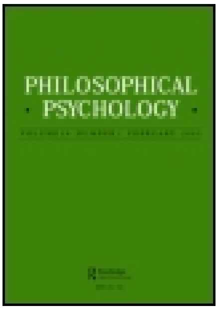

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Proving universalism wrong does not prove relativism right: Considerations on the ongoing color categorization debate

Yasmina Jraissati

For over a century, the question of the relation of language to thought has been extensively discussed in the case of color categorization, where two main views prevail. The relativist view claims that color categories are relative while the universalistic view argues that color categories are universal. Relativists also argue that color categories are linguistically determined, and universalists that they are perceptually determined. Recently, the argument for the perceptual determination of color categorization has been undermined, and the relativist view has regained some ground. This paper argues that although the universalistic account of color categorization has been called into question, this is not enough to establish relativism. Color categories can still be said to be universal or particular, independent of the accounts of their universality or relativity. Because of its polarization, the debate has disregarded some issues that are key in our understanding of color categorization: the question of what a color category is and how to identify it.

Keywords: Basic Color Terms Theory; Categorization; Color; Sapir-Whorf Hypothesis; Universalism

1. Introduction

Why is our experience of color discontinuous with our cognitive relation to it? In the psychology of perception literature, and in earlier studies starting in the nineteenth century, two types of answers have been thought to exhaust all possibilities. Either color categories are universal and are determined by our perceptual mechanisms (the universalistic view), or color categories are particular to languages and are determined by language use (the relativist view).

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The historical debate between these two views revolves around two distinct key questions: (1) how are color categories formed? And (2) does language affect perception? Research in the past ten years focused on the second question, and it has been shown on several occasions that language does influence perception, or our experience of color (Davies, Sowden, Jerrett, Jerrett, & Corbett, 1998; Kay & Kempton, 1984; Roberson & Davidoff, 2000; Roberson, Davies, & Davidoff, 2000; Siok et al., 2009; Tan, Chan, Khong, Yip, & Luke, 2008; Winawer et al., 2007). More specifically, "categorical perception" effects were found to occur cross-culturally at the boundaries of categories that are particular to language. The notion of categorical perception of color was introduced to describe the following phenomenon: adjacent colors that straddle a category boundary are perceived as more different from each other than adjacent colors belonging to the same category (Harnad, 1987). This effect is observed in discrimination tasks involving memory, but also in tasks where memory is not involved. Consequently, both universalistic and relativist stands have recently converged on this point (Regier & Kay, 2009). However, when it comes to the first question, the two approaches still diverge. In this paper, I will focus on question (1) (how are color categories formed?), and on the ongoing discussion related to it.

The universalistic claim (U) is that color categories are universal. A given color C is named "x" because it belongs to category x. As a consequence, category x to which a color C is seen as belonging exists before its being named "x." To this extent, it has been argued that category x is innate. Diametrically opposed to this account, the relativist explanation (R) of color categorization is that a given color C belongs to category x because it is named "x." It is here implied that category x results from language use, which is itself affected by the environment and the habits of the group.

The innate versus acquired nature of color categories debate is deeply tied with the claims regarding their universality versus relativity, respectively. The way research on color categorization developed historically testifies to that link. The universalistic account of category formation historically unfolded according to the following line of reasoning:

If:

U1. There are regularities in color categories across languages.

Then:

U2. Color categories are universal.

U3. Admitting that all humans are biologically similar and finding biologically-universal reductions of color categories would explain (U1), and therefore establish (U2).

U3.1. The consistent choice of focal colors across languages suggests that categories are structured by prototypes.

U3.2. Behavioral data suggest that these prototypes are natural: they have cognitive advantages.

U3.3. Prototypes can be reduced to neuronal mechanisms.[1]

Starting in the mid-1990s, findings in vision science, experimental psychology, and cognitive science have served, for some, as a basis for rejecting the biological reduction of color categories. It was argued that color categories' prototypes or foci could not be reduced to low-level neuronal responses (U3.3) (Abramov & Gordon, 1994; De Valois & De Valois, 1993; Tailby, Solomon, & Lennie, 2008); it was shown that these so-called universals did not have the cognitive advantages they were believed to have (U3.2) (Roberson et al., 2000); and finally, it was conceded that categories do not seem to be organized around a clearly identified natural prototype (U3.1) (Regier, Kay, & Khetarpal, 2007).

Given the connection between innateness, or biological reduction, and universality, the rejection of the universalistic claims U3.1, U3.2, and U3.3 is interpreted as a confirmation of the relativist approach to color categorization. In this paper, I would like to make the following point: calling into question the neuronal groundings of universal color categories is not enough to call into question the universality of color categorization. The centrality of the claim (U3) (finding biologically universal reductions of color categories would explain and establish universality in color categorization) is due partly to historical reasons. So is the way relativism has been opposed to universalism. Indeed, universalism and relativism are logically opposed notions, but the accounts of categorization respectively put forward by proponents of the universalistic and the relativist views are not jointly exhaustive. Thus, the falsity of one account does not imply the truth of the other. Negating the universalistic account of categorization is not enough to establish relativism.

2. The Basic Color Terms Theory

2.1. Color Universals: Claims U1 to U3

In 1969, Brent Berlin and Paul Kay published a study in a monograph that introduced Basic Color Terms Theory (BCTT) and revolutionized the way color categorization is approached. Opposing the Sapir-Whorf hypothesis (which was very influential in the first half of the twentieth century; Sapir, 1929; Whorf, 1956), the authors contended that:

> U1. There are regularities in color categories across languages.

What the Sapir-Whorf hypothesis of linguistic relativism stands for is the claim that language use and culture determine the way we categorize the world. One of Whorf's most popular examples is that of the Eskimo snow lexicon. Eskimos live in a snowy environment; therefore, the argument goes, Eskimos produce a language that describes snow in its various states (Whorf, 1956, p. 216). In some of his writings, Whorf suggests further that as a consequence, this way of describing snow would, in its turn, determine the way Eskimos perceive snow (Whorf, 1956, p. 67, but also see Martin, 1986 and Pullum, 1991).

Going beyond Whorf's study of the Eskimo snow lexicon, people also commonly believe that Eskimos have an exceptional lexicon of color. It is widely assumed that Eskimos have numerous terms for white (the number most regularly cited is 17). Although this generally consists in a lay belief, it does surprisingly appear in some academic works (Singh, 2006; Sivik & Taft, 1994). While the proliferation of the

Eskimo words for snow has a clear origin in Whorf's work, there is no such clear origin in the case of their color lexicon. No anthropological work ever claimed that Eskimos have more than one term for white (Heinrich, 1974; Rivers, 1902). Nevertheless, the color lexicons of other languages have been cited as evidence supporting the Sapir-Whorf hypothesis (Lenneberg & Roberts, 1956; Ray, 1952); these are taken as showing that color categorization is relative to language and culture.

In their study, Berlin and Kay argue that, on the contrary, color categorization is universal. They utilize an existing extensive ethnographic literature to gather data on some 78 languages. They also obtain experimental results from some 20 languages (Berlin & Kay, 1969). Berlin and Kay argue that when only basic color terms and categories are considered, some regularity is discernable across color lexicons. Thus:

U2. Color categories are universal.

Based on their ethnographic data, Berlin and Kay claim that there are 11 basic universal color terms and categories. Differences do exist across languages. However, the differences do not lie in the nature of the color categories, but in their number. Indeed, Berlin and Kay hypothesize that universal color categories emerge in the different languages following a constrained evolutionary sequence. At stage 1, a given language displays only the categories of WHITE and BLACK, followed by RED (at stage 2), YELLOW (stage 3), GREEN (stage 4), BLUE (stage 5), BROWN (stage 6), and PINK, ORANGE, PURPLE, and GREY (stage 7). [2]Thus, a stage 1 language includes categories WHITE and BLACK, while a stage 4 language includes categories WHITE, BLACK, RED, YELLOW, BLUE, and GREEN. This evolutionary sequence explains the differences in color terms and categories between languages.

