

Culture and Cognition: What is Universal about the Representation of Color Experience?

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Abstract

Research in color naming and categorization has been dominated by two opposing views: (1) a Cultural Relativist view which suggests that color perception is greatly shaped by culturally-specific language associations and perceptual learning; and (2) a Universalist view which emphasizes the structure dictated by pan-human physiological opponent-color processing as the basis for color naming coherence within and across cultures. In this article a third view is presented which suggests that color naming and categorization are shaped by both pan-human cognitive universals and socio-cultural evolutionary processes. This third view is supported by evidence that color processing mechanisms differ both intra-culturally and cross-culturally. This divergent color processing undermines the physiological basis proposed by Universalists for within-culture color-naming coherence, and raises new questions about the sources of observed cultural coherence and cross-cultural universality. A new theory proposes that universalities in color naming and categorization may arise because, across cultures, color language and color categories primarily reflect the culturally modal mapping of linguistic items and categories shaped by universal cognitive constructs and culturally salient color appearances. Thus, a shared cultural representation of color based on widely shared cognitive dimensions may be what is truly universal about color naming and color categorization. Across cultures this form of representation may result from convergent responses to similar evolutionary pressures.

Overview

Research in color naming and categorization has been dominated by two opposing views. A Cultural Relativist view suggests that color processing is shaped by learned language associations and perceptual learning specific to a given culture. A Universalist view emphasizes structure dictated by pan-human physiological processing of color stimuli as the basis for color naming coherence within and across cultures.

However, recent evidence brings two new insights: (1) considerable variation in color processing exists between individuals in the same culture, and (2) important differences in color naming and categorization can be seen cross-culturally. In light of this evidence, this article considers two important questions: (1) if divergent color processing exists among individuals within a culture, what is the basis for within-culture color-naming coherence; and (2) are the processes that produce cultural coherence also the basis for observed similarities in color-naming and categorization across cultures?

The argument offered in the pages that follow proposes that both cultural and cross-cultural color-naming coherence arise as the result of convergent evolution shaped by similar psychological and social demands. To explain how individuals in different cultures might develop similar ways of communicating about color experience, a psycho-social framework for mapping color language with color percepts is described. This framework is further elaborated as a model of Interpoint Distance relations among color sensations.

The proposed model provides an alternative to existing explanatory theories of color categorization and naming coherence. While it shares features presented in other theories of the phenomena (e.g., Berlin, Kay, Maffi & colleagues, MacLaury, Roberson, Davies, Davidoff & colleagues, Dedrick, and Saunders & van Brakel), most importantly, it suggests that the shared cultural representation of color may be what is truly universal about color naming and color

categorization. This explanation provides a new psychological perspective for evaluating color naming phenomena, and leads to new empirical hypotheses for color-naming phenomena both within and across cultures.

Introduction

The accepted model of color naming and categorization, proposed by Berlin and Kay (1969), is founded on the construct of pan-human shared color vision processing mechanisms across all individuals and all ethnolinguistic backgrounds (c.f., Kay, Berlin, Maffi & Merrifield 1997). Subsequent research offers support for the theory that the cross-cultural universality of 11 basic color terms and categories is due to a pan-human neurophysiological substrate underlying color perception (Ratliff 1976; Kay and McDaniel 1978; Boynton & Olson 1987, 1990; Kay, Berlin and Merrifield 1991; Kay, Berlin, Maffi & Merrifield 1997; See Hardin & Maffi 1997 for a collected review). Most recently Kay and Maffi (2000) have reemphasized that: "... two of the original empirical generalizations of Berlin & Kay (1969) have been maintained. I. There exists a small set of perceptual landmarks (that we can now identify with the Hering primary colors: black, white, red, yellow, green, blue...) that individually or in combination form the basis of the denotation of most of the major color terms of most of the languages of the world.... II. Languages are frequently observed to gain basic color terms in a partially fixed order. Languages are infrequently or never observed to lose basic color terms..." (original emphasis, p. 744).¹

However, as R. M. Boynton notes, using Hering fundamental color-opponent processing as a basis for universal category focal salience is at best a dubious proposition: "... the concept of fundamental neural response categories as defined by Kay, Berlin, and Merrifield (1991) should be expanded... Their appeal to the early research of DeValois and colleagues is misguided, if only because sensations surely do not arise from the lateral geniculate nucleus which was the site of their recordings. Moreover, DeValois's use of the names red, yellow, green and blue to classify groups of data was entirely arbitrary and ignored a virtual continuum of opponent responses that exists as a function of crossover wavelength in the data of individual [neural] units... We simply do not yet know what kind of activity in the brain generates our color sensations..." (Boynton 1997, p. 148).

This view is been echoed by Valberg (2001), Zaidi (2001) and others. Nevertheless, the idea that universality emerges from underlying neural opponent-process mechanisms continues to dominate the most influential studies in the color perception and naming literature.

The remainder of this article explores the basis for universality in color naming and categorization. Analyses of both existing and new results on color naming and perception in observers with normal and abnormal color perception yield conclusions that differ from the most widely accepted notions about universality of color naming and categorization. Although it is correct that color vision mechanisms are in general similar across cultures, it is incorrect to suggest that color vision mechanisms are the factor responsible for the cross-cultural similarities in color-naming and categorization. What is shown is that it is more accurate to say that observed universality arises from the shared cultural representation of color. To reach this conclusion results from (i) molecular genetic studies of retinal processing; (ii) psychophysical studies of color

¹The hierarchical sequence of eleven basic color terms is: Black, White, Red, Yellow or Green, Green or Yellow, Blue, Brown, followed by terms for Purple/Pink/Orange or Gray in a nondetermined order.

perception variation; (iii) investigations of color perception, color naming and color categorization from anthropology, linguistics, and cognitive psychology; and (iv) gender-linked differences in color processing from the literatures just mentioned. Examining these results reveals phenomena which contradict the main thesis of the Berlin and Kay theory of color-naming (incl. Kay, Berlin, Maffi & Merrifield 1997), and which reestablish the contributions of language and culture to color-categorization, -naming and -cognition. The new model of color naming and categorization proposed encompasses this larger literature.

This article is organized in five sections. Section 1 reviews evidence of important individual differences in color processing. Section 2 discusses the consequences of such intracultural variation for cross-cultural color-naming research. Section 3 analyzes how phenomenological color perception processing differences relate to the ways individuals learn color lexicons and perceptual color categories. Section 4 focuses on cross-cultural color naming universality and describes an alternative explanatory model. Section 5 relates the proposed alternative model to existing research, and discusses empirical considerations in studying cross-cultural color naming and color appearance representation.

1 Intracultural Variation in Color Perception

Many studies focus on the representation of cognitive color space (Griffin 2001; Moore, Romney & Hsia 2000; Paramei, Bimler & Cavonius 2001; Bimler 1999; Paramei & Cavonius 1999; Furbee, Maynard, Smith, Benfer, Quick, & Ross 1997; Sturges & Whitfield 1997; Shepard & Cooper 1992; Chang & Carroll 1980), and make direct comparisons across ethnolinguistic cultures or perceptual subgroups (Boynton & Olson, 1987,1990; Uchikawa & Boynton 1987; Lin, Luo, MacDonald & Tarrant 2001). Their common goal is identifying linkages between the physical and perceptual similarity of color appearances and cognitive representation of color. Or, put differently, to provide a full characterization of what Brindley (1970) identifies as *psychophysical linking hypotheses* connecting (1) physical color stimuli to perception, (2) color perception representation to color naming, categorization, and cognition, and (3) cognitive color representation to intracultural similarity structures and cross-culturally universal representations.

Most of these studies are interpreted as supporting the research perspective that posits a pan-human neurophysiological basis for color perception and color naming (Berlin & Kay 1969, Kay, Berlin & Merrifield 1991, see Hardin and Maffi 1997 for a review). This perspective relies on a model of daylight processing (e.g., DeValois, Abramov and Jacobs 1966, DeValois and DeValois 1993) which includes (1) luminance processing from a combined retinal stimulation signal, and chromatic processing beginning with the selective stimulation of three retinal cone classes, and (2) postreceptoral processing at which ratios of cone classes define the basis of color sensations and form the color opponent-process neural mechanisms typically identified with the Hering primaries (i.e., Black-White, Red-Green and Yellow-Blue).

The cross-culturally oriented among these additionally focus on investigating phenomena for a culturally “normative” model of color experience. The normative model consists of “normal” Trichromats in the general population (those people possessing three classes of retinal photopigments - each class being maximally sensitive to, roughly, the short-, medium- and long-wavelength regions of the visible spectrum). Thus, most investigations choose to exclude deficient dichromat individuals (roughly 2% of the Caucasian male population) who possess only two of the

three typical retinal photopigment classes (i.e., just the shortwavelength-sensitive (SWS) and the medium-wavelength-sensitive (MWS) classes, or just the short-wavelength-sensitive (SWS) and the long-wavelength-sensitive (LWS) classes, but not all three).

New evidence from molecular genetics reveals that color perception is probably more variable even within “normative” ethnolinguistic populations than previously thought. For example, recent molecular genetics research on the genes underlying color vision shows that there are several allelic variants, or forms, of X-linked opsin genes (i.e., the MWS and LWS opsin genes).² When allelic variations for these photopigment classes occur at crucial loci on the genetic array they are known to give rise to shifts in spectral sensitivity which impact color perception (e.g., Neitz & Jacobs 1986, Winderickx, Lindsey, Sanocki, Teller, Motulsky & Deeb 1992, Asenjo, Rim & Oprian 1994). The impact of the genotype-phenotype relation on perception is further underscored by studies showing perceptual phenotype differences in monozygotic and dizygotic twins of similar genotypes (Paramei, Bimler & Mislavskaya, 2001).

