aggregate of (1)–(5). In my opinion, the position of RYGB in today's color science derives precisely from the fact that the intuitions and the actual as well as putative facts concerning (1)–(5) loosely concur, thus conferring *prima facie* plausibility upon the aggregate notion of RYGB as colors that are primary in human perception.

Admittedly, (1)–(5), if considered separately, allow for a host of intermediate positions. For instance, one could try to argue that there is a set of unique hues in the narrow sense of (1) and (3) which is nonetheless distinct from the

[2] Such as, the shape of the human perceptual color space, or influence of the languages of the Western colonialism, or the importance of communicating about certain colors for survival in one's natural environment.

RYGB set; or that RYGB are indeed unique according to (1) and (3), yet do not stand in a double-opponent perceptual relation; or that there is some sort of perceptual opponency that does not imply perceptual composition in the sense of (3). However, I believe it is only the whole conglomerate of the aspects (1)–(5) what is really attractive, as its robustness in a sense compensates for the shaky nature of each.[3] Once some of these aspects are discarded, the remaining ones arguably lose much of their appeal. In this sense, the present paper attempts to challenge the aggregate notion of RYGB as four unique hues, or perceptually privileged colors, rather than to examine which of its components could be possibly saved. (If my criticism is correct, it might be still legitimate to hypothesize, for instance, that there are five (rather than four) unique hues in the narrow sense of (1) and (3). But I am worried that if (2), (4) and (5) as well as the very intuitive RYGB set are gone, it is much less clear whether it is a meaningful hypothesis at all, or how it could be examined. As the following investigation will hopefully demonstrate, uniqueness in the narrow sense does not appear as a fruitful concept outside of the context of all the other features that purportedly distinguish RYGB among other hues.)

In a similar vein, I do not take my challenge to the overall unique hues notion to imply that RYGB have no prelinguistic perceptual salience whatsoever. They may have some, anyway, and this can help explain their strong categorical status in many of the world's languages. In particular, Philipona and O'Regan (2006) argue for RYGB's privileged status in different terms than the five aspects above, namely in terms of the peculiar way in which the surfaces of these colors alter the incoming light for a human observer.[4] But noting that RYGB are perceptually peculiar in *some* respect certainly does not amount to showing that they, in some sense, form primary components of human color perception. In *other* respects, *other* hues are peculiar for sure. Thus, observations of this kind do not seem to re-establish the glory of RYGB as unique and perceptually privileged hues, in case that the reader finds this common idea shaken by the present paper's criticism.

Also, hints on prelinguistic salience of certain colors may be provided by the literature on what is rather misleadingly called categorical perception of color, particularly in infants (as similar effects in adults are usually claimed to be influenced by patterns of color naming; see *e.g.* Clifford et al., 2009; Franklin and Davies, 2006; Ozturk et al., 2013, for infants, and Clifford et al., 2011, 2012; Özgen and Davies, 2002, but also Witzel and Gegenfurtner, 2013, for adults). The phenomenon can be more precisely characterized as the enhanced discrimination of perceptually equidistant stimulus pairs in some regions of the perceptual color space compared to other regions. The research up to date has largely concentrated on the green-blue boundary, and it is furthermore ques-

[3]As regards (2), that is opponency, note that I only question the idea of red-green and yellow-blue as opponent perceptual channels, in no way putting in doubt the findings concerning opponent color coding in the retina or LGN.

[4]However, see the criticism of Johnson and Wright (2008), which is only partly addressed by the reply Philipona and O'Regan (2008). Cf. also Mollon's (2006) suggestions concerning the extraordinary features of particular "unique hues".

tionable whether the observed effects reveal anything like genuine *categories* in the prelinguistic perception. So, this type of prelinguistic salience cannot be plausibly taken in support of RYGB as perceptually privileged hues, although it is conceivable that this perceptual constraint will some day help explain the strong position of the RYGB categories in many of the world's languages.

3 Criticism

3.1 Unique hues as referents of necessary and sufficient color descriptors

One of the two major motivations usually given for describing red, yellow, green and blue as perceptually unique is straightforwardly linguistic. Unique hues are claimed to be those corresponding to the set of terms that are, individually or in pairs, necessary and sufficient for the description of any point of the hue space (circle). A slightly different definition to the same effect (namely, selecting the four familiar hues) is that a hue is unique if and only if it cannot be described by names other than its own; this is how unique hues are officially defined by CIE (1987). In both these closely related senses, the uniqueness of RYGB has been repeatedly corroborated by experiments on forced naming of colors, beginning with Sternheim and Boynton (1966). This "linguistic" notion of a unique hue (in either variant) is employed by, for instance, Broackes (2011); Hardin (2005); Miller (1999); Panorgias et al. (2010); Stoughton and Conway (2008); Werner and Bieber (1997).