In Berlin and Kay (1969), the authors briefly tackle the difficult question of the reasons behind the universality of color categories and the order of their appearance in the lexicon. They resort to physiological structure:

> Perhaps we have here in the domain of semantics a finding analogous to some phenomena recently recorded in the areas of syntax and phonology. Chomsky (1965) and Lenneberg (1967) have argued that the complexities of language structure together with some known limitation of human neurophysiology, imply that human language cannot be considered simply a manifestation of great general intelligence. Rather it must be recognized as a species-specific ability, ultimately based on species-specific bio-morphological structures. (Berlin & Kay, 1969, p. 109)

How, exactly, color semantics are taken to be physiologically grounded is not yet made explicit. However, the authors state their belief that future research would unveil the neuronal mechanisms underlying universal color categorization, and regard their study as pointing in that direction:

> Sufficient evidence has already accumulated to show that such connections [with biological structures] must exist for the linguistic realms of syntax and phonology. The findings reported here concerning the universality and evolution of basic color lexicon suggests that such connections are also to be found in the realm of semantics. (Berlin & Kay, 1969, p. 110)

Clearly, if neuronal reductions of color categories could be found, the observed regularity in color categorization would be explained, and color universals established. Therefore:

> U3. Admitting that all humans are biologically similar and finding biologically universal reductions of color categories would explain (U1), and therefore establish (U2).

Thus, since the first publication of the BCTT, the explanation of color universals is sought for in the neuronal structure of the human brain.

2.2. The Cognitive Advantages of Universal Color Categories: Claims U3.1 and U3.2

Basic color categories, to which basic color terms refer, are taken to jointly partition the color space (Kay, 1999; Kay & Maffi, 1999). In other words, every color we experience necessarily falls under a basic category. Other (non-basic) color categories fall within the extensions of the basic categories, and are not taken into consideration. It naturally follows that a stage 1 language with only two basic color categories does not partition the color space like a stage 7 language would, where eleven color categories are found. WHITE in a stage 1 language does not have the same extension as does WHITE in a stage 7 language. In a stage 1 language, the category WHITE encompasses all light colors, including yellows, pinks, light blues, and light greens. However, in English (a stage 7 language), WHITE does not include such shades in its extension. Still, Berlin and Kay claim, WHITE in both stages has the same focal color, or best example. Thus, given that the category extensions necessarily vary across languages, it is the stability of the focal color across different evolutionary stages that mainly enables the BCTT to claim that categorization is universal.

When it comes to focal colors, the BCTT initially owes most of its conceptual apparatus to Rosch's important work on basic color categories of the early 1970s. Rosch gathered color naming data from the Dani population in New Guinea, (Rosch [Heider], 1972a), which is thought to have only two basic color terms, 'mola' (referring to light and warm colors) and 'mili' (referring to dark and cool colors), and compared this lexicon with English. Rosch tested the ability of the Dani to learn new color categories and new color terms. Her results are taken to show that the focal colors of basic categories are more easily remembered than non-focal colors. They are more easily learned, or paired with names, than non-focal colors (Rosch [Heider], 1972b; Rosch [Heider], 1973). Rosch thus introduced the notion of "prototype," which she equates with that of "focal color." Coupled with the stability with which focal colors are chosen in the 1969 Berlin and Kay study, Rosch's results suggest that categories are structured around prototypes. Thus:

> U3.1. The consistent choice of focal colors across languages suggests that categories are structured by prototypes.

The superiority of prototypes over non-prototypical colors in memory and learning allows Rosch and proponents of the BCTT to state that basic color categories and their prototypes are natural, and have the observed cognitive advantages as a consequence.

One more result lends further support to Rosch's claim. Rosch and Olivier (1972) showed color samples spanning the color space to Dani and to English-speaking American participants and tested them for color recognition. Their results indicate that Dani and American speakers have very similar performances in color recognition, and consequently, that color categories are independent of language. Thus, not only do prototypes play a crucial role in category learning, they are also remembered independently of language. Rosch and Olivier conclude that color prototypes are natural, and that they have a special cognitive status:

> U3.2. Behavioral data suggests that these prototypes are natural: they have cognitive advantages.

Based on studies in color vision science, Rosch (1972b) finally asserts that:

> U3.3. Prototypes can be reduced to neuronal mechanisms.

2.3. The Neuronal Grounding of Color Universals: Claim U3.3

Indeed, in the late 1960s, what could be called the standard view of color vision was prevalent. According to Young-Helmholtz, color vision is trichromatic and can be understood on the basis of the three chromatically sensitive receptors in the retina, thought to be maximally sensitive to red, green, and blue (or violet) (Hurvich & Jameson, 1957). However, according to Hering, a psychologist of the late nineteenth century, color perception has to be understood not on the basis of three photoreceptors but on the basis of four unique hues: red, blue, green, and yellow; and two achromatic unique hues: white and black (Hering, 1964). A major reason behind Hering's rejection of the Young-Helmholtz trichromatic approach is that we have an impression of unique yellow. Being unique, yellow cannot result from a combination of primaries, as the trichromatic approach suggests.

Hering argues that all our color impressions can be understood on the basis of the four unique primary colors and the two achromatic hues. Furthermore, he argues that the four unique hues are orthogonally related. As much as orange can be understood as a yellowish red—or a reddish yellow, there is no such thing as a reddish green, or a bluish yellow. Red and green, yellow, and blue, are opponent colors that can never mix. From these opponent relations results a particular approach to our perceptual space, structured by two orthogonal axes, at the tips of which are respectively found red and green, yellow, and blue, leading to a color circle divided into four quarters.

In the 1950s, Hering's suggestion was supported by Jameson and Hurvich's psychophysical experiments on color opponency, where viewers "cancel" color impressions by mixing in opponent colors (Jameson & Hurvich, 1955). The sensation of a blue component, perceived at a certain wavelength, is cancelled out, or nullified, by the addition of a yellow component of a certain wavelength, yielding an impression of white. This psychophysical experiment confirms Hering's idea according to which unique hues are opposed. Also, in the late 60's, some experiments by De Valois et al. suggested further that these psychophysical cancellation effects are explained by the reactions of opponent cells in the lateral geniculate nucleus (LGN), the specifically visual nucleus in the thalamus that is located at the end of the optic nerve and involved in low-level processing of light information (De Valois, Abramov, & Jacobs, 1966). These center-surround opponent cells fire in response to green stimuli and are inhibited in response to red stimuli, and vice versa. The same is true of the so-called yellow/blue opponent cells.

The quantification of the Hering unique hues by Jameson and Hurvich, and their localization in the LGN by De Valois et al., established the Hering approach to color vision. The standard theory of color vision thus adopted Young-Helmholtz' trichromatic approach when it comes to the photoreceptors' nature in the retina, and the Hering approach when it comes to the activity of the opponent cells in the LGN, which have as an input different combinations of the photoreceptors' output.

Given that the four unique opponent hues are red, yellow, green, and blue, and that the two unique non-opponent hues are black and white, the BCTT finds in the standard theory of color vision a very suitable explanation of universal color categorization: the prototypes of the universal color categories around which color categories are organized would be grounded on the neuronal responses of the opponent cells in the LGN (Kay & McDaniel, 1978). Thus, not only are focal colors natural prototypes that have cognitive advantages, they are also directly based on clearly identified low-level neuronal responses, thereby verifying claim U3.3.