In addition to diversifying the existing forms of “normal” trichromacy, such genotypic variation gives rise to a third type of perceptual phenotype known as *anomalous trichromats* (estimated as 6% of the caucasian male population) These individuals have three classes of color photoreceptors like a normal trichromat does; however, in one of these classes (either the MWS-class or the LWS-class) the wavelength at which the photopigment maximally responds is shifted, sometimes, due to a single amino-acid substitution at a critical locus in the gene sequence, producing one of the allelic forms of the photopigment class in the functioning retina.

In general, anomalous trichromats and individuals experiencing color perception deficiencies can be identified by color vision assessment tests as having variable or different percepts from normal trichromacy. Such differences can produce perceptual confusions and disagreements with normal trichromats about color matches, and for this reason such subjects are often excluded from studies of ‘normative’ color perception. Interestingly, for reasons that are discussed later, such confusions in color perception typically do not produce confusions in everyday color language.

Thus the photopigments of an anomalous trichromat, and indeed those of the standard trichromat, can vary considerably, and even among trichromats there is a plurality of observer types. Asenjo et al. 1994 describe no fewer than five variants of the middlewavelength photopigment, and six of the long-wavelength photopigment (p. 1133). Such differences at the level of the genotype impact spectral sensitivity (Winderickx, Lindsey, Sanocki, Teller, Motulsky & Deeb 1992), even under viewing circumstances which arguably minimize differences that might occur. Furthermore, they are likely to have as great, if not a greater, impact on color perception behaviors under visually rich, or naturalistic, viewing circumstances (see Jameson, Highnote and Wasserman [2001] for a discussion). The range and variety of photopigment variants is surprising in view of color vision models that postulate just three “normal” pigments. It implies that in a given population, the forms of initial color processing are almost certainly more diverse than originally anticipated by three-pigment theories.

In addition to variation seen in dichromats and anomalous trichromats, recent molecular genetic evidence points to groups of individuals in the general population who are both genotypically and phenotypically more complex than expected by the normal three-photopigment opponent-process model on which color naming universality is typically grounded (Kay, Berlin &

²The genes for the shortwavelength-sensitive cone pigments are located on chromosome seven and are very rarely omitted in phenotype expression.

Merrifield 1991; Boynton and Olson 1987, 1990, etc.). For example, it is established that between 15-20% of Caucasian females possess the genetic potential to express four classes of retinal photopigments (Sharpe, Stockman, Jaegle & Nathans 1999, p. 40). Those individuals who express four photopigment types are properly called “retinal tetrachromats.” One issue still debated is whether post-receptoral processing of the signals from additional retinal photopigment classes produces color perceptions not available to normal trichromats (Mollon 1992, 1995). Independent use of signals from a fourth photopigment class would require a revision of the classic opponent-colors processing theory, and would provide further support of Jameson & D’Andrade’s (1997) claim that psychophysical data suggest that the originally proposed neurophysiological color opponencies (i.e., Hering’s cardinal axes Red vs. Green, Yellow vs. Blue) are not privileged axes of cognitive color appearance since other non-cardinal color axes have been shown to be empirically robust (e.g., D’Zmura & Knoblauch 1998; Derrington, Krauskopf & Lennie, 1984; Krauskopf, Williams, & Heeley 1982). If a robust structural difference in perception were linked to the presence of a fourth retinal photopigment, then such observers would be “functional tetrachromats.” Functional tetrachromacy is not permitted by the pan-human universal model which since 1970 has been the foundation for the vast majority of cross-cultural color cognition and color naming research.³

Although perceptual tetrachromacy is well established in non-human species (Thompson, Palacios & Varela 1992, for a review), studies of human retinal tetrachromat perception have not been extensive and there are mixed findings about the existence and degree of a such difference. However, Jameson, Highnote and Wasserman (2001) found that genotypically identified female retinal tetrachromats do experience differences in color perception which are substantially different from normal female trichromat controls. Briefly summarized, in a task which requires subjects to provide spectral delineations for a diffracted spectrum stimulus subjectively experienced as a luminous “rainbow,” Jameson, Highnote & Wasserman (2001) hypothesized that the ability to perceive and delineate bands of chromatic difference along the spectrum was a function of the detection and discrimination of noticeable differences in spectral wavelengths. Such discrimination differences were expected to covary with the number of photopigment classes possessed.

Table 1 presents a summary of the results, and demonstrates that the number of spectral bands a subject delineates systematically varies with the number of photopigments a subject is presumed to express. The most stringent test of this hypothesis, which rules out the possibility that the result is due to gender differences in socialization, is provided by comparing female Trichromatic “controls” with female Heterozygote subjects. As shown in rows 1 and 2 of Table 1, the number of bands observed between the two female groups is significantly different ($p < .01$). Overall, Table 1 indicates a systematic relationship between the observed number of bands delineated by subjects and the number of photopigments they are presumed to express. These results suggest that higher-order color experience for heterozygote females is more com-

³Note that as discussed by Jameson, Highnote & Wasserman (2001) functional tetrachromacy does not necessarily follow as a consequence of retinal tetrachromacy; in order for functional tetrachromacy (or *strong tetrachromacy*) to occur either more than three neural channels, or a different form of higher-order color processing, are presumably needed to process all available color signals. Interestingly, studies of squirrel monkey photopigment genotypes suggests that the functional advantages of heterozygosity enjoyed by trichromatic female monkeys is the causal basis for the presence and maintenance of photopigment polymorphisms (Bowmaker, Jacobs & Mollon 1987).

<i>Subject Partition</i>	<i>M</i>	<i>SD</i>	<i>n</i>
(1.) Four-pigment Females (of heterozygote genotype)	10.0	2.96	23
(2.) Trichromat Females	7.6	1.80	15
(3.) Trichromats (Females and Males)	7.3	1.93	37
(4.) Dichromat Males	5.3	1.53	4

Table 1: Mean Number of Perceived Spectral Delineations for Four Subject Partitions. Note: Classification of subject partition (1.) is inferred strictly from the genotype analysis determining heterozygote and (based on results found in existing molecular genetics and microspectrophotometry research) is probabilistically linked to the four-photopigment phenotype (with an estimated 56% incidence of occurrence). Partitions (2.), (3.), (4.) are based on results from both genotype tests and color-vision screening tests. Partition (2.) is a sub-partition of group (3.). As expected from trichromatic theory, dichromat individuals (in this case protanopes) delineate fewer chromatic bands than trichromats (Student’s T-test, two-tailed distribution, two-sample equal variance $p < .05$ on rows 4 and 3). Also, male Trichromats ($n=22$) and female Trichromats ($n=15$) were not significantly different regarding the number of chromatic bands each group on average delineates ($p=.44$). Contrary to what Trichromatic theory predicts, significant difference ($p < .01$) were found between the number of bands delineated by Heterozygotes and Trichromats (males and females) subjects (rows 1 and 3).

plicated than “normal” trichromatic color vision; or, less conservatively, that some females are functionally tetrachromatic. In addition, as expected given their color vision deficiency, Dichromat participants were found to delineate far fewer chromatic bands (about 5) than the other subjects participating in the study.

Further support for a tetrachromat perceptual difference is found by comparing color vision assessment results between individuals possessing retinal-tetrachromat genotypes and individuals with trichromatic genotypes. Novel multidimensional scaling analyses reveal that one standardized color perception test isolates some retinal tetrachromat individuals (who otherwise exhibit above-average chromatic discrimination) by a non-normative trichromat diagnosis. The analyses also reveal that performance differences in the red to green region of color space seem to underlie the misclassifications (Jameson, Bimler & Wasserman, submitted; Jameson, Bimler & Wasserman, 2002; Jameson & Wasserman, 2002) .

The foregoing discussion of dichromats, anomalous trichromats, and retinal tetrachromats suggests that intracultural individual variation in color perception is much more substantial than previously recognized in studies of color-naming and categorization, and that the variation may have a stronger effect on color perception behaviors than previously thought. In light of this, it is seems natural to consider how the variability in X-chromosome inherited photopigment opsin genes may affect intracultural color-naming and the study of cross-cultural color universals.⁴

⁴Some of the additional factors that vary across individuals and are known to effect response properties of photoreceptors are photopigment optical density, photoreceptor orientation and length, lens density and discoloration, macular pigment density, and coloration of the iris (eye color). These features of the visual system are presumed to produce small difference in the visual systems response sensitivity to visible light even between two individuals who possess the same set of retinal photopigments (i.e., with identical absorption spectra). In vision

1.1 Support X-linked Color Perception Differences?:

Do the kind of perceptual differences demonstrated by Jameson, Highnote & Wasserman (2001) and Jameson, Bimler & Wasserman (submitted, 2002) make a difference in the color-naming behaviors seen in individuals of a given culture? Indirect empirical support for this possibility can be found in the existing psychology, perception, cross-cultural, and anthropological literatures, which show the existence of substantial gender differences in color perception and color cognitive processing.