It is rather obvious that according to this definition, unique hues are language-relative. (Cf. the criticism in Saunders and van Brakel, 1997a, and Jameson, 2010.) Usual concise introductory claims about universality of unique hues in this sense, mechanically referring to Berlin and Kay (1969), are false. A great deal of the world's languages do not have a set of color terms that would correspond in meaning to the English "red", "yellow", "green" and "blue". That much can be inferred even from Berlin and Kay (1969), not to speak of more recent and more sound cross-linguistic evidence. As the monograph Kay et al. (2009) makes clear, there are many languages (such as Bauzi or Cayapa) which do not have separate terms for what we call green and blue; some (like Bété or Ejagam) also merge green and blue with black; some (like Mayoruna or Nafaanra) merge what we call red and yellow in one category, etc. The naming arrays displayed in the book, which take into account the interindividual agreement on particular color terms, suggest that some languages (such as Campa or Walpiri) lack established color terms in large regions of the color space. It is clear that in none of the mentioned languages the four familiar hues can come out as referents of necessary and sufficient descriptors, or as exactly the set of hues that cannot be described by other names then their own. So, the privileged status of the RYGB hues in relation to linguistic descriptors is a fact of particular languages, and does not lead to any conclusions regarding their primacy in prelinguistic color perception.

3.2 Unique hues as phenomenologically pure color experiences

Another major motivation for setting RYGB apart from all other hues, sometimes proposed in explicit divergence from the CIE linguistic definition and arguably more influential nowadays, is their alleged phenomenologically unique character. The focal red, yellow, green and blue are claimed to be "pure" in a sense in which other hues are not. A whole variety of expressions is employed in the literature to express this phenomenological observation. Unique hues, like red, are perceptually *simple*, *unitary*, *unmixed*, do not *contain* any other hue; unique yellow *appears neither* red *nor* green; unique red does not *seem/look* in any way yellow*ish* or blu*ish*. Other hues, such as orange, have unique hues *in* them as *constituents*, they *consist* or are *composed* of them, are perceived as *mixtures* or *blends* of the unique hues (possibly in a specific *percentage*, such as 72 % of red and 28 % of yellow); they also *share* hue qualities with other non-unique hues (*e.g.*, orange and lime share a yellow component). (Cf. Bornstein, 2006; Broackes, 2011; Byrne and Hilbert, 1997; Dedrick, 1998; Hardin, 2005; Jameson and D'Andrade, 1997; Mollon, 1995, 2009; Panorgias et al., 2010; Wuerger and Parkes, 2011; Xiao et al., 2011; Logvinenko, 2012.)

The core of my criticism of this uniqueness notion consists in noting that the assumed independence of these phenomenological remarks of a particular language, or a group of languages one is familiar with, is simply illusory. Sure, there is no red or green in focal yellow, while there is some yellow and some red in focal orange; and focal orange is reddish and yellowish and can perhaps be called reddish yellow, while focal yellow cannot be called "limeish" and "orangeish" and cannot be labeled "orangeish lime". These statements are true, but they are true *both* because of what human color perception is like *and* because this is how "yellow", "red", "orange" and "lime" are *properly used in English.*

The actual interdependence of the "linguistic" and the "phenomenological" notion of a unique hue is nicely illustrated by frequent cases of unintended blending of both:

- "What is the minimal set of component hues sufficient to specify colour as perceived by normal trichromats?" (Logvinenko, 2012.)
- "Experiments have shown that terms such as orange and purple are not necessary, but can be reduced to yellowish-reds and reddish-blues, respectively, whereas red, green, yellow, and blue cannot be reduced to any other hues." (Werner and Bieber, 1997.)
- "All colors can be described in terms of four non-reducible 'unique' hues: red, green, yellow, and blue". (Stoughton and Conway, 2008.)