In the 1970s, several researchers conducted surveys and experiments, confirming that color categories are regular across cultures (Hage & Hawkes, 1975; Hays, Margolis, Naroll, & Perkins, 1972; Pollnac, 1975). In parallel, proponents of the BCTT initiated the World Color Survey (WCS), which today gathers color naming data on 110 languages of non-industrialized societies (Cook, Kay, & Regier, 2005). All of these studies corroborate the BCTT universalistic hypothesis (Corbett & Morgan, 1988). They also generate data that challenge the BCTT framework, generally resulting in smooth theoretical changes (although some cases are problematic for the BCTT: Levinson, 2000; Lyons, 1995; MacLaury, 1987).

For example, Berlin and Berlin (1975) showed that in Aguaruna, GREEN does not, in fact, emerge before BLUE. This observation caused some important changes in the way the evolutionary sequence was modeled (Kay, 1975). It was suggested that a larger category, including green and blue colors, precedes both the GREEN and BLUE categories. The partitioning of this larger category seems to yield the BLUE and GREEN categories. Thus, instead of the 1969 sequence expressed in terms of WHITE, BLACK, RED, YELLOW, etc., with categories appearing in that order (as described in section 2.1), the 1978 updated evolutionary sequence was modeled in terms of primary colors, suggested both by the standard theory of color vision and the hypothesis that category foci and prototypes are grounded in neuronal responses (Kay & MacDaniel, 1978). Thus, at stage 1 of the lexicon's evolution, WHITE and BLACK are composite categories comprising primary colors white/yellow/red for the first one, and black/

blue/green for the second. The new evolutionary sequence was viewed as the trajectory of the emergence of these primary colors, which are first included in larger categories. Once these primaries are singled out and become basic categories in their own right, they yield so-called complex basic categories, constituted by a mixture of the primaries. For example, ORANGE is a complex category resulting from the mixture of the yellow and red primaries (Kay, Berlin, & Merrifield, 1991).

3. The Rejection of the Biological Reduction of Color Categories

According to the proponents of the Sapir-Whorf hypothesis, the linguistic relativity view, there is no such thing as a color universal. Color categories vary across languages and are determined by language use. If the notion of basic color categories is rejected, and non-basic color categories are also taken into consideration, variations across lexicons suggest that color categorization is not universal. For example, in Lenneberg and Roberts (1956) study the Zuni color lexicon, they note the absence of a category for orange in this language. In the same way, Davidoff, Davies, & Roberson (1999) compare the color space partitions of English and Berinmo speakers, a population of New Guinea whose color lexicon comprises five color terms, and show that Berinmo categories are not related to English ones (Davidoff et al., 1999).

The line of reasoning for the relativist view historically unfolds in the following way:

If:
- R1. There are no regularities in color categories across languages.

Then:
- R2. Color categories are not universal.
- R3. Admitting that all humans are biologically similar and finding no biologically universal reductions of color categories would explain (R1), and therefore establish (R2).
  - R3.1. The inconsistent choice of focal points across languages suggests that categories are not structured by prototypes, but by their linguistic boundaries.
  - R3.2. Behavioral data suggest that these prototypes are not natural: they have no cognitive advantages.
  - R3.3. Prototypes cannot be reduced to neuronal mechanisms.

Each (R) claim is a negation of the corresponding (U) claim. More specifically, claims U3.3, U3.2, and U3.1 have been rejected, implying claims R3.3, R3.2, and R3.1. This rejection is an important blow to the universalistic account of color categorization.

3.1. Rejecting U3.3: What Neuronal Mechanisms?

At the turn of the 1990s, several problematic observations shed doubt on the standard theory of color vision, namely regarding the +R-G cells (i.e., opponent cells in the LGN that fire in response to a red stimulus and are inhibited in response to a green stimulus) (Abramov, 1997; Abramov & Gordon, 1994). Namely:

(1) The +R-G cells also react to a white stimulus. However, these cells cannot both react to red and to white, given that in the standard model, for the cells to react to red, the responses to luminance have to be cancelled.
(2) When the +R-G cells shift from excitation to inhibition, a unique yellow sensation should occur (not green or red), according to the model. However, typically, these shifts occur at wavelengths that should be experienced as yellow-green, not unique yellow.
(3) None of these +R-G cells shows responses to shorter wavelengths; however, these wavelengths produce a sensation of purple, which supposedly includes red, to which these cells should positively react.
(4) Furthermore, in this view, the sensation of blue depends on the sole output of the Blue cones. If we know that the sensitivity of the B cones starts to decrease markedly at 520 nm, how then, can we account for that persisting impression of blue at 550 nm in certain circumstances?

As a consequence, the standard theory of color vision was revised. Although the first stage of the model—consisting of the description of the photoreceptors in the retina and the cells they connect to—remains mostly unchanged in more recent models, stage two, in which the activity of the opponent cells were thought to yield our impressions of unique hues, has been substantially modified. It is argued that unique hues cannot result from the activity of the opponent cells in the LGN, and it is suggested that there must be another site of adaptation. Therefore, a third cortical stage in color processing is hypothesized (Abramov 1997; De Valois & De Valois, 1993; Tailby et al., 2008).

Thus, unlike the standard theory of color vision, the more recent model of color vision proposes that there are at least three stages, not two, in the visual processing of light information. The central suggestion of this revision of the standard model is that there is effectively one color axis in the parvo-retino-geniculate pathway, whereas the hypothesis of the standard model was that there might be separate channels (De Valois et al., 1966). This single path is formed by 90–95% of the cells whose central receptive fields get their inputs from L and M cones (previously known as the red and green cones respectively). However, this axis is not a unique hue axis, as previously believed. It could, rather, be described as an orange/cyan axis. Furthermore, the hypothetical role of the antagonist system S (previously known as the blue cones) is to modulate the antagonist LM cells in two different ways, by breaking this dominant chromatic axis into two separate axes, RG and YB. The system S is, however, suggested to break the dominant LM axis at the third stage of the processing, at the cortical level.

In other words, the M and L cones have a central contribution not only to the RG system, but to the YB system as well (De Valois & De Valois, 1993; De Valois, De Valois, & Mahon, 2000, and also see Lennie, Krauskopf, & Sclar, 1990 about the physiological underpinnings of unique hues). This new model explains the problematic observations listed at the beginning of this section at the cost of depriving the unique hues of their neuronal grounding in the opponent cells. As a consequence, our impressions of unique hues cannot be straightforwardly explained on the basis of the activity of the opponent cells in the LGN, as was suggested by the standard theory of color vision.

For the universalistic view, these results have a great impact on the way prototypes are to be biologically reduced. Prototypes were thought to be directly based on the LGN's opponent cells, as offered by the Hering-inspired standard theory of color vision. With Hering's unique hues losing this ground, the universalistic view crystallized in the BCTT loses one of its important cornerstones: the innateness of the prototypes. Thus, the claim U3.3 is rejected:

> U3.3. Prototypes can be reduced to neuronal mechanisms.

And in the absence of support of U3.3, the claim R3.3 can be implied:

> R3.3. Prototypes cannot be reduced to neuronal mechanisms.

3.2. Rejecting U3.2: What Cognitive Advantages?

Acknowledging R3.3 in 1997 (Kay, Berlin, Maffi, & Merrifield, 1997, p. 53, note 4), the proponents of the universalistic view argue that, independently of the neuronal grounding of the prototypes on low-level mechanisms, it could still be said that color categories are universal on the basis of U1. Furthermore, universal categories are based on Hering's unique hues, taken in a phenomenal sense. In other words, we still have impressions of a unique blue, red, green, yellow, black, and white, regardless of the nature of the neuronal mechanisms underlying these sensations. These categories still have cognitive advantages and are structured around prototypes, as was previously shown by Rosch (claims U3.1 and U3.2).