Kuehni (2001) studied unique hues using Munsell surface stimuli and showed female observers have wider ranges (about twice as wide) around their mean unique reds than male observers. Kuehni makes the tentative suggestion that the differences in unique red settings might arise “as individual variations ... that can be caused by genetic differences or variation in the opponent system responses” (p.65). The region of Munsell color space producing the variation is identified in new results using the Munsell 100-hue test as a diagnostic for potential tetrachromacy (Jameson, Bimler & Wasserman, submitted).

The following gender differences in visual processing can be found, supporting the notion that gender differentiates observers even at this very basic level of psychological processing: the persistence of afterimages, Ganzfeld experiences, tolerance of brightness, visual detection thresholds (McGuinness, 1976); contrast sensitivity as a function of spatial frequency and stimulus orientation (Brabyn & McGuinness, 1979); as well as for color discrimination for which females were more responsive to the long-wavelength region of the frequency spectrum of a stimulus (McGuinness & Lewis 1976). Gender differences in the visual processing of spatial information (most likely attributable to early visual processing differences) are also known to exist (Blough & Slavin, 1987).

A portion of the literature explores whether gender differences are found in the ways individuals categorize and name their color perceptions. Color vision capabilities are believed to develop and function equally in males and females by one year of age. Between five and six years of age the ability to identify primary colors by name is significantly greater in girls than in boys (although no significant differences are found for the same subjects for drawing geometric designs). One explanation is that “various constitutional and environmental factors undoubtedly influence the acquisition of color-naming ability by children,” and that “verbal skill and interest in colors may vary between boys and girls” (Anyan & Quillan, 1971, p. 1631). An alternative explanation is that X-chromosome-linked differences in color vision might be the basis for differentiating early childhood color perception behaviors. A number of adult studies suggest that color lexicons differ in fundamental ways by gender (Nowaczyk, 1982; Swaringen, Layman & Wilson, 1978; Thomas, Curtis & Bolton, 1978; Rich, 1977). One recent study isolates gender differences in color naming as occurring strictly for surface samples with a reddish spectral component (Bonnardel, Miller, Wardle, & Drews, 2002). And some studies empirically demonstrate the anecdotal finding of male-female differences in color preference (Saito, 1996a, 1996b, 1999). Results on color memory

science these factors have been quantified to define a margin of error that is sometimes corrected for, and at other times treated as individual variation. It should be noted that these features vary both intraculturally and cross-culturally. For example, it has been suggested that people living in equatorial climates will exhibit increases in lens yellowing due to heightened levels of UV-radiation reaching the eye, and that this kind of environmental circumstance might contribute to differences observed in the cross-cultural color naming and categorization results of equatorial populations compared to nonequatorial populations (Ratliff 1976).

matching find that females remember colors better than males, and are generally more accurate at matching saturation and hue (Pérez- Carpinell, Baldoví, de Fez & Castro 1998).

Studies showing color naming differences favoring female performance over male performance isolate effects across gender and age (Simpson & Tarrant 1991), for the development of color naming (in children 2.5-4.5 years) (Johnson, 1977); in the perception of color mass (Philip, 1938); and in longitudinal study of color vocabulary (Sleight & Prinz 1982).

Other investigations show gender differences in the color-naming representations of males and females. In a study of triadic comparisons of judged color-sample similarity, males and females are differentiated by their derived similarity structures. Specifically, females are found to represent more strongly a red-to-yellow-to-green dimension when compared to their male counterparts. As a result, the female representation of color similarity required an additional dimension in the scaling solution (Furbee, Maynard, Smith, Benfer, Quick & Ross 1997).

Such gender differences in color behavior do not accord with a model of shared, pan-gender visual processing mechanisms. Moreover, they often go unnoticed (especially in aggregate analyses); and, when not ignored, they are usually attributed to gender dependent socialization. Gender differences are not a focus of much of the cognition and categorization literature of color because most researchers do not consider them to be a differentiating factor in color perception.

Thus, although the assumption of a pan-human uniform neural substrate for color processing was reasonable in light of early findings on retinal photopigments in humans and non-human primates (DeValois, Abramov & Jacobs 1966; Dartnall, Bowmaker & Mollon 1983), new research indicates there are at least two good reasons to question the common neural substrate model as the primary determinant of pan-human color naming and color categorization. First, recent evidence on the genetic variation underlying photoreceptor spectral sensitivities suggests that a universal model of retinal color-signal processing is likely to be too simplistic to account for color-signal variation occurring across individuals intraculturally. Second, the recent confirmation of intracultural gender differences in behavior in color perception tasks does not accord with a pan-human model of color processing.

Clearly, theory must be revised to explain how such findings of substantial intra-cultural differences in perceptual color experience can exist along side robust findings of inter-cultural similarities in color naming and categorization.

2 Intracultural Variation and Cross-Cultural Studies of Color Cognition

What are the implications of the preceding discussion for the cross-cultural universality of color-naming and color categorization? Based on the few studies that have examined photopigment opsin genotype frequencies cross-culturally, different incidences of deficient and anomalous color perception phenotypes are to be expected across groups of different ethnic ancestry. Stockman, Jaegle & Nathans (1999) review these results across some groups of different ancestry (1999, p. 30).

One example of the kind of cultural impact possible from inherited perceptual abilities is described by Oliver Sacks in *The Island of The Color Blind and Cycad Islands* (Sacks 1997). Sacks reports on a population from the Caroline Islands in Pacific Micronesia. He describes the

cultural practices in a society in which many individuals share a genetic defect for monochromacy or congenital achromatopsia. This photopic vision defect, associated with extreme sensitivity to light, color blindness and very poor foveal acuity, illustrates that over time cultural practices (e.g., night fishing) accommodate perceptual phenotypes. See Sacks (1997) for further description of the cultural knowledge and mythology developed for the Micronesia achromatopes.

Cross-cultural studies investigating color naming universals generally do not take into account individual variation in color perception. However, psychophysical studies have shown that there are established differences in discriminability and dimensionality as a function of the color vision phenotype of the observer. For example, if we consider the number of just-noticeably-different color perceptions that are experienced by individuals from different perceptual phenotype groups, we find that a Rod Monochromat's sensation space consists of 10^2 different color experiences (all black and white combinations). By comparison, Dichromat individuals experience 10^3 different color experiences (variants along two the dimensions of luminance – black and white combinations – and a Tritan axis of yellowish/lime-bluish/violet). Trichromats perceive 10^6 different color experiences varying continuously along three directional axes (i.e., a lightness axis, a Tritan axis, and an axis varying Reddish to Blue-Green). Anomalous trichromats experience something intermediate to that of Dichromats and Trichromats.

Thus, because there is considerable variation in the number of colors perceived by individuals in different perceptual groups (e.g., dichromats & trichromats) there must be considerable variability in the mapping of color percepts to language. Yet individuals in these groups use color lexicons in very similar ways (Shepard & Cooper, 1992; Jameson & Hurvich 1978, discussed further below).

Intracultural and cross-cultural variation in perceptual phenotype points to an interesting puzzle in color-naming research. If the potential for individual variation in color perception is so common, and the perceptual consequences are, in some cases, substantial, then why is so little *intracultural* disagreement observed in everyday color naming and categorization? Moreover, given that color vision phenotype frequencies may vary across cultures, how is it that empirical results demonstrating *cross-cultural* universals in color-naming are so robust? A closer look at how color phenomenology is represented may reveal how social forces can reconcile the perceptual differences among members of a culture.

3 Representations of Perceptual Similarity and Color Naming Similarity

It seems even dramatic perceptual differences need not preclude a shared intracultural understanding of color categories and color naming because the perceptual representation of color and the semantic representation of color are separate and in many ways different (see also Johnson, Pavio & Clark, 1996; Roberson, Davidoff & Braisby 1999). To illustrate this, we consider the mappings between perceptual and cognitive representations for three different groups of observers. Figures 1A, B & C show discrimination and naming relations for three intracultural perceptual phenotypes. Each figure depicts a unit plane from a three-dimensional color appearance solid (consisting of horizontal vertices Red, Green and Blue and a vertical continuum of lightness ranging from dark to light extremes).

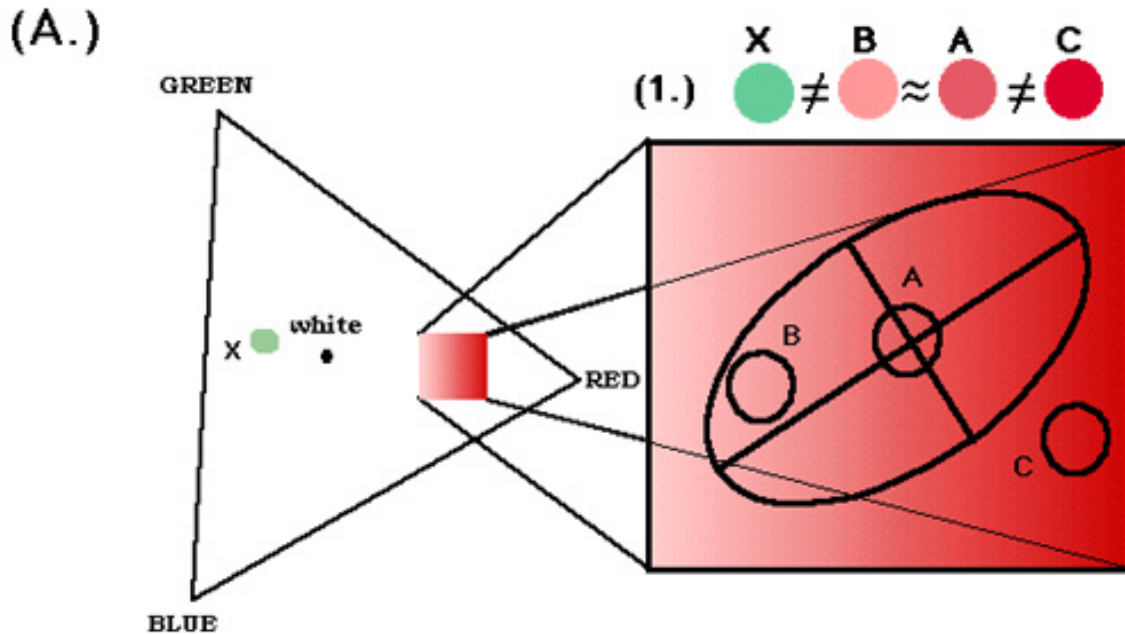


Figure 1. (A.). Two-dimensional schematic of a Trichromat color discrimination region and a trichromat naming relation in (1.).