But one cannot describe a color by means of other colors; one has to use *words* for that. All three quotes are ambiguous between the "linguistic" and the "phenomenological" concept, or at least sloppy in their operation with the linguistic one. That is probably licensed by the authors' confidence that these two notions, after all, extensionally coincide. Yet, provided that the phenomenological notion is presented as strictly language-independent, careless use of words such as the quoted is rather suspicious. Broackes has the following: "There are certain features that make a particular hue [...] count as [...] *unique* yellow: *(a)* its *looking maximally unmixed* [...] and *(b)* its forming one of a collection of hues (...) that can be said to be 'in' other hues and which together are sufficient for characterizing all hues whatever." (Broackes, 2011, p. 617, original italics.) Here, somewhat surprisingly, we have "being in other hues" on the linguistic side, or vaguely in between, rather then clearly on the phenomenological side. Is it just a happy coincidence that the hues that can be properly said to be (that is: *are*) in other hues, themselves containing no other hues, are identical to the hues the names of which are necessary and sufficient to describe any other hue in English?

The overall story seems to be as follows: There are four unique hues in the prelinguistic color perception, completely independent of the acquired language skills. By a weird chance (or maybe cultural superiority?), English and other Western languages, unlike many (maybe most) languages of the world, have four privileged color terms that focally refer exactly to these perceptually unique hues. I do not deny that there *might* be such a coincidence. But it is hard to suppress the feeling that the proponents of unique hues are getting it way too cheaply; especially if authors do not even agree whether red's being "in" orange is evidence for the perceptual primacy of red, or rather for the linguistic primacy of the term "red". It seems much more likely that the coincidence is not established via independent examination of the perceptual on one hand and the linguistic on the other, but achieved by a straightforward projection of the latter to the former. Hardin (2005) unwittingly provides a telling example: "Names for the Hering elementary colors are necessary and sufficient for naming all of the colors, a fact that justifies singling them out as perceptually elementary."

A large part of the vocabulary employed to express the alleged perceptual uniqueness of RYGB primarily relates to the physical composition of objects and substances: *unmixed, contain, in, mixture, consist*, etc. If one is engaged in mixing pigments, these may be taken literally: orange will often consist of red and yellow.[5] But in describing perceptual experience, there is no point in interpreting them literally, as referring to physical or psychological componency which one should further trace, maybe in neurophysiological terms. Orange can be said to perceptually contain red and yellow, yet *literally* there is as little of red in orange as there is, *literally*, of luck in odd numbers.

The perceptual reality as regards red, yellow and orange is not that orange in any literal manner consists of the former two, but that orange lies between red and yellow in the perceptual space of colors; that is, in the ideal metrical representation of the perceptual similarity and difference of colors, as approximated in the artificial color spaces such as CIELAB, or color order systems, such as the Munsell system (cf. Fairchild, 2005). The RYGB terms in English have a privileged status in referring to regions of the perceptual color space; this status

[5]On the other hand, one can get green as a mixture of blue and yellow; the analogies between talk about pigments and the hue-oriented talk are far from perfect.

also involves the appropriateness of expressing certain positions in this space in terms of "containing blue", "being a mixture of yellow and red" or "appearing reddish". That is a fact of English, from which little can be concluded about the character of the prelinguistic, biologically grounded perception of color. I therefore believe that it is merely a reification of idiosyncratic language patterns when color perception is described as discontinuous with reference to unique hues, as in Conway and Stoughton (2009, p. R442): "the familiar color circle, composed of a continuous series of colors, is perceived as discontinuous, punctuated by four unique hues – red, green, blue, and yellow." Moreover, this kind of reasoning creates a superfluous puzzle. Namely: if there really are unique hues that function as perceptual discontinuities, should this not be reflected in perceptual color spaces such as CIELAB?

The case of unique hues is not strengthened by the fact that unique yellow, green etc. have been repeatedly located in the spectrum of monochromatic light by means of precise psychophysical experiments. Indeed, subjects in general have little problems with adjusting, *e.g.*, a color in the yellow region of the spectrum when instructed that the result should be pure yellow without any hint of red or green. Moreover, they place their subjectively pure colors in the physical spectrum with considerable interpersonal agreement (for qualifications cf. Broackes, 2011; Jameson, 2010; Saunders and van Brakel, 1997a). However, in all these psychophysical experiments it is an assumption, embodied in the instruction to the subjects, that there *are* unique hues, namely one in yellow, one in green etc. (Jameson, 2010; Saunders and van Brakel, 1997a; Wuerger and Parkes, 2011.) Sufficient interpersonal agreement in performance is then supposed to reveal their precise location. But however strong interpersonal agreement of normal trichromatic observers there is on locating "pure yellow, without a hint of red or green" at a specific wavelength, it need not reflect phenomenological primacy of the respective hue in human color perception. The only appropriate conclusion is that it reflects the observers' command of English, in particular of how "yellow", "red" and "green" are properly used.