Indeed, although the rejection of U3.3 weakens the original universalistic assertion which sought to establish the universality of categorization on the basis of clearly identified neurological mechanisms, it still leaves Rosch's unquestioned results supporting U3. In section 2.2, we saw the importance of Rosch's work for the universalistic stand. Independent of the biological reduction of unique hues, the behavioral data she gathered in the 1970s are taken to establish the universality of color categorization. Rosch's results imply that focal colors, or prototypes, structure categories (U3.1), and that the basic categories that are organized around them are independent of language and are natural, subsequently supporting the claim of their cognitive advantages (U3.2).

However, no study ever tried to reproduce Rosch's behavioral experiments until Roberson et al. (2000) tested the Berinmo in 1999. Surprisingly, Roberson et al. failed to replicate Rosch's results. In these studies, Roberson et al. show, contra Rosch, that color memory and recognition depend on color lexicon, and are thus not independent of language. When it comes to the role of focal colors in short term memory, Roberson et al. faced the same difficulties that Rosch faced. In Rosch's work, the Dani recognized two focal stimuli out of eight on average, which should have brought about the conclusion that the "inherent" features of focal colors are not enough to account for recognition. Such is the conclusion that is reached in the case of the Berinmo.

For Rosch, the most powerful proof of the primacy of focal colors or prototypes lay in the fact that Dani participants learned color terms more easily when they were associated with focal colors than with non-focal colors. In the experiment conducted by Roberson et al., however, only two participants out of 12 were able to learn color terms in association with focal colors. The 10 remaining participants quickly lost interest and abandoned the training. Even in a more ecological version of this experiment, where color terms are associated with focal-colored objects taken from the Berinmo's natural environments, Roberson et al. failed to obtain results in any way comparable to Rosch's. Thus, claim U3.2 is rejected, and R3.2 is implied:

> R3.2. Behavioral data suggest that these prototypes are not natural: they have no cognitive advantages.

3.3. Rejecting U3.1: The Abandonment of Universal Foci and Relativity of Perceptual Saliency

With prototypes having lost their neural grounding (R3.3) and their cognitive advantages (R3.2), the consistent choice of focal colors across languages is the only remaining feature on the basis of which to argue that categories are structured around prototypes (U3.1). However, it was shown on several occasions that the choice of focal color is variable across participants and languages (Kuehni, 2001; Kuehni, 2004; Webster & Kay, 2007). Thus, it was conceded that categories are probably not structured by focal colors, as previously understood, after all (Regier et al., 2007).

Relativists contend that prototypes are only epiphenomena resulting from the determination of the category extension by its linguistic boundaries (Roberson et al., 2000). Contra this relativist claim, and in response to the challenges the BCTT is confronted with, some of its proponents suggested an alternative account of universal color categorization (Regier et al., 2007). This new account avoids the use of focal colors and prototypes altogether.

In the most recent version of the universal color categorization model, the following observation is put forward: members of perceptual categories seem to always be maximally similar to each other and maximally dissimilar to members of other categories. (That is also the case in vowel space; Liljencrants & Lindblom, 1972). Regier et al. therefore hypothesize the existence of a cognitive ability to optimally categorize. In doing so, Regier et al. draw from the suggestion by Jameson and D'Andrade (1997) that color categories optimally divide the perceptual space.

Optimality is here understood in terms of the distance between categories. RED, for example, emerges in the lexicon after BLACK and WHITE because red is the most distant color from black and white in our perceptual space, and therefore RED is the most optimal and informative category to have in a system that partitions the color space into WHITE and BLACK. Regier et al. also adopt Jameson and D'Andrade's view according to which the perceptual space is best understood, not in terms of a

Hering-like color circle structured by two red/green, yellow/blue orthogonal axes, but in terms of its irregularities.

Our visual color processing system treats small variations in input in the green/yellow/red region as equal in magnitude to larger variations in the blue/green regions. Consequently, similarity relations between colors, represented in terms of distance in color space, vary accordingly (Churchland, 2007; MacAdam, 1942), and lead to a perceptual space with protuberances and depressions. To illustrate, take the different color samples from the Munsell system that fall under the extension of the English category yellow. The Munsell system, used by the BCTT and the World Color Survey, is a system based on perceived equidistance between neighboring samples (Munsell, 1941). When the samples called "yellow" are projected by conversion in a CIElab space, they appear closer to each other than, say, to the neighboring color samples we would call "green" (see Regier et al., 2007 for such a projection). The CIElab space is based on a representation of the sensitivities of our visual system and features a Euclidean metric. Knowing that distances in a color space correspond to similarity relations, the fact that color samples we call "yellow" in the Munsell space lay closer to each other in CIElab shows that similarity relations are not uniform across the space. Or, more specifically, that we are differently sensitive to different areas of the space.

Thus, if the color space is irregular, then given our ability to optimally categorize according to perceptual distances between colors, our color categories are universally constrained in the same way. In support of this new account of universal color categorization, Regier et al. argue that "every color is focal (perceptually salient) to some extent, and some, such as the six listed above [white, black, red, blue, green, and yellow], are simply more focal than others" (Regier et al., 2007, p. 1436). This change to the BCTT, allowing for some flexibility in the localization of color foci, enables the BCTT to overcome its most recent challenges, but at the cost of the demise of the focal color as it was previously understood. Thus, claim U3.1 is rejected, and it can no longer be argued that categories are structured by prototypes, as the notion was previously understood.

Unlike the earlier changes the theory has gone through, this last modification to the BCTT is a major theoretical shift. Since its first publication in 1969, the BCTT has heavily relied on the notion of color foci and prototypes to account for universal categorization. With the 2007 changes, the BCTT may have solved most of the issues it was confronted with, but now it has to address new questions pertaining to perceptual salience, the notion suggested as a theoretical substitute for focal colors.

If colors are perceptually salient, then colors are more or less salient instead of inherently, or absolutely, focal. Salience is necessarily a relative notion, and one can see in the context of the 2007 theoretical framework of the BCTT how this is indeed the case. According to the BCTT, in a lexicon with three categories, apart from WHITE and BLACK, the third category is RED—not YELLOW, BLUE, or GREEN. In the same way, in a lexicon with four categories, the fourth category is YELLOW—not GREEN or BLUE. If some colors are more salient than others, as is contended by Regier et al. (2007), then arguably, the reason why the category RED emerges before the categories YELLOW, BLUE, or GREEN is that in a lexical system where the two existing categories are WHITE and

BLACK, red is more salient than yellow, blue, or green. In the same way, the reason why the fourth category is YELLOW is, arguably, that in a lexical system where the space is partitioned into WHITE, BLACK, and RED, yellow is the next most salient color. Given the BCTT's evolutionary approach to color lexicon, colors' perceptual salience depends, at least, on the nature of the existing categories. It may be argued that as the space is partitioned, different colors *become* salient.

The BCTT's new framework therefore seems to imply that the saliency of colors also depends, at least, on the partitioning of the perceptual space. In other words, not only is the structuring of categories by focal colors called into question, but the importance of existing boundaries in the emergence of new categories is also implied by the 2007 model of color categorization put forward by proponents of the BCTT. Thus, although this new account of universal categorization is promising, it potentially has worrying implications for a universalistic approach, at the core of which is the idea that color categories are universally perceptually determined. If the lexical categories RED, YELLOW, GREEN, and BLUE emerge one after the other in the lexicon, and are not simultaneously encoded, it is because they become salient under certain conditions. If a color becomes perceptually salient, then it cannot be argued that this saliency is purely perceptual, in the strict sense. Perceptual saliency has to result from the interaction of these colors' perceptual characteristics with, at least, the partitioning of the perceptual space, and possibly other external factors that cannot be excluded in principle in the BCTT's new theoretical framework.