3.1 Trichromat Color Perception Behavior:

Figure 1(A.) presents a schematic of a perceptual discrimination tolerance for a Trichromat observer. A small cut-out corresponding to a region of reddish color appearances is expanded on the right side of the figure. The circles marked A, B, and C define three possible color samples drawn from that cut-out area. The region typically referred to as a “discrimination tolerance” is indicated by the outlined ellipsoid centered on stimulus patch “A.” The contour of this discrimination ellipsoid defines an area of color appearance space containing all color appearances *matching* sample A. Thus, for this hypothetical trichromat observer, appearance A is perceptually indistinguishable from the appearance denoted as “B” because A and B occur within the same discrimination ellipse. Practically speaking, these would be referred to as phenomenologically “the same,” or “a match,” even though they are physically different in spectral composition (such stimuli are called “metameric”). Also in Figure 1(A.) are color appearance patches “C” and “X.” Appearance C is similar to A and B, but would not be considered a “match” to A because it lies outside both the ellipsoid for A and an ellipsoid that defines the set of A’s “matches” (not shown in the figure). By comparison, X is a bluish-green sample and is not even of the same color category as A, B or C. It appears at the left of the schematic, far removed from the ellipse defining A’s perceptual matches. These perceptual discrimination relations are described by the expression in 1.A.(1.):

$$X \neq B \approx A \neq C,$$

which specifies that B and A are indistinguishable (denoted “ \approx ”), and X is distinguishable (denoted “ \neq ”) from B and A, as is C.

Figure 1.A.(1.) defines the trichromat *discrimination relation* for these four stimuli. It also defines the *shared linguistic relation* that specifies the lexical labels describing the four color appearances when two individuals communicate verbally about these stimuli. For Trichromat observer, the lexical relation is essentially given by the discrimination relations for large color differences, even though the shape and locations of ellipses will vary somewhat across individuals and will be non-uniform in size across color appearance space.

3.2 Dichromat Color Perception Behavior:

Figure 1.(B.) shows a similar schematic representation of color appearance space for a Dichromat observer. Dichromat perception and naming has been widely studied (e.g., Boynton & Scheibner, 1967; Scheibner & Boynton, 1968; Smith, Porkorny & Swartley, 1973; Hurvich & Jameson, 1974/5; Jameson & Hurvich, 1978; Paramei, 1996; Paramei, Bimler & Cavonius, 1998). As described earlier, Dichromats confuse (or cannot distinguish) some colors that Trichromats see as different. This deficiency is approximated by the solid lines appearing within the Dichromat color appearance triangle. In general, appearances falling between two lines in the triangle are perceptually equivalent for the dichromat. As in Figure 1.(A.) the square area of reddish appearance space is expanded on the right of the diagram, and a discrimination tolerance ellipsoid is depicted for a hypothetical color sample *A*. *A* in Figure 1.(A.), samples *B*, *C*, and *X* are compared to *A*. However, for the Dichromat, all four samples fall within the two solid lines indicating that none of the appearances that were perceptually distinguishable by the Trichromat can be differentiated by this hypothetical Dichromat. Thus the relation defining the Dichromat discrimination

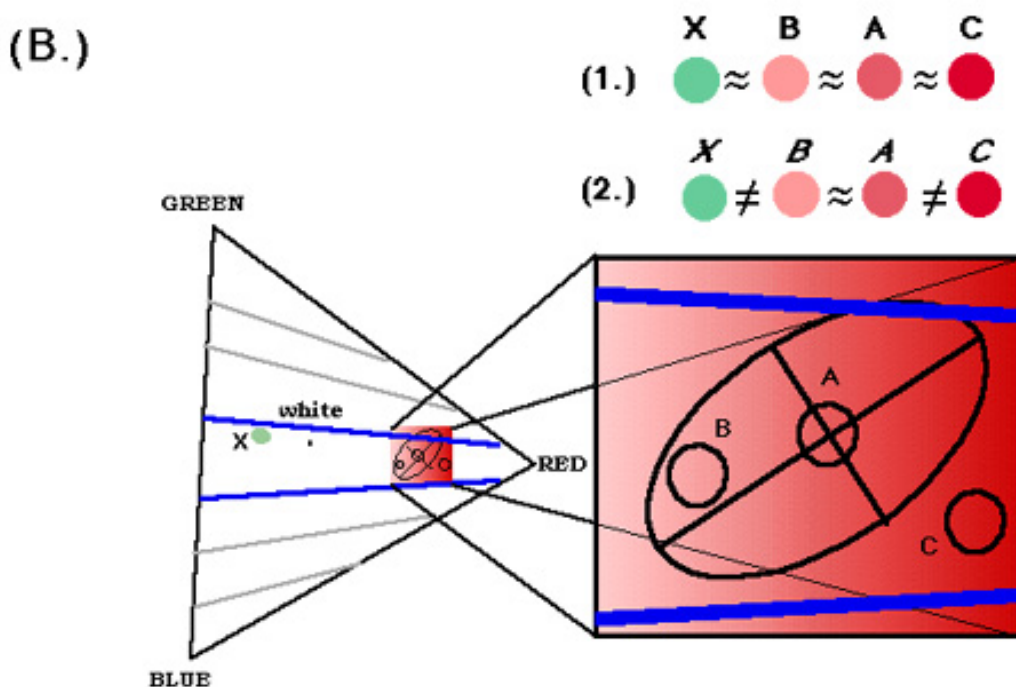


Figure 1. (B.). Schematic of a Dichromat color discrimination region. Note that different (1.)

discrimination and (2.) naming relations are proposed. The dichromat confusion regions shown by solid lines in this figure are schematic adaptations of confusion loci empirically identified by D. Farnsworth – See Wyszecki & Stiles (2000).

relation for this example is given by the expression B. (1.)

$$X \approx B \approx A \approx C,$$

which states that X , B , A and C are all perceptually indistinguishable. Although the Dichromat cannot perceptually distinguish these samples, in this example he still possesses the same *shared linguistic relation* as the Trichromat. This linguistic relation is depicted as a cognitive construct separate and different from the individual perceptual construct defined by B.(1.). The shared linguistic relation is given by relation B.(2.):

$$X \neq B \approx A \neq C,$$

(note that the lexical parameters are italicized to denote that A , B , C , and X are category labels rather than color percepts). The implication of this hypothesized dissociation between perceptual and linguistic representations is that the Dichromat’s cognitive representation of color is more complicated than that of the Trichromat. For the Dichromat there must exist two considerably different mappings – one for the discrimination of color appearance, and a second for the structure of linguistic relations shared with the majority of trichromat individuals in the culture. One implication is that Dichromats are aware that some of the colors that look the same to them map on to different labels in the shared lexicon. This is empirically demonstrated by Jameson & Hurvich (1978) who showed that dichromats use dissimilar names for perceptually similar colors. Separate perceptual and linguistic representations were also found by Shepard & Cooper (1992) who derive similarity structures for Dichromat observers.

Shepard and Cooper’s (1992) Figure 2 (p. 100) compare the structure of color appearance similarity and the structure of color word similarity. Interestingly, the Dichromat lexical representation closely maps the one produced by Trichromat observers, whereas the structure of the color appearance representation differed in ways that reflected the known perceptual deficit.⁵

The existence of similar lexical representations, distinct from color perception representation, may account for why Dichromat observers generally go undetected in everyday social interactions with Trichromats. Perhaps Dichromats learn that communication about color often reflects a specificity that they cannot appreciate perceptually, even though other observers do.⁶ This is a highly cognitive (albeit apparently “automatic”) meta-awareness about one’s own color experience compared to others in the culture. Thus, Dichromats are not as socially disadvantaged as one might expect from their color matching behavior– they understand Trichromats comparisons

⁵Indeed, Shepard and Cooper show that some congenitally blind individuals (i.e., about 50% of their sample) produce roughly the same structural mapping of the color lexicon as Trichromats, even though they have never experienced color sensations. Similar results were found by Marmor (1978). Such results support the suggestion of separate perceptual and lexical representations.