Let me finally comment on the position of two authors who have defended the "phenomenological" notion of a unique hue explicitly against the objection of relativity to a particular language.

Broackes (1997), first, finds it intuitively very hard to think in terms of a different set of unique hues than RYGB and to see, for instance, an orange component in red instead of the other way around. In my opinion, intuitions of a Western speaker are simply irrelevant here. In Western societies, RYGB are highly cognitively salient colors which can be for many reasons considered "basic". They are, on the whole, the first chromatic color categories to be learned, and other colors are often presented to children in terms of the previous four. (For the query "toy blocks", Google returns images where red, yellow, green and blue blocks heavily prevail over blocks of all other chromatic colors.) Such a strong cultural salience of RYGB makes any intuitions in favor of their *perceptual* primacy unreliable.

Second, Broackes wonders if there are some languages that exercise sets of unique hues different from the RYGB set. But suppose there turned out to be none, and, at the same time, reducing colors to RYGB proved to be more than our parochial cultural practice. That would still imply nothing to the effect of primacy of these hues in prelinguistic color perception, for different explanations would be conceivable. In particular, one could try to argue that the significant status of RYGB categories across languages follows from other perceptual constraints (as examined in the recent color categorization models) or from environmental factors. For instance, it could follow from the shape of the perceptual color space together with the inclination of categories to efficiency (compactness), as suggested in Jameson and D'Andrade (1997) and Regier et al. (2007), or from the proportion of certain types of color blindness in the human population, as examined in Jameson and Komarova (2009).

Ingling (1997) defends the phenomenological, language-independent primacy of unique hues very emphatically: "Over the wavelength range, roughly between 520 and 570 nm, the observer will notice no marked transition in hue. The colors seen are various shades of yellow-green. For wavelengths longer than, say, 590 nm, although yellowness persists, there is no green. Upon crossing a wavelength around 575 nm, something has happened. The color changes from greenish to reddish as a point called unique yellow is crossed. It is *sheer obstinacy to deny* that this transition is not qualitatively different from crossing a wavelength of, say, 550 nm. [...] There are objective transition points in the spectrum that have properties not dependent on language. The fact that discontinuities can be described by language does not mean that languages cause discontinuities." (Italics are mine.)

But saying "really!" won't help. To repeat my point, the statement that a light at 575 nm of wavelength is purely yellow without a hint of red or green is correct, and it correct because this is how "yellow", "red" and "green" are properly used in English. Rather than "the (non-linguistic) experience of yellow" being pure at that wavelength, it is the case that the (non-linguistic) experience at that wavelength defines the correct use of "(pure) yellow" in English. The perceptual change that occurs when the wavelength is changed from, roughly, 570 to 580 nm is appropriately described as a change from greenish yellow to reddish yellow via pure yellow. The change from 545 to 555 nm is not. Whether these two physical changes are perceptually comparable or not, that is up to a perceptual color space to decide.[6] I can ascribe no other sense to the "qualitative difference" referred to by Ingling. In my opinion, there is a substantive amount of ethnocentric naivety in claiming that English belongs to a fraction of languages of the world that faithfully mirror perception as they apply special terms just to the colors that *really are* special.

[6]The latter difference will be probably found smaller, but that is a fact of different resolution abilities in different parts of the spectrum. It is not relevant for Ingling's case: at other wavelengths one can as well find, on one hand, a pair of hues both describable as greenish yellow, and, on the other hand, a pair consisting of a reddish yellow and a greenish yellow hue, such that the perceptual difference (captured in a color space) within the first pair is greater that within the second.

3.3 Minor Motivations for Unique Hues

Several other motivations have been proposed for the idea of the perceptual primacy of RYGB. (Cf. Fairchild, 2005, ch. 1; Werner and Bieber, 1997.) Sometimes they are cautiously presented as Hering's original impulses for his opponent-processing theory, without the authors explicitly subscribing to them. Each of these motivations (possibly with exception of the last but one) clearly fails to support the notion of the focal RYGB as unique or perceptually privileged hues. Here I briefly recapitulate them, as well as their flaws, in order to forestall the possible impression that everything, by and large, points to the perceptual uniqueness of RYGB, or that this uniqueness provides a useful account for a whole bunch of perceptual phenomena. Many bad reasons do not constitute a good one.[7]

Color exclusions It has been stated on countless occasions in the literature that red-green and yellow-blue are opposite in that they do not mix; one cannot see a reddish green or a yellowish blue. Let me avoid repeating the qualification that this is true because it respects the appropriate use of "red" etc. in English (cf. Wittgenstein, 1977); for there is an independent problem. It must have been only by force of tradition that only these two pairs were repeatedly noted to be exclusive. There is no more conceptual or perceptual exclusion between (focal) red and green, yellow and blue, than there is between red and turquoise, red and lime, orange and violet, and indefinitely many other hue pairs that are sufficiently remote in the color space.