The recent account the BCTT gives of color categorization does not explicitly enounce such consequences; however, it does imply them. In this sense, the demise of the focal color consists of a crucial theoretical change in the context of a universalistic approach to categorization. Thus, given that the claim U3.1 has been rejected, and given the implications of the notion of perceptual saliency, the claim R3.1 may be seen as gaining legitimacy:

> R3.1. The inconsistent choice of focal points across languages suggests that categories are not structured by prototypes, but by their linguistic boundaries.

4. Proving Universalism Wrong Does not Prove Relativism Right

4.1. The Link between Biology and Categorization in U3 and R3 Was Inherited

In section 2, we went through the key claims of the universalistic account of color categorization. Proponents of this view argue that color categories are universal, and are observed as such. They seek to account for this universality on the grounds of biological reductions, and were able to do so based on results in experimental psychology and the standard theory of color vision. In section 3, we went through key claims of the relativist account of color categorization. We saw that in recent years, research in experimental psychology has called into question the biological reduction of category prototypes (U3.3), the cognitive advantages of prototypes and color universals (U3.2), and the structuring of color categories around prototypes (U3.1).

The conclusion we can draw from these studies is that, for the time being at least, color categories cannot be biologically reduced. This does not prove that there are no universal color categories, or that color categories are relative, but the absence of evidence for biological reductions leaves open the question of the universality or relativity of color categories.

Nevertheless, the absence of evidence for biological reductions can be seen as acting in favor of the relativist view. If biologically universal reductions of color categories are excluded, this would indeed explain why color categories are not regular across languages. If the irregularity of color categorization across languages can be explained, then the relativity of color categorization is established. Thus, it may be suggested that the rejection of U3 implies the following:

R3. Admitting that all humans are biologically similar and finding no biologically universal reductions of color categories would explain (R1), and therefore establish (R2).

In the last decade, research in cognitive psychology sought to overthrow the universalistic view on color categorization by rejecting its account of color category formation that crucially rests on claims pertaining to the neuronal reduction of category prototypes. To this extent, claims U3 and R3 seem pivotal in both lines of reasoning, respectively.

In the remainder of this section, I will argue first that the presence or absence of a link between low-level neuronal mechanisms and categorization, mentioned in claims U3 and R3, is independent from the claim of the universality or relativity of color categories. The biological reduction of color categories can be seen as mostly inherited from previous studies in anthropology, and is not logically necessary. Second, I will argue that claims U3 and R3 are not as constraining as they are suggested to be.

Several works of linguistics, racial anthropology, and experimental psychology of the late nineteenth century presuppose a link between neurophysiology and cultural expressions, and argue that language reflects perceptual capacities. That Homer inadequately describes (by current standards) the color of the sky, horses, sheep, or land, as well as the absence of the word ‘blue’ in Homeric writings (Gladstone, 1858) and in the ancient Veda hymns (Geiger, 1880), are taken as evidence of the fact that these ancient populations did not perceive color the way nineteenth-century Europeans did. This hypothesis is also confirmed by Rivers (1901), an experimental psychologist who observed the populations of Murray Island in the Torres Straits in situ at the turn of the twentieth century. Rivers notes that these people mainly have words for ‘white’, ‘black’, ‘red’, barely for ‘blue’. He concludes on the basis of a psychophysical experiment (which, however, makes use of language) that they have a poor perception of blue.

The line of thought underlying the views of Gladstone, Geiger, and Rivers is as follows: to the extent that human kind is universal, all humans are destined to achieve the same state of physical and mental completion observed in the white European man of the nineteenth century. Given that not all people seem to have the same cognitive and cultural capacities, different peoples and races express the different stages of that evolution, some of them incarnating the primeval state of the human species. In this theoretical framework, given their poor color lexicon, it is concluded that ancient and primitive populations have undeveloped perceptual capacities and are not yet fully sensitive to color.

Some seventy years after their publication, Berlin and Kay use the ethnographic data gathered by Rivers in the Torres Straits (Berlin & Kay, 1969; Saunders, 1988). Although they note that in some languages, there seems to be basic terms only for WHITE, BLACK, and RED, Berlin and Kay do not reach Rivers' conclusion. They agree with the nineteenth-century color studies that color lexicons of some populations are limited. They also agree with the claim that color categories are physiologically determined by color perception. However, they reject the idea that these lexical differences express a difference in perceptual capacities. In the context of the BCTT, it is not the perceptual capacities that evolve. It is the color lexicon.

Thus, it is important to place the BCTT in its historical background and note that it follows from an older tradition of research on color categorization even if it rejects some of its key claims. In this context, the BCTT's tendency to seek a link between basic color categories and neuronal mechanisms seems, to some extent, inherited from previous ethnographic, anthropological, and psychological studies. In the same way, the contemporary relativist stand on color categorization is inherited, through Whorf, from Boas. As universalism historically seeks to link race and biology to culture, relativism historically consists of a criticism of this link. When referring to the Sapir-Whorf hypothesis, the literature usually goes only as far as Whorf in history. However, in mentioning the famous example of the Eskimo snow lexicon, Whorf actually refers to a previous study by Boas, who strongly criticized views such as the one expressed by Gladstone, Geiger, and Rivers.

Boas was the first to report on the Eskimo snow lexicon (Boas & Powell, 1911). His familiar claim, adopted by Whorf, is that rules of categorization are relative to cultures, according to which they vary, depending on the needs and interests of the different peoples. This, however, is only part of Boas' assertion. In *The mind of primitive man*, Boas analyzes the conceptual underpinnings of racism, and aims to show that they are invalid. In the introduction to this book, Boas explains that "we are accustomed to speak both of primitive races and primitive cultures as though the two were necessarily related" (Boas, 1938, p. 4). This link that is drawn between race and culture, where race determines culture and culture expresses the inferiority or superiority of race, is unjustified and wrong. Boas argues that differences in culture and thought processes, as expressed in language in the case of categories, for example, depend on the different needs of a society. The Eskimo word for snow is one of many examples where terms "must to a certain extent depend upon the chief interests of a people" (Boas, 1938, p. 211).

Exploring further the relation of culture to thought, and of language to thought and mind, Boas says:

> The fact that generalized forms of expression are not used, does not prove inability to form them, but it merely proves that the mode of life of the people is such that

they are not required; that they would, however, develop just as soon as needed. (Boas, 1938, p. 218)

Thus, applied to the case of color categories, Boas' full argument may be formulated as follows: discrepancies in categorization may be observed across cultures; *these discrepancies are not symptomatic of discrepancies in perceptual capacities*. They merely express that different peoples, living in different environments, need different categories to adequately describe and relate to the world. It is arguable that Boas emphasizes the cross-cultural disparities in systems of categorization mainly in order to deter the idea of cross-cultural and cross-racial inequality (which naturally results from the Eurocentrism-laden universalistic view of the late nineteenth century), and replace it with that of cross-cultural difference.

4.2. The Negation of U3 Does Not Imply R3

The main point of this historical detour is to shed some light on the link naturally assumed between categorization and neurophysiology by some, and also on the relationship between universalism and relativism when it comes to this biological reduction. Inherited from Boas, the meaning of relativism has been, for over a century, to reject universalism and the physiological groundings it sought for cultural expressions such as linguistic categories. Proponents of relativism have, in the past few decades, continuously argued that categories are particular to culture (Conklin, 1973; Davidoff, Davies, & Roberson, 1999; Kuschel & Monberg, 1974; Levinson, 2000; Lucy & Schweder, 1979; Roberson, Davidoff, Davies, & Shapiro, 2005; Saunders & van Brakel, 1997), in order to argue that color categories are not universal, and therefore have no biologically universal reductions.

In this sense, the relativist account of color categorization is the historical negation of the universalistic account. For this reason perhaps, and given that universalism is logically opposed to relativism, universalistic and relativist accounts of categorization have been considered as jointly exhaustive. However, negating claim U3 (admitting that all humans are biologically similar and finding biologically universal reductions of color categories would explain U1, and therefore establish U2) does not imply claim R3 (admitting that all humans are biologically similar and finding no biologically universal reductions of color categories would explain R1, and therefore establish R2).