⁶These proposed distinct types of representation are consistent with a distinction made by Brindley (1960) for Class A and Class B operations. Class A treats matching as a perceptual relation of identity (metameric classes), whereas Class B treats matching as a perceptual relation of equivalence. For Class B the percepts can be made partly equivalent but not wholly identical. Thus, under Class B operations, representations are fuzzy (c.f. Kay & McDaniel 1978) and inferences about invariance properties are risky.

of *red* and *green* as opposing categories, and they are only at a disadvantage when they have no other cues except color differences to differentiate two items in a real-world circumstance.⁷

3.3 Tetrachromat Color Perception Behavior:

Figure 1.(C.) illustrates possible perceptual and linguistic consequences for a hypothetical Retinal Tetrachromat (defined earlier). It depicts a discrimination tolerance potentially available to a Retinal Tetrachromat compared to that described for the Trichromat depicted in Figure 1.(A.).

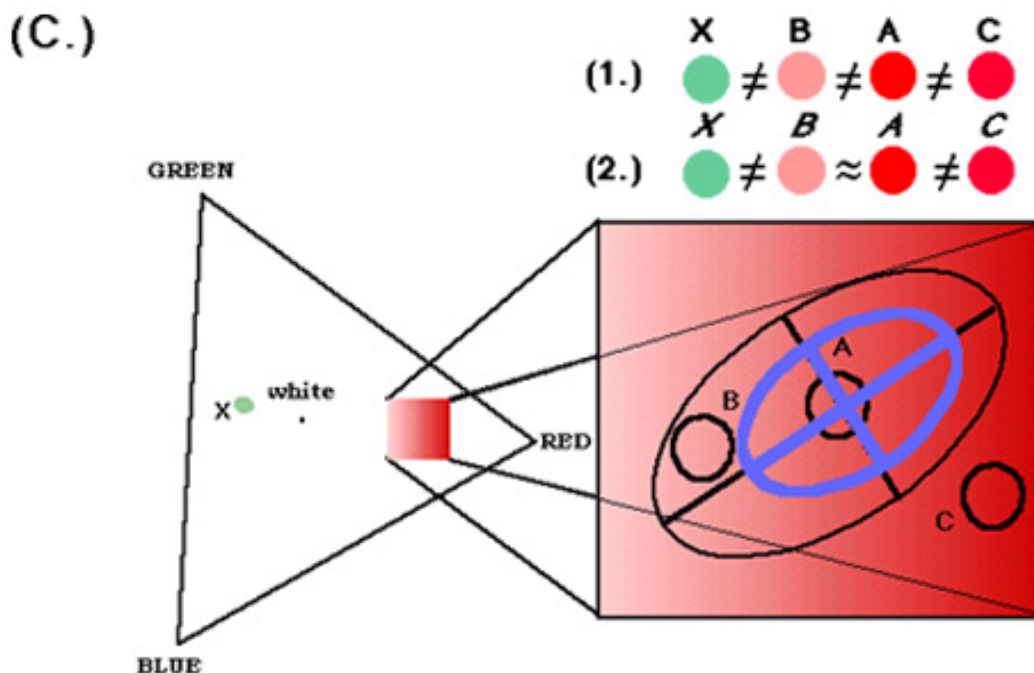


Figure 1. (C.). Schematic of a Retinal Tetrachromat hypothetical color discrimination region. Note that separate (1.) discrimination and (2.) naming relations are proposed.

As in Figures 1.(A.) and 1.(B.) the same small region of reddish color appearance is expanded on the right side of the diagram. The Trichromat discrimination tolerance region is centered on sample *A*. Additionally, a second, smaller ellipsoid is centered on the same sample. This represents the discrimination tolerance region hypothesized for retinal tetrachromats. Its size indicates that an individual possessing four classes of retinal photopigments may experience reduced regions defining some color equivalence-class contours compared to that of a Trichromat.

⁷In fact, Dichromats often develop the ability to distinguish otherwise indiscriminable colors on the basis of subtle lightness cues alone, as exemplified by their ability to detect color camouflaged objects (Morgan, Adam & Mollon 1992). Moreover, dichromat color discrimination data for large-fields show that residual red-green discrimination is possible through the S-cones (McMahon & Macleod, 1998) and the rods (Nagy & Boynton, 1979), thus rendering better-than-dichromat color vision. However, under many naturalistic viewing circumstances when the only varying dimension is color, red and green appearances can be impossible to differentiate.

This finding is a generalization of results from Jameson, Highnote and Wasserman (2001) who empirically compare the discrimination capabilities (as measured by spectral banding) of female retinal tetrachromats with those of male and female trichromats. As summarized earlier, their results suggest that for certain regions of the visible spectrum (i.e., those associated with spectral shifts arising from genetic dimorphisms), retinal tetrachromats identify significantly more color differences in a diffracted spectrum than either male or female Trichromats. An observer possessing an extra variant of the LWS photopigment class, in addition to the usual three retinal photopigment classes (SWS, MWS and LWS cone pigment types), would potentially experience greater specificity in reddish color discrimination and thereby exhibit a smaller region in which color appearance are considered perceptually equivalent.

The hypothetical retinal tetrachromat perceptual *discrimination relations* are described by the relation in C. (1.):

$$X \neq B \neq A \neq C,$$

implying that appearances A , B , C , and X are all perceptually discriminable. Unlike Trichromats, the Retinal Tetrachromat can distinguish between sample A and B . Like the Dichromat, however, the Retinal Tetrachromat shares and makes use of the color lexicon used by the majority of Trichromat observers in the culture. This is described by the *lexical relation* in (C.) 2.:

$$X \neq B \approx A \neq C.$$

The Retinal Tetrachromat may be capable of much more specificity than is reflected in the culture's color lexicon (Jameson, Highnote & Wasserman, 2001), and more than can be resolved by the Trichromat. The Trichromat also resolves more than is represented by the lexicon; while the Dichromat resolves much *less* perceptual specificity than is represented in the color lexicon.

As with Dichromats, learning explains how Retinal Tetrachromats grow to accept and comfortably use this nonuniform mapping of color appearances to color language and categories. Consider a plausible scenario: Given a female retinal tetrachromat growing up in a family and culture of Trichromats and learning *de novo* about how people name the colors they see. This female learns primarily by discovering that despite the fact that two things may appear different in color to her, other people nevertheless agree that those two things “match.” After repeated exposure to such learning experiences she may develop the following implicit definition about color: “Color *matching* occurs when two things have *almost the same* color appearance to me, *and* when other people see them as identical.” This heuristic can of course be made generative: colors which to the Retinal Tetrachromat's eye are closely similar are colors that she describes as a “match” (in agreement with her Trichromat peers). Thus the Retinal Tetrachromat's cognitive construct of a color-match is more flexible than a Trichromat's (i.e., allows more variability), and as a result the number of disagreements about color between two groups with varying perceptual abilities is minimized.

The case of the Retinal Tetrachromat shows how intracultural variation in color perception, and in particular gender differences in perception and color cognition, may be significantly present and yet remain undetected in studies of psychological and cross-cultural studies of color. It should be noted, however, that until the mid-1990's when the X-chromosome linked inheritance of human color vision photopigments became explicit and incorporated into the knowledge-base of interdisciplinary researchers, there simply was no reason to expect males and females to differ in terms of the perceptual basis of color vision. All theoretical models of color vision reasonably

assumed a common mechanistic substrate across observers. When differences in male and female color processing were noted, most were reasonably attributed to social and cultural factors, or to varying amounts of individual error, as opposed to real visual processing differences.

The point of this analysis of Dichromat, Trichromat and Retinal Tetrachromat color processing is that it is plausible to hypothesize different levels of cognitive representations of color: one representing an individual's idiosyncratic perceptual structure, a second for the shared cultural color lexicon and color category structure, and perhaps a third linking the first and the second. This third level of representation might, for example, capture the Dichromat's awareness of the category discrepancies between his color equivalence classes and those of Trichromat individuals. It also might permit reconciliation between the Retinal Tetrachromat's construct of color-matching with that of Trichromats in her culture, and allow for individually varying representations of higher-order relations related to color compatibility, color preference, color memory, and so forth (c.f., Saito, 1994, 1996a, 1996b; Pérez-Carpinell, Baldoví, de Fez & Castro, 1998).

3.4 Emphasizing a Shared “Modal” Model of Color-Naming:

In this theory of color representation, within-culture color naming and categorization follows the “majority rule.” Because Trichromat perception constitutes the majority in almost every culture, the *lingua franca* for color is one that reflects the modal Trichromat representation. This emphasis on the majority is by no means a new idea. For example, in 1987 an issue of *American Behavioral Scientist* was devoted to topics relevant to intracultural variation and the modal, or consensual, model (in particular see D'Andrade 1987; Roberts 1987; Romney, Batchelder and Weller 1987; Weller 1987) or Cultural Consensus Theory (Romney, Weller & Batchelder 1986; Moore, Romney & Hsia 2000). One well-developed theoretical and mathematical model of this majority-based perspective is Cultural Consensus Theory (CCT). CCT assumes that “... culture exists in the minds of members of the culture and that there is variability among individuals in how much they actually know about various aspects of the culture” (Romney 1994, p. 269). In this theory an informant's individual competence in the tested domain is a function of how much that informant's response patterns correlate with the responses of other sampled individuals who share, among themselves, high patterns of response agreement. By defining “expertise” through one's correlation with consensus, or the modal response pattern, Romney and colleagues define “culturally correct answers” as those that are most widely held and agreed upon by the most competent informants sampled. Thus, CCT (Romney et al., 1986) theory provides a quantitative method for realizing the “majority rule” aspect of the shared cultural representation of color proposed in this article. This perspective is also consistent with the general approach for cognitive representation presented by Romney, Boyd, Moore, Batchelder, & Brazill (1996).