Color complementarity A usual motivation for schematizing two hues as opposite in "the" hue circle is that the mixture of corresponding lights in equal proportions appears achromatic; that is, the two colors "cancel" to gray.[8] First, indefinitely many hue pairs are like that. Second, red-green and yellow-blue are not. A mixture of focal red and green light has a yellow tint, mixture of yellow and blue, green. It takes, roughly, turquoise to cancel red to gray, and bluish purple to cancel yellow.

Negative afterimages The idea of RYGB as double-opponent unique hues has been also related to the perceptual effect of afterimages seen on a white background after adaptation (approximately one minute is enough) to a saturated color stimulus. But the situation is similar to the case of color complementarity. *All* saturated hues produce afterimages. Moreover, the afterimage of focal red does not appear green but turquoise, and the afterimage of focal yellow is bluish purple rather than blue.

[7] On purpose, I mostly omit references to the literature where these motivations are mentioned, as it is not clear that the authors would be willing to defend them explicitly. If a particular motivation turns out not to be seriously defended by anyone nowadays, the better for my case.

[8] Note that this is not necessarily the case for "opposite" hues if the color space is defined on the basis of judgments of perceptual similarity and difference.

Simultaneous contrast It has been pointed out that green appearance of a stimulus is supported by red background, yellow appearance by blue background, etc. But the although effects of simultaneous contrast are comprised in the modern color appearance models (Fairchild, 2005), nobody has, to my knowledge, shown that the perceptual oppositions red-green and yellow-blue come out of these effects as privileged in any way.

Invariant hues Unique hues are occasionally identified with the "invariant hues", that is the hues corresponding to the wavelengths of light that are not affected by the Bezold-Brücke variance of the perceived hue with changes in luminance. Hue invariance seems to be a well-defined concept which can in principle select a small amount of hues as in a sense perceptually privileged. But the attested set of invariant hues does not coincide with the set of unique hues identified on the "linguo-phenomenological" basis. (Cf. Panorgias et al., 2010; Saunders and van Brakel, 1997a.) Hence, hue invariance does not support the mainstream notion of RYGB as perceptually privileged hues. At best it can define a different – much weaker – notion of perceptual saliency.

Color blindnesses It belongs to the traditional motivations for the alleged perceptual primacy of RYGB, and it is still appealed to by Fairchild (2005, ch. 1), that the common types of color blindness can be described as deficiencies in discrimination either between red and green or between yellow and blue, or, in other terms, as perception of colors either exclusively on the yellow-blue, or exclusively on the red-green scale. It is, for instance, common to talk about the "red-green color blindness". But that is, I believe, just a very loose specification by which the primacy of RYGB is assumed rather than corroborated. Known variants of color blindness have been accurately explained in terms of genetic mutations causing deviations in the physiology of the retina, namely in the number of cone types and/or in their sensitivity across the range of wavelength (Jameson and Komarova, 2009; Mollon, 1995). A neutral description of color-blind perception would be in terms of the impairment of discrimination in various regions of the wavelength range. As is patent from the discussion in Byrne and Hilbert (2010), the question "how do things look to the color blind?" is a particularly intricate one, and too often it has been approached with the ready assumption of the opponent red-green and yellow-blue perceptual channels. The present paper is meant to cast doubt on the overall notion of RYGB as opponent unique hues; therefore color blindness should not be brought in as an argument in their favor unless it can be shown that the two specific oppositions are derivable from color blindness data that are fully independent of that traditional notion.[9]

[9] Also, even if it turned out that the phenomenon actually does support the two particular oppositions in perception, it would not be completely clear to what extent this vindicates also the uniqueness of RYGB in the narrow sense of the aspects (1) and (3) above. As one of the anonymous reviewers noted, *e.g.* the fact that there is an auditory scale from very loud to very silent, which has a clear biological basis, does not make the intermediate loudness levels perceptually composed of very loud and very silent.