In the universalistic framework, claim U3 is justified. If biologically universal reductions of color categories were to be found, this would be sufficient to explain why regularities in color categorization are observed, thereby establishing the universality of color categories. But color categories can be universal for reasons that are independent of biology. Alternatively, color categories can be universal for reasons that are both biological and non-biological. In this sense, such biologically universal reductions are not necessary for the universalistic claim U2. Claim U3 may be a sufficient argument in favor of universal categorization, but it is not necessary. That the explanation for the universality of color categorization was essentially sought for in neuroscience is mainly a historical accident.

Conversely, in the relativist framework, claim R3 is justified. If biologically universal reductions of color categories were found, the claim that color categories are relative (R2) would lose all grounds. Thus, in order to argue that color categories are relative, it is necessary to establish that color categories have no biologically universal reductions. However, finding no biologically universal reductions of color categories is not sufficient to sustain that they are relative. It cannot be excluded that color categories can be universal for reasons that are not biological, or for reasons that are both biological and non-biological. Thus, R3 is necessary to argue for relativism, but it is not sufficient to establish it.

The necessity and non-sufficiency of R3, as well as the sufficiency but non-necessity of U3, lead to one main conclusion: relativism and universalism do not exhaust the logical space of all possible accounts of color categorization. In fact, other directions of research were suggested—the change in daylight color; the statistical distribution of color in the environment; communication constraints, to name only a few (Belpaeme & Bleys, 2005; Regier & Kay, 2009; Shepard, 1992; Yendrikhovskij, 2001)—but did not get the same degree of attention in the literature.

Thus, it is not true that color categories are either universal and reducible to neuronal mechanisms, or relative and determined by language use. It may well be that color categories are universal but not biologically reducible; or that color categories are universal and determined by language use and external factors; or that color categories are partly universal, partly relative, partly biologically reducible, partly determined by language use, or that they result from a combination of biological and non-biological factors.

In other words, the link that is generally assumed between universality and innateness is conceptually not justified. Conversely, the link assumed between the rejection of innateness and relativity is equally not justified. Consequently, U1 and U2 can be established independently of the refutation of claims U3.1, U3.2, and U3.3. The same applies to R1 and R2.

4.3. The Proof of Universalism or Relativism Rests on Claims U1 and R1

What proponents of the relativist view have accomplished in recent years is to undermine the biological reduction of color categories. I have just shown that universalism and innateness are not necessarily linked. Therefore, the rejection of the innateness claim cannot be said to lead to the rejection of the universality of color categories. Thus, U2, pertaining to the universality of color categories, is still supported by U1, pertaining to the observation of cross-cultural regularities in color categorization, regardless of the refutation of U3.1, U3.2, and U3.3. The universality or relativity of color categories can be established by the observation and comparison of color categories across languages. Either there is some consistency and regularity, thereby verifying U1 and establishing U2, or not, thereby verifying R1 and establishing R2.

Unfortunately, the verification of U1 or R1 is not as easy as it may seem. There is no agreement, across the opposed theoretical stands, on what to count as noteworthy color categories, or on how to operationally define them. Given this disagreement, one could worry that what counts as a refutation of the BCTT from the perspective of relativists might not do so from the perspective of universalists—simply because the two groups disagree about what the evidence is. Furthermore, not only are the respective notions of color categories developed within universalistic or relativist frameworks deeply embedded in these theories, but these respective definitions also have important limitations, and are therefore not reliable.

The BCTT offers an operational definition of basic color categories that is widely used in the literature, but it has been criticized starting in the late 1970s (Crawford, 1982; Hickerson, 1971; Lucy & Schweder, 1979; Lyons, 1999). It is argued that the operational definition offered by the BCTT proponents, which rests on eight criteria, is arbitrary and not applicable to all languages in all cases. Furthermore, the way basic categories are, in fact, identified in the ethnographic and anthropological literature (Berlin & Berlin, 1975; Hage & Hawkes, 1975; Hays et al., 1972; MacLaury, 1991; Maffi, 1990; Pollnac, 1975; Stanlaw, 1997) suggests that at most two criteria out of eight can truly be considered necessary: the criteria of psychological saliency and of non-hyponymy (i.e., that a basic color term cannot be included in the extension of another basic color term).

However, the criterion of non-hyponymy is problematic for two reasons. First, if the lexicon is believed to evolve, then, at some point in the history of the English language, the color samples that we today call "orange" must have been called "red." The color of these samples was therefore described as a "kind of red." However, in today's lexicon, these color samples are called "orange." The question is then, when does "orange" stop being a kind of RED, and start being the basic color category ORANGE in its own right? (MacLaury, 1991). The criterion of non-hyponymy is difficult to reconcile with the evolutionary thesis of the Basic Color Terms Theory.

Second, and more importantly, it is not clear on what grounds one decides that SCARLET is a kind of RED, instead of RED being a kind of SCARLET. Applying the criterion of non-hyponymy and eliminating SCARLET as non-basic in favor of RED presupposes the primacy of RED over SCARLET, whereas it is precisely the existence of such basic primary colors that the BCTT sets out to demonstrate. The non-hyponymy criterion is circular to the extent that it presupposes the perceptual and psychological primacy of some colors over others.

Thus, the only truly unquestionable and necessary criterion in the suggested operational definition is the criterion of psychological saliency. In other words, basic color terms are those that are used most often, and that are used by the majority of the linguistic community in reference to the same color samples. Psychologically salient terms are referentially stable and in this way easily identifiable. However, referential stability and psychological saliency do not necessarily result from perceptual factors alone. It has been shown that the more a term is used, the more it stabilizes in a lexicon (Fitch, 2007). And term use can be determined by external factors as well as by internal ones. For the BCTT, this is problematic. The fact that the psychological saliency of a color term may be due to external factors, and is not necessarily due to perceptual ones, is in direct contradiction with its core thesis according to which perception alone determines the way we form our color categories.

So-called relativists, on the other hand, have suggested that category membership could be determined based on categorical perception, or CP (Roberson, Davidoff, & Braisby, 1999). CP is usually described as a greater sensitivity to the difference in appearance of colors straddling category boundary than to the difference in appearance of colors belonging to the same category. Harnad canonically describes the notion of CP in the following terms:

> Equal-sized physical differences between stimuli are perceived as larger or smaller depending on whether the stimuli are in the same category or different ones. Indeed, the effect is not only quantitative but qualitative: A pair of greens of different shades look more like one another than like a shade of yellow. (Harnad, 1987, p. 3)

Thought to result from lexical category possession, CP at boundaries is the most natural way to identify color categories for a view that claims that categories are structured by their boundaries, not by their prototypes, and accounts for categorization on the basis of language use. To the extent that CP is observed at the boundaries of lexical categories, when CP occurs, the existence of a category is inferred.

Yet, recently, the understanding of CP seems to have shifted. Hanley and Roberson (2011) proceeded with the reassessment of data gathered through discrimination tasks across several years. They showed that CP was observed within categories as well as at the boundaries, therefore calling into question the meaningfulness of their usual interpretation. When, in discrimination tasks, all colors are from within the category, a CP effect is nevertheless observed if the target color is a better example of the category than the distracters. This means that the experienced qualitative difference between colors does not only occur at category boundary, and therefore is not due to differences in category naming. To the extent that CP also occurs within category and not only at boundaries, it is no longer clear how CP can be used to determine category membership.