There are also, of course, social mechanisms at work when individuals from the same culture converse about color appearances that are valuable or salient in cultural interactions. (Social mechanisms influencing color-term usage are not easily accommodated by models advancing a pan-human neural substrate determinant of color naming.) One such mechanism is the principle of “linguistic charity” in the mapping of lexicon to stimuli and to categories (Putnam, 1988; Jameson & Alvarado submitted, in-press). The idea that a hearer routinely grants a speaker *linguistic charity* implies that variations between two individuals about the meanings of specific words are subordinated to maintaining a coherent overall meaning and the need to communicate.

Thus, if disagreements about subtle differences in color seriously prohibited social commerce, or were to result in grave consequences (e.g., ingestion of poisonous mushrooms), then those differences would be marked by social salience, and would be very likely to be accommodated in the language (through redundant coding, modifier embellishment, and so forth). Lesser disagreements about color differences are acknowledged from time to time, but for the sake of facilitating communication they are disregarded on the basis of *linguistic charity*. This occurs because, ultimately, conversants prefer to communicate and be understood rather than be dominated by color minutiae in the course of their interpersonal interactions. Like all language, color language is subject to the demands of pragmatic communication. Practically speaking, this semiotic feature of the phenomenon minimizes individual variation in the shared representation of color lexicons and allows for the reconciliation of individual differences in perception with the larger differences perceived by nearly everyone within a culture.

4 Cross-cultural Universality in Color Naming and Categorization

Given the potential for individual variation in color perception and color representation described above, how can we understand existing empirical results on color universality? In this section we explain: (1) why cross-cultural research should rule out models which rely strictly on a pan-human neurophysiological substrate; (2) why universalities in color lexicons and categories are best described as a common solution which all cultures co-evolve in naming their color experiences; and (3) how a model involving structural interpoint distance relations expresses this theoretical explanation as a set of cognitive heuristics.

4.1 Cross-cultural variation in Photopigment Opsin Genotype Frequencies:

Previous discussion focused consequences arising from photopigment opsin gene variation and *intracultural* variability in color vision genotype frequencies. As further data become available, it is becoming apparent that principles of inheritance and genetic drift also produce different frequencies of genotypes across populations of different ethnic ancestry. In light of current theories of color-naming universals, do such variations in phenotype frequencies across populations of different ethnic ancestry significantly impact different cultures' color lexicons. If the modal representation is indeed the representation adopted by a culture as its shared cultural representation, and if such a modal representation is affected by the color vision phenotypes predominant in a culture, then we should expect a culture's lexicon to reflect this frequency in some way, as in the extreme case described by Sacks (1997).

Although sufficiently large studies of retinal photopigment genotype frequency are yet available, preliminary data indicate that incidences of Dichromat and Retinal Tetrachromat genotypes do differ substantially across populations of different ethnic ancestry. For example, 8% of males of European or Brahmin Indian ancestry are red-green deficient, compared to less than 2% of Australian Aborigines, American Indians, and South Pacific Islanders. Generally speaking, there tend to be fewer opsin gene variants in the arrays of non- Europeans (Sharpe, Stockman, Jaegle &

Nathans 1999, p. 27). Some populations seem to have a negligible number of females who possess multiple variants of X-linked photopigment opsin genes (e.g., Asian groups as preliminarily reported by Martinez, Jameson & Wasserman 1999), although general estimates of the frequency of female Retinal Tetrachromat phenotypes range between 15-20%.⁸ A more substantial estimate of Retinal Tetrachromat phenotypes derives from inheritance estimates and measures from retinas of female eye donors: Neitz, Kraft & Neitz (1998) report that about half of all women (presumably of European descent) are expected to have at least four spectrally distinct cone types including nearly equal numbers of two LWS variants plus MWS and SWS cones (p. 3221).

Thus, just as the frequency of occurrence of males exhibiting X-linked color vision anomalies varies across populations, so too does the occurrence of female carriers of deficiency, and heterozygous carriers of multiple opsin gene variants (see Sharpe, Stockman, Jaegle & Nathans 1999 for a review). The degree to which such differences might be reflected in differences in color-lexicons across ethnolinguistic groups has not yet been explored. One plausible hypothesis is that if this frequency is greater in one population compared to another, then the degree of complexity or variability in a given color lexicon will covary systematically with phenotype proportions, especially if the consequent perceptual differences are socially salient.

Despite the fact that perceptual phenotype frequencies are expected to vary cross-culturally, *cultural consensus* and *linguistic charity* are social principles that strongly influence an individual's acquisition of color terms. Thus, these two principles universally allow pragmatic concerns to shape and contribute to the lexicon, and thereby provide for a far more realistic and compelling explanation than that of a universal color vision substrate favored in the current literature. Color-naming researchers should discontinue the overemphasis on biological models and consider plausible social and cultural explanations.

4.2 Universal Naming Heuristics:

Given the potential for intracultural and cross-cultural variability in color perception, why is the cross-cultural universality of color naming and categorization so empirically robust? We suggest that this robustness is simply a consequence of the universal adoption of specific cognitive heuristics. These heuristics arise universally because they are best suited to solving a problem occurring across all cultures – how to lexically partition and label color space.

They result from historical consequences of different ethnolinguistic groups solving, in very similar ways (by convergent evolution), the communication problem of how to label color experience in a socially optimal manner. Three aspects of color experience make this convergent evolution possible. First, Color is a stimulus domain that is both universally accessible and universally regular, compared to stimulus domains with features that vary cross-culturally (e.g., categories of fauna or cultural artifacts). Second, the dimensionality of color appearance space is relatively constrained compared to most other stimulus domains. It continuously varies across a few dimensions (generally considered to be three dimensions, as described, for example, by Shepard, 1997), and the physical properties of visible light are, in the main, universally uniform.⁹

⁸Indeed, in a study of more than 100 Male donor eyes Sjoberg, Neitz, Balding & Neitz (1998) found that 8% of males exhibited Retinal Tetrachromacy. This finding is noted despite the ongoing debate on genotyping using postmortem retina mRNA and the expression of multiple LWS on the gene array.

⁹The suggestion that three dimensions are sufficient to describe the complexities of the perceptual color space is a simplification primarily used to describe color perception for a Maxwellian-view small-field stimulus,

Third, all cultures' color lexicons and color representations arise from the common problem of how to organize and label culturally salient color perceptions. To explain the universalities of color naming, we propose an interpoint distance model (IDM) that assumes the minimal dimensions (lightness, saturation and hue) for an idealized color space. This assumption relies on the rationale that (1) at least these dimensions will be present in both light and surface spaces, and, (2) as in practical applications of color, "the eye does not care whether the signal is self-luminous or non-self-luminous [surface reflectance], but self-luminous signals usually have a dark, and non-self-luminous signals, a bright, surround" (Judd, 1973, p. 65).

The problem that all color nomenclatures solve is how to assign lexical labels to the culturally important regions of this well-encapsulated and continuous domain of color space. In the IDM theory presented here the assignment of labels follows from the universal cognitive processing of the domain. Thus, cross-cultural similarity in color naming arises because cognitive universals have lead different cultures to the same solution (with varying degrees of complexity) about how to best define color categories in visible color space. In contrast, cross-cultural variation in color-naming arises from socio-cultural pragmatics, because different cultures deem different color appearances salient enough to deserve a distinct lexical category or label. Kay and Maffi (2000) describe a widespread tendency for salient stimulus domains like color to be partitioned by lexical mappings as the partition principle (p. 745). A similar idea has been expressed by Yendrikhovskij (2001). As the original Berlin & Kay (1969) universal hierarchy of color naming suggests, all cultures carve up color appearance space in the same orderly manner, in stages. They primarily differ in which stage they find the divisions most optimal. In this way each distinct language reflects a substage of the most general form of Berlin and Kay's universal hierarchy (Berlin and Kay 1969, Kay and Maffi 2000). Thus, the overarching principle behind color-naming universality is that all cultures' color lexicons solve essentially the same problem. The model proposed here differs from these approaches in several ways, but is not incompatible with them.

4.3 An Interpoint-Distance Model of Color Categories:

Other researchers have noted the importance of color naming system features that are also important to the IDM Framework of color naming and categorization proposed here. Some of these features were discussed by Dedrick (1997) and include, communication accuracy and codability, socio-cultural pragmatics of color communication, color appearance dimensional salience (e.g., brightness, saturation and hue), symmetry and polarity of color best exemplars and category partitions, among others. The IDM Framework differs from earlier explanations in four key respects: (1) the framework de-emphasizing the importance of the hue dimension (crucial to an opponent-color explanation); (2) The framework encompasses color-space area irregularities attributable to variation on brightness (c.f., MacLaury 1992) and saturation dimensions (previously

viewed monocularly, in the context of an otherwise dark surround (essentially a retinal cone-response mixture space). Empirical results also suggest that the structure of cognitive color space is greater than the typically assumed three-dimensions (e.g., Paramei, Bimler & Cavonius, 2001; Paramei, & Bimler, 2001a, 2001b). Other investigators have empirically and theoretically shown that the dimensionality of color appearance space increases dramatically (Chang & Carroll 1980) even when a simple chromatic surround is added as a modification to the standard monocular viewing format (Mausfeld & Niedere 1993; Niedere, 1993), and that the complexity of surface viewing conditions precludes a strictly three-dimensional structure for color appearance space (Maloney 1992).

described as color space “bumps” by Jameson & D’Andrade, 1997); (3) the IDM framework is derived using a generalizable abstraction of color appearance space (similar to Davidoff’s, 1991, Internal Color Space) as opposed to using a given color order system (i.e., Munsell, OSA, or other surface color space; or CIE light mixture space); and (4) the IDM framework strongly differentiates the development of a culture’s color naming system, from the manner in which individuals acquire and use a that color naming system. The importance of these four features is explained in the context of IDM Framework described below.