Cross-linguistic focality Lastly, occasional appeals to straightforwardly linguistic findings can be mentioned: especially to the fact that in a substantial part of the world's languages, color categories are focused roughly in the hues that have been identified as "unique" according to the two dominant definitions. The actual strength of this coincidence is disputable (cf. Jameson, 2010; MacLaury, 1997; Saunders and van Brakel, 1997b). But the main point is that linguistic evidence is principially not too relevant here. Even a hypothetical complete agreement of languages on the extension and focusing of color categories would support the thesis of the perceptual primacy of RYGB only indirectly, namely as one conceivable source of cross-linguistic uniformity among others. For cross-linguistic patterns of color categorization, multiple explanations are imaginable, and examined in the recent color categorization literature (as mentioned above). A representation of human prelinguistic color perception is an indispensable component in any explanation of the existing linguistic patterns, but as such it must not be influenced by them. Neither can cross-linguistic patterns of uncertain origins be allowed to co-define prelinguistic color perception if the latter is to be directly explicable in neurophysiological terms.

4 Conclusion

Having rejected all reasons that, to my knowledge, have been proposed for regarding the focal RYGB hues as perceptually unique, I conclude that these four hues lack the prominent place in human color perception that is commonly ascribed to them in the present-day color science. (Needless to say, it is a waste of effort to search for neurophysiological underpinnings of non-existent psychological structures.) The RYGB hues (or some other set of hues, for that matter) may nevertheless be in some sense salient in the prelinguistic color perception, and that could certainly help explain the observed cross-linguistic tendencies of color naming. However, such a finding needs to be established independently of the loose (and rooted) conceptual conglomerate that presents these four hues as perceptually primary in many distinct ways. I hope to have demonstrated that this conglomerate deserves no more tolerance in color science: it is not that we tolerate *some* looseness in lack of a better conception, it is rather the case that virtually *nothing* of the conglomerate survives a thorough scrutiny in a way that could compensate for shortcomings at other parts. Whether it is possible to make independent sense of particular components of that conglomerate, *e.g.* of perceptual opponency without uniqueness in the narrow sense, or the narrow uniqueness without it being RYGB that are actually unique, remains though an open question.

The critical reader may ask a question about the falsifiability of my claims: what conceivable evidence, what sort of experiment could *verify* the hypothesis of RYGB as the set of hues constitutive of human color perception? Well, many of the facts discussed above could have been otherwise and more indicative of the perceptual primacy of RYGB (some of them more directly, some of them less). Languages of the world could have been much more homogeneous in treating RYGB as salient categories; negative afterimages or color exclusions could have concerned solely the red-green and yellow-blue pairs; speakers of exotic languages in which RYGB are in no way four salient categories of color could have nevertheless shared our Western intuitions about the phenomenal purity of some hues and about the composed character of others... But if all that is not the case, is the hypothesis worth yet more examination? Doesn't the urge to suggest further experiments only follow from the steady intuition that, after all, RYGB *are* primary colors? The whole present paper argues for giving up that intuition.

The rejection of RYGB as unique hues places all the weight of capturing the perceptual relations of colors on perceptual color spaces. It solves puzzles arising from the alleged need to represent color perception as, simultaneously, continuous *and* discontinuous. There is no conceptual place for unique hues in a perceptual color space such as CIELAB, and that is perfectly fine if there are none.

Also, when the uniqueness and fundamental opponency of RYGB is dismissed, so can be all demands to the effect that in a perceptual color space, the red-green and the yellow-blue opposition should coincide with two orthogonal axes. Hardin (2005) presents it as a puzzle that the World Color Survey data suggest "first, that red and yellow are more like each other than either is like blue or green, and second, that green is more like blue than red is like yellow". But that is no puzzle anymore: without assuming four fundamentally opponent unique hues, there is no reason to expect uniform perceptual spacing of the RYGB hues in the first place. Jameson and D'Andrade (1997) convincingly argue *against* the coincidence of two dimensions of the color space with the red-green and the yellow-blue opposition. They imply (p. 311) that uniqueness ("non-reducibility") of RYGB is the *only* reason for keeping this traditional notion, as opposed to many good reasons to the contrary. Once the very idea of RYGB as perceptually unique hues is rejected, even this last reason falls.

So, as regards color categorization and its cross-linguistic patterns, the conclusion is two-fold. First, the alleged perceptual uniqueness of RYGB (or "the Hering primaries") is not justified as an independent explanatory factor. Second, the research should not rely on color spaces that have been construed upon the widespread assumption of the four perceptually unique hues organized in a double-opponent manner.

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