Furthermore, the empirical observation of CP effects presupposes that categories have already been identified. CP is manifested by an improved discrimination performance at category boundary. Thus, in order to say that the improved discrimination performance corresponds to "categorical perception," it must be shown to occur at a category boundary. In other words, a minimal correlation of discrimination performance to category identification is required to infer the existence of CP (Schouten, Gerrits, & van Hessen, 2003). Thus, contending that the observation of CP implies the existence of a category is a circular argument. Therefore, beyond the fact that universalists and relativists disagree on what to count as noteworthy color categories—thereby making it impossible for universalists to deny R1 and R2 and for relativists to reject U1 and U2—both universalistic and relativist operational definitions of color categories have important limitations. As things stand today, the universality or relativity of color categorization can only remain an open question.

5. Conclusion

Research in color categorization, starting in the late nineteenth century, assumed a link between biology and color categories. Universalists typically argue that color categories are universal and perceptually determined, and therefore innate. Relativists typically argue that color categories are particular and determined by language use, and therefore acquired. The discussion in the past decade mainly focused on the innate nature of color categories, and more specifically of their prototypes. However, the most recent theory of color vision suggests that unique hues, on which universalists believed category prototypes would be based, do not result from the responses of the opponent cells in the LGN. Furthermore, proponents of the relativist view showed that so-called basic color categories and their prototypes did not have the cognitive advantages that served as an argument in favor of their naturalness. Finally, several results suggested that color categories could not be structured around prototypes.

Thus, research in the past few decades indicates that, for the time being, nothing suggests that color categories are innate. However, I argued in this paper that rejecting the innateness of color categories is not sufficient to establish their relativity. The accounts of color categorization offered by universalists and relativists do not exhaust all possibilities. It may well be that color categories are partly universal and partly relative, or that they are universal even if they cannot be biologically reduced. The link between biology and color categories is assumed in the literature for historical reasons, and because of the way relativism historically opposed universalism. Universality or relativity of color categorization can be argued for on the sole basis of the cross-cultural observation of color categories.

However, given the disagreement on what to count as a color category and the limitations of the current operational definitions of color categories, we lack the tools to fruitfully answer this question. What is a color category? How do we identify it? Such questions should be at the heart of future research efforts.

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Notes

[1] Throughout this paper, universalistic and relativist arguments are analyzed in a series of claims labeled U and R, respectively. The formulation of these claims are due to the author of this paper.

[2] In this paper, I adopt Berlin and Kay's initial way of labeling basic color categories, with small caps. For instance, the label WHITE in a stage 1 language does not refer to white as we

understand it in English, but to the extension of this category that encompasses white color samples among other samples.

References

Abramov, I. (1997). Physiological mechanisms of color vision. In C.L. Hardin & L. Maffi (Eds.), *Color categories in thought and language* (pp. 89–117). Cambridge: Cambridge University Press.

Abramov, I., & Gordon, J. (1994). Color appearance: On seeing red—or yellow, or green, or blue. *Annual Review of Psychology*, *45*, 451–485.

Belpaeme, T., & Bleys, J. (2005). Explaining universal color categories through a constrained acquisition process. *Adaptive Behavior*, *13*, 293–310.

Berlin, B., & Berlin, E.A. (1975). Aguaruna color categories. *American Ethnologist*, *2*, 61–87.

Berlin, B., & Kay, P. (1969). *Basic color terms: Their universality and evolution*. Berkeley, CA: University of California Press.

Boas, F. (1938). *The mind of primitive man*. New York: Macmillan.

Boas, F., & Powell, J.W. (1911). *Introduction to the handbook of American Indian languages*. Lincoln, NE: University of Nebraska Press.

Chomsky, N. (1965). *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.

Churchland, P. (2007). On the reality (and diversity) of objective colors: How color-qualia space is a map of reflectance-profile space. *Philosophy of Science*, *74*, 119–149.

Conklin, H.C. (1973). Color categorization. *American Anthropologist*, *75*, 931–942.

Cook, R.S., Kay, P., & Regier, T. (2005). The world color survey database: History and use. In H. Cohen & C. Lefebvre (Eds.), *Handbook of categorisation in the cognitive sciences* (pp. 224–242). Amsterdam: Elsevier.

Corbett, G., & Morgan, G. (1988). Colour terms in Russian: Reflections of typological constraints in a single language. *Journal of Linguistics*, *24*, 31–64.

Crawford, T.D. (1982). Defining 'basic color term'. *Anthropological Linguistics*, *24*, 338–343.

Davidoff, J., Davies, I., & Roberson, D. (1999). Colour categories of a stone-age tribe. *Nature*, *398*, 203–204.

Davies, I.R.L., Sowden, P.T., Jerrett, D., Jerrett, T., & Corbett, G. (1998). A cross-cultural study of English and Setswana speakers on a colour triads task. *The British Psychology Society*, *89*, 1–15.

De Valois, R., Abramov, I., & Jacobs, G.H. (1966). Analysis of response patterns of LGN cells. *Journal of the Optical Society of America*, *56*, 966–977.

De Valois, R., & De Valois, K. (1993). A multi-stage color model. *Vision Research*, *36*, 833–836.

De Valois, R., De Valois, K., & Mahon, L. (2000). Contribution of S opponent cells to color appearance. *Proceedings of the National Academy of Sciences*, *97*, 512–517.

Fitch, T. (2007). An invisible hand. *Nature*, *449*, 665–667.

Geiger, L. (1880). *Contributions to the history of the development of the human race*. London: Tubner and Company.

Gladstone, W.E. (1858). *Studies on Homer and the Homeric age*. Oxford: Oxford University Press.

Hage, P., & Hawkes, K. (1975). Binumarien color categories. *Ethnology*, *14*, 287–300.

Hanley, J.R., & Roberson, D. (2011). Categorical perception effects reflect differences in typicality on within-category trials. *Psychonomic Bulletin & Review*, *18*, 355–363.

Harnad, S. (1987). Psychophysical and cognitive aspects of categorical perception. In S. Harnad (Ed.), *Categorical perception: The groundwork of cognition* (pp. 1–28). New York: Cambridge University Press.

Hays, D., Margolis, E., Naroll, R., & Perkins, D. (1972). Color term salience. *American Anthropologist*, *74*, 1107–1121.

Heinrich, A.C. (1974). Color classification of some central Canadian Eskimos. *Arctic Anthropology*, *11*, 68–72.

Hering, E. (1964). *Outlines of a theory of the light sense*. Cambridge, MA: Harvard University Press.

Hickerson, N. (1971). Review of basic color terms: Their universality and evolution. *International Journal of Amercian Linguistics*, *37*, 257–270.

Hurvich, L.M., & Jameson, D. (1957). An opponent-process theory of color vision. *Psychological Review*, *64*, 384–404.

Jameson, K. & D'Andrade, R. (1997). It's not really red, green, yellow, blue: An inquiry into perceptual color space. In C.L. Hardin & L. Maffi (Eds.), *Color categories in thought and language* (pp. 295–320). Cambridge: Cambridge University Press.

Jameson, D., & Hurvich, L.M. (1955). Some quantitative aspects of an opponent-colors theory. I. Chromatic responses and spectral saturation. *Journal of the Optical Society of America*, *4*, 546–552.

Kay, P. (1975). Synchronic variability and diachronic change in basic color terms. *Language in Society*, *4*, 257–270.

Kay, P. (1999). The emergence of basic color lexicons hypothesis. In A. Borg (Ed.), *The language of colour in the Mediterranean* (pp. 77–92). Wiesbaden, DE: Otto Harroasowitz.

Kay, P., Berlin, B., Maffi, L., & Merrifield, W. (1997). Color naming across languages. In C.L. Hardin & L. Maffi (Eds.), *Color categories in thought and language* (pp. 21–56). Cambridge: Cambridge University Press.

Kay, P., Berlin, B., & Merrifield, W. (1991). Biocultural implications of systems of color naming. *Journal of Linguistic Anthropology*, *1*, 12–25.