4.3.1 IDM Framework shift in Dimensional Emphasis:

What general cognitive principles underlie the Berlin & Kay stages, leading many cultures to similarly subdivide and label color space? To answer this question principles are sought from the color-naming and categorization literature.

First, it is assumed that visual processing constraints contributing to cognitive principles will be gradient-dimensional in form. We assume this because it is characteristic of a number of processing variables (some reviewed earlier) known to contribute to normal individual variation in the signal processing of identical stimuli such as photopigment phenotype (Jameson et al., 2000), optical density of pigment (Shevell & He, 1995; Neitz, Neitz, He & Shevell, 1999), discolored lens and macula (Stockman, Sharpe & Fach, 1999), and cone ratios (Otake & Cicerone, 2000). This assumption further implies that the absolute determination of perceptually salient boundaries and inflection points will vary enough across individuals to preclude uniform limiting thresholds or discrete categorical constraints even with a standard trichromat model of color appearance space. Given that these visual processing constraints allow only the dimensional structure to be uniform across observers (contra the accepted universal color focals construct) what specific dimensions exist?

To answer this question, we must first discuss dimensional similarity structures and stimulus classification. Garner (1974) describes a general cognitive principle used by subjects when classifying stimuli. According to Garner, a general form of classification learning is seen when a subject partitions total sets of stimuli, or stimulus domains, into subsets or classes in which all stimuli are alike in some way, while at the same time all different from stimuli partitioned into the other classes (p. 97). Garner suggests: “... the subject classifies the stimuli so that he maximizes the perceived differences between classes while at the same time maximizing perceived similarities within classes” (p. 98). In Garner’s (1974) original theory of the structure of information, this principle is suggested as a common heuristic that is prevalent in human cognitive processing under categorization tasks. This heuristic is incorporated into the Interpoint Distance Model (IDM) of color space suggested by Jameson and D’Andrade (1997).

As explained in detail below, the IDM differs from most of the existing theories of color naming systems because it emphasizes foremost dimensions of brightness and saturation, and to a lesser extent the hue circle. D’Andrade and Egan (1974) show that lightness (or brightness) and saturation are more cognitively salient than hue. MacLaury (1992) suggests that brightness is arguably the salient dimension in some of languages. Dedrick (1997) suggests that research does not support universal processing of color-opponent unique hues as a cross-cultural basis for category foci and structures. Jameson and Alvarado (in-press) and Alvarado and Jameson (in-press) empirically show that lightness and saturation lexical mappings agree in Vietnamese and English, whereas hue term mappings do not. Moreover, lightness (as measured by V-lambda)

and saturation are the most uniform dimensions of color vision experience across the wide range of individual observer types that can exist in a population. Thus, the IDM considers lightness and saturation dimensions as more integral than hue to color naming and categorization.

4.3.2 Development of color naming systems:

Within the cognitive constraints suggested above, how does a given culture develop a color naming system? Our proposed answer to this question relies upon both the pragmatic importance of color-language as a cultural tool for communicating about color, and the importance of assigning names and categories that minimize individual and interpersonal confusion in an information theoretic manner (c.f., Dedrick 1997; Freyd's 'shareability,' 1983; Jameson & Alvarado submitted; and researchers cited in these sources).

The IDM of color space labeling suggests that a universal cognitive heuristic is the basis for color space partitioning. The heuristic states that to establish a named color category, newly introduced category best exemplars are always maximally distant from existing best exemplar regions in each culture's normative perceptual color space. Each culture's hierarchy of color terms progressively defines a socially adequate color naming system by adherence to this heuristic.

As with information codes in general, the first lexical partition of the color space constrains the subsequent partitions (up to some limit).¹⁰

Recall that the Berlin and Kay theory (e.g., 1969, Kay & Maffi, 1999) describes a universal evolutionary hierarchy of partitions and labeling of color space in which color names emerge in a predictable sequence (see the description earlier in this article). The IDM can explain the successive partitions of the Berlin and Kay theory as follows: First, as observed in all cultures studied, the first distinction in the Berlin and Kay hierarchy is the gloss for light and dark (*White/Black* or *Warm/Cool*) (see also MacLaury, 1992). Without question this is the most universally accessible distinction from a visual processing perspective. This distinction is accessible to nearly all observer types, including dichromats and rod monochromats. Jameson and Hurvich (1978) suggest that dichromats use the lightness dimension and its correlation with hue to learn the hue name structure describing normal trichromat percepts. It is even accessible to Sacks's culture of rod monochromats (Sacks, 1997). This partition would undoubtedly produce the greatest amount of intracultural agreement among perceptual subgroups about the mapping of perceptual stimuli to cognitive representations and the lexicon.

For the next step of Berlin & Kay's (1969) universal hierarchy, the emergence of red, the IDM provides the following explanation. Several factors contribute to the definition of a third category partition which is maximally differentiated from *White* and *Black*. Among the most important of these are dimensional and relational salience. For example, after a *White/Black* division, a red partition yields a region of color appearances maximally different from *White* and *Black*

¹⁰In considering the locations of focal exemplars and partitions, the IDM emphasizes topological structural relations between color category exemplars as opposed to strictly Euclidean interpoint distances. (Principles governing this emphasis are discussed below.) This emphasis is supported by the empirical results of Smallman and Boynton (1990, 1993). They show that individual performance arising under individualized structure-preserving rotations of the modal category structure produce search results on a par with (or better than) the modal structure. In contrast, some models of representation (e.g., Romney, Moore, Batchelder & Hsai 2000) generally emphasize the metric distances arising in similarity representation data. In the IDM formulation Euclidean distances do not define the representation *per se*. Any structure-preserving affine transformation is characteristic of the domain.

best-exemplars on three classical dimensions of color space (Hue, Saturation and Brightness). In this way, the emergence of a Red partition satisfies dimensional salience. A relationally salient partition is a region of color appearances that defines a category partition equal in size and as varied in exemplars, as the categories already formed. Once a White/Black or warm/cool partition has been made, the two color categories satisfying these conditions are glossed by *Red* and *Green*. It can be argued however that red is the optimal choice because it also maximizes the saturation dimension of the color space. A high degree of saturation has been shown to be a universally salient color attribute.¹¹

After the categories glossed by *White*, *Black*, and *Red*, cross-cultural variability is more prevalent in subsequent category partitions. In the Berlin and Kay system the next partition after *Red* is either a term glossing *Yellow* or a term glossing *Green*. The IDM suggests that the partition that is adopted next depends on which symmetry conditions are emphasized. If symmetry is emphasized only for the saturation dimension, then a category glossed by *Yellow* is a likely choice because Yellow best exemplars are found in the least saturated region of the color space, and thus could serve as the saturation complement to the highly saturated Red best exemplar region.¹²

If, however, the emphasis following the Red partition is on conditions that satisfy first, chromatic balance (e.g., as White balances Black for lightness), and second, spatial symmetry (e.g., a White/Black division forms equal spatial partitions), then the next category partition would be chromatically opposite to Red in the three-dimensional color solid, a partition emphasizing a bluish-green to green. If this bluish-green partition is secondarily defined to approximate the spatial area encompassed by the Red partition (as mentioned above), then the most likely category partition is Green.¹³ Thus, for the partitioning of visible color space, Green – not Blue or Yellow, both of which encompass comparatively small category areas – would be the color partition to follow Red in the hierarchical sequence.

The category glossed by *Green* would also follow from Garner's suggestions described earlier, since it is a partition that maximizes the perceived differences between color categories while simultaneously maximizing the perceived similarities within color categories. (Any other reasonable partition would introduce a color blend (i.e., blue-green) or a category partition with far fewer within-category just-noticeable-difference exemplars than the other three categories Black, White and Red).

The IDM conditions of category dimensional- and spatial-symmetry, maximized at this point by the Green partition, are related to the principle of "polarity" seen in the literature. Thus,

¹¹One might also reason that Red seems especially psychologically salient because it is the color of blood. More interesting is the notion that Red is salient because, based on some evolutionary models, it was the most recent opsin gene to emerge in primate photopigment evolution and it is phenomenologically most fundamentally different from the original primordial X-linked pigment (the M-pigment gene). Reddish light defines one extreme of the range of visible light with the other pole tending toward the ultraviolet, and the practical effect of the emergence of the L-photopigment was an expansion of the visible gamut of color experience – essentially taking a species with dichromatic perception to a species with the expanded dimensionality of trichromacy. If the markedness of this could in any way be transmitted through human culture, this might be significant enough to warrant the especially salient status of Red cross-culturally (see Kay and Maffi 2000, p. 747-748 for a discussion of empirical results demonstrating Red's salience).

¹²Kay and Maffi (2000) discuss Yellow as an inherently light color with an affinity to White.

¹³A Blue-Green partition would be too large to complement the spatial extent of the Red partition, and a Blue partition alone would be too small.

Green as an emergent category after Red & White/Black represents the next ordered category partition that regularizes the distribution of available color appearances into four categories.¹⁴

We propose that under the cognitive constraints described, many cultures similarly solve the problem of how to collectively name color appearances. This process is analogous to a widely accepted principle in biology called adaptive convergent evolution. Convergent evolution states that two animal species can independently evolve similar features to solve similar environmental problems. So, for example, the red tube-shape flowers of many plants independently co-evolved to optimize pollination by hummingbirds; or the need to excavate insect food sources forced independent evolutions of the probe shaped snout of the Giant Anteater (South America), Giant Armadillo (North America), Spiny Anteater (Oceania) and Giant Pangolin (Africa). Extrapolated to cross-cultural color naming systems, convergent evolution suggests that various pressures presented by cognitive, socio-cultural, and environmental constraints produce similar problems that lead cultures to find similar solutions. The pragmatic uses of color language place substantial constraints on color lexicon evolution. For a color-naming system to be viable it needs to be a useful code for the majority of the speakers of the language. Such constraints force the culturally shared color-naming system towards a ‘normative’ representation irrespective of individual variations in representation that might arise due to diversity in perceptual observer types (such as dichromacy). Linguistic charity (Putnam, 1988; Jameson & Alvarado submitted; and Freyd’s, ‘shareability’ 1983) also contributes to adoption of the normative model of lexical representation of color (despite its possible inappropriateness for some observer types). This pragmatic principle implies that errors or ambiguity in the mapping of a color term to a color appearance near a category boundary may be forgiven by speakers of the language. This is perhaps due to the probabilistic nature of the assignment of appearances to lexical categories but is socially tolerated as a non-fatal obstacle to successful color communication. Thus, the culturally normative solution is a good color naming system.

Pragmatic constraints can also impose cross cultural differences, not just similarities, in color naming. For example, differences in color naming solutions will arise due to color appearances imbued with culturally-specific value; variation in environmentally prevalent and salient chromaticities; and existing linguistic structures for naming other naturally occurring categories and object attributes. Note that the forces which shape a culture’s color lexicon development and maintenance are not the same as those that affect an individual learning an established naming

¹⁴Hardin (1988) tentatively advances “polarity” as a significant subjective criterion in color processing, although suggestions of a linkage to visual processing opponency seems unnecessary. It also seems unnecessary to emphasize hue as significant in Warm/Cool distinctions because the division of hue categories into a Warm/Cool partition is a natural consequence of a single partition arising from the dual application of the lightness and saturation dimensions. By IDM theory such a partition should only be observed in lexicons of Stage I status – as indicated in the Berlin/Kay/Maffi theory – which precedes the separate differentiation of polarity for the lightness and saturation dimensions. In tests where individual sorting of color samples are presumed to recapitulate the emergence of color terms in lexical evolution, it is correct to argue that the empirical instructions requiring participants to simultaneously address both lightness and saturation dimensions in a task, by requiring an initial dichotomous partition, should observe the Warm/Cool distinction. However, any subsequent subdivisions of this initial partition allows lightness and saturation polarity partitions to be performed and should exhibit the successive divisions described by the Berlin/Kay/Maffi theory and the IDM heuristics described above. Indeed, Koenderink provides a different, and non-ad hoc, characterization of the warm/cool distinction based on a spectral analyses of surface color reflectances. (See the material presented by Koenderink at <http://www.phys.uu.nl/~wwwpmp/Pres-JK01/jks01.html>).

system. In the existing literature these two processes have not been clearly differentiated.

As noted above, the cognitive constraints, or dimensions, that seem to be most relevant in the emergence of these early partitions, and the ones which seem uniformly to impose symmetry or polarity constraints (see Hardin 1988), are: *lightness, saturation, category size* (including area balance and spatial symmetry, see Griffin, 2001). Lightness produces the White/Black polarity. Saturation produces the Red/Yellow polarity between minimal and maximal dilute hues with neutral lightness. Dark and Light, Red and Green, Yellow and Blue constitute symmetric categories of similar size. To recover some of the solid empirical ground dismissed by Saunders & van Brakel (1997), Jameson (1997) emphasizes the importance of existing research results on Lightness (a.k.a. “brightness”) and Saturation dimensions in multidimensional representations of color similarity. Moreover, Jameson, Kaiwi & Bamber (2001) empirically demonstrate that dimensions of hue and brightness are behaviorally separable perceptual dimensions in applied information processing circumstances.¹⁵

Explaining Green+Blue (“GRUE”) and Yellow+Green (“Y/G”) categories

How does the IDM explain color naming systems possessing Green-plus-Blue (“Grue”) or Yellow-plus-Green (“Y/G”) categories?. In contrast to previous models, the IDM’s greater emphasis on polarity relations, and the dimensions of Brightness and Saturation, as opposed to Hue, give it more explanatory power for addressing why GRUE and Y/G categories exist in some cultures. For example, in the GRUE category the elemental hue foci for Blue and Green differ primarily in hue. That is they seem to differ less on lightness and saturation than do, for example Green and Yellow, or Red and Yellow, or Red and Blue (this is expressed in MacLaury’s 1997, Axiom 3 on p.87). So if a labeling system is evolving to name the color category following the Black/White & Red partitions, *and* aims to maximizing the encoding of labels for the domain where polar opposites light-dark and saturated-desaturated are very important, *then* a GRUE category (which subserves regions of relatively similar saturation and brightness) might develop instead of the separate Green and Blue category distinctions (then followed by Yellow, Brown and so on).

A GRUE category that is not defined by hue might be expected to exhibit focus variation of the sort described by MacLaury and colleagues where the focus for Grue in Tarahumara can alternatively favor either green or blue, and the two prototypical examples of green and blue are found to represent the category almost equally well (Burgess, Kempton & MacLaury 1983, MacLaury 1997) . Observing this alternating focus for GRUE seems to imply that hue is not an

¹⁵The deemphasis of hue by the IDM framework seems counter-intuitive given the subjective salience of hue as *the* defining attribute of *color*. However, due to individual perceptual variation, hue is the dimension for which individual differences would be the greatest intraculturally. Thus, the IDM asserts that cultures’ color nomenclatures are based on the commonly shared salient properties of color experience not those that are idiosyncratically most salient. The depiction of hue as a circumplex obscures the actual relationships among colors in color appearance space (see Young 1975, p. 159, or Rapoport & Fillenbaum 1972). As Boynton (1997) suggests: “... there is no chromatic plane in OSA space that includes all of the basic colors. Yellow, Orange and Pink simply do not exist at the lower lightness levels, and Purple, Brown and Red are absent at higher lightness levels” (p. 147). Thus, if a hue circle, or circumplex, exists for color category best exemplars, it is spatially oblique to lightness and saturation dimensions and is more aptly described as an envelop, or connected region, that does not exist in any planar section of color space. See material by Koenderink (<http://www.phys.uu.nl/~wwwpmp/Pres-JK01/jks01.html>) for an alternate scaling solution to the typically depicted planar hue circumplex of surface color. The appearances presented in the hue circumplex as typically characterized share the common characteristic of being maximally saturated category exemplars.

essential attribute of the category area indexed by the Tarahumara Grue label. Davidoff, Davies and Roberson (1999) found that in Berinmo, certain appearances English would label Green and Blue are grouped under the category “Nol” with a focus very near a “Green” focal. Davidoff et al. (1999) also reveal that the regions mapped by English “Blue” and “Green” categories are similar with respect to saturation (6.7 vs. 7.3 average chroma respectively) and lightness (5.57 vs. 5.18 value respectively). Compared to their English categories, the observed Berinmo Grue, “Nol,” category seems, on average, more saturated (average chroma = 7.96), with similar average lightness (i.e., 5.26). This might suggest a comparative similarity between Berinmo and English Blue-Green category structure *with respect to lightness*, but differences with respect to saturation and hue. (It should be noted that trichromat spectral saturation functions (see Jameson & Hurvich (1955) p. 551) are clearly minimized (575 nm) at a point coincident with the maximization of the spectral luminous efficiency function ($V\text{-}\lambda$) of the visual system (540-575 nm) (see Wyszecki & Stiles, p. 397). Lightness and saturation are considered by psychologists to be perceptually integral dimensions (i.e., they perceptually covary). For this reason their separate roles in color category development and naming is more difficult to untangle compared to the role played by the perceptually separable dimension of hue (Garner, 1974).)

These examples lend support to the idea that for GRUE categories the lightness dimension is crucial, and hue is less important. This kind of analysis can be extended to yellow-green-blue categories as well as the “cool” black-green-blue categories that have been observed in the literature. MacLaury has previously emphasized the importance of the lightness, or “brightness,” dimension in explaining yellow-green-blue partitions (MacLaury 1992).

The important point is that GRUE presents a puzzle in cross-cultural studies of color categorization and developing color lexicon sequences only when *hue* is upheld as the dominant feature of color category partitions. When instead the key emphasis is placed on Lightness and Saturation dimensions as determining the unfolding of color category partitions in language, then it is plausible that because of the relative similarity of the lightness and saturation of elemental blue and elemental green, they are not differentiated early in the development of the lexicon because candidates which are more distinctive in lightness and saturation exist (e.g., yellow).

One prediction for lexicon development that follows from this is that the order of successive partitions aims to maximize distinctiveness first on the basis of Lightness, second on Saturation (