Kay, P., & Kempton, W. (1984). What is the Sapir-Whorf hypothesis? *American Anthropologist*, *86*, 65–79.

Kay, P., & Maffi, L. (1999). Color appearance and the emergence of basic color lexicons. *American Anthropologist*, *101*, 743–760.

Kay, P., & McDaniel, C.K. (1978). The linguistic significance of the meanings of basic color terms. *Language*, *54*, 610–646.

Kuehni, R.G. (2001). Determination of unique hues using Munsell color chips. *Color Research and Application*, *26*, 61–66.

Kuehni, R.G. (2004). Variability in unique hue selection: A surprising phenomenon. *Color Research and Application*, *29*, 158–162.

Kuschel, R., & Monberg, T. (1974). ''We don't talk much about colour here'': A study of colour semantics on Bellona Island. *Man*, *9*, 213–242.

Lenneberg, E.H., & Roberts, J. (1956). *The language of experience: A study in methodology*. Baltimore, MD: Waverly.

Lennie, P., Krauskopf, J., & Sclar, G. (1990). Chromatic mechanisms in striate cortex of macaque. *The Journal of Neuroscience*, *10*, 649–669.

Levinson, S.C. (2000). Yélî dnye and the theory of basic color terms. *Journal of Linguistic Anthropology*, *10*, 1–53.

Liljencrants, J., & Lindblom, B. (1972). Numerical simulation of vowel quality systems: The role of perceptual contrast. *Language*, *48*(4), 839–862.

Lucy, J., & Schweder, R. (1979). Whorf and his critics: Linguistic and nonlinguistic influences on color memory. *American Anthropologist*, *81*, 581–615.

Lyons, J. (1995). Colour in language. In E.T. Lamb & J. Bourriau (Eds.), *Colour: Art and science* (pp. 194–224). Cambridge: Cambridge University Press.

MacAdam, D.L. (1942). Visual sensitivities to color differences in daylight. *Journal of the Optical Society of America*, *32*, 247.

MacLaury, R. (1987). Color-Category evolution and Shuswap yellow-with-green. *American Anthropologist*, *89*, 107–124.

MacLaury, R. (1991). Social and cognitive motivations of change: Measuring variability in color semantics. *Language*, *67*, 34–62.

Maffi, L. (1990). Somali color term evolution: Grammatical and semantic evidence. *Anthropological Linguistics*, *32*(3–4), 316–334.

Martin, L. (1986). ''Eskimo words for snow'': A case study in the genesis and decay of an anthropological example. *American Anthropologist*, *88*, 418–423.
Munsell, A.H. (1941). *A color notation: An illustrated system defining all colors and their relations*. Boston, MA: Hoffman Brothers.
Pollnac, R. (1975). Intra-Cultural variability in the structure of the subjective color lexicon in Buganda. *American Ethnologist*, *2*, 89–109.
Pullum, G. (1991). The great Eskimo vocabulary hoax. In his *The great Eskimo vocabulary hoax and other irreverent essays on the study of language* (pp. 160–171). Chicago, IL: University of Chicago Press.
Ray, V.F. (1952). Techniques and problems in the study of human color perception. *Southwestern Journal of Anthropology*, *8*, 251–259.
Regier, T., & Kay, P. (2009). Language, thought, and color: Whorf was half right. *Trends in Cognitive Sciences*, *13*, 439–446.
Regier, T., Kay, P., & Khetarpal, N. (2007). Color naming reflects optimal partitions of color space. *Proceedings of the National Academy of Sciences*, *104*, 1436–1441.
Rivers, W.H.R. (1901). Introduction and vision. In A.C. Haddon (Ed.), *Reports on the Cambridge anthropological expedition to the Torres Straits* (pp. 8–139). London: Cambridge University Press.
Rivers, W.H.R. (1902). The colour vision of the eskimo. *Proceedings of the Cambridge Philosophical Society*, *11*, 143–149.
Roberson, D., & Davidoff, J. (2000). The categorical perception of colours and facial expressions: The effect of verbal interference. *Memory & Cognition*, *28*, 977–986.
Roberson, D., Davidoff, J., & Braisby, N. (1999). Similarity and categorization: Neuropsychological evidence for a dissociation in explicit categorization tasks. *Cognition*, *71*, 1–42.
Roberson, D., Davidoff, J., Davies, I.R.L., & Shapiro, L.R. (2005). Color categories: Evidence for the cultural relativity hypothesis. *Cognitive Psychology*, *50*, 378–411.
Roberson, D., Davies, I., & Davidoff, J. (2000). Color categories are not universal: Replications and new evidence from a Stone-Age culture. *Journal of Experimental Psychology: General*, *129*, 369–398.
Rosch [Heider], E. (1972a). Probabilities, sampling, and ethnographic method: The case of Dani colour names. *Man*, *7*, 448–466.
Rosch [Heider], E. (1972b). Universals in color naming and memory. *Journal of Experimental Psychology*, *93*(1), 10–20.
Rosch [Heider], E. (1973). Natural categories. *Cognitive Psychology*, *4*, 328–350.
Rosch [Heider], E., & Olivier, D.C. (1972). The structure of the color space in naming and memory for two languages. *Cognitive Psychology*, *3*, 337–354.
Sapir, E. (1929). The status of linguistics as a science. *Language*, *5*, 207–214.
Saunders, B. (1988). Re-evaluating basic colour terms. *Cultural Dynamics*, *1*, 359–378.
Saunders, B., & van Brakel, J. (1997). Are there non-trivial constraints on colour categorization? *Behavioral and Brain Sciences*, *20*, 167–228.
Schouten, B., Gerrits, E., & van Hessen, A. (2003). The end of categorical perception as we know it. *Speech Communication*, *41*, 71–80.
Shepard, R.N. (1992). The perceptual organization of colors: An adaptation to regularities of the terrestrial world? In J. Barkow, L. Cosmides, & J. Tooby (Eds.), *The adapted mind* (pp. 495–532). Oxford: Oxford University Press.
Singh, S. (2006). Impact of color on marketing. *Management Decision*, *44*, 783–789.
Siok, W.T., Kay, P., Wang, S.Y.W., Chan, A.H.D., Chen, L., Luke, K., & Tan, L.H. (2009). Language regions of brain are operative in color perception. *Proceedings of the National Academy of Sciences*, *106*, 8140–8145.
Sivik, L., & Taft, C. (1994). Color naming: A mapping in the NCS of common color terms. *Scandinavian Journal of Psychology*, *35*, 144–164.

Stanlaw, J. (1997). Two observations on culture contact and the Japanese color nomenclature system. In C.L. Hardin & L. Maddi (Eds.), *Color categories in thought and language* (pp. 240–260). Cambridge, MA: Cambridge University Press.

Tailby, C., Solomon, S., & Lennie, P. (2008). Functional asymmetries in visual pathways carrying S-cone signals in macaque. *The Journal of Neuroscience*, *28*, 4078–4087.

Tan, A.H.D., Chan, L.H., Khong, P.L., Yip, L.K.C., & Luke, K. (2008). Language affects patterns of brain activation associated with perceptual decision. *Proceedings of the National Academy of Sciences*, *105*, 4004–4009.

Webster, M., & Kay, P. (2007). Individual and population differences in focal colors. In R.E. Paramei & D. Dedrick (Eds.), *The anthropology of color* (pp. 29–53). Amsterdam: John Benjamins.

Whorf, B. (1956). *Language, thought, and reality: Selected writings*. New York: Free Press.

Winawer, J., Witthoft, N., Frank, M.C., Wu, L., Wade, A.R., & Boroditsky, L. (2007). Russian blues reveal effects of language on color discrimination. *Proceedings of the National Academy of Sciences*, *104*, 7780–7785.

Yendrikhovskij, S.N. (2001). A computational model of colour categorization. *Color Research and Application*, *26*, 235–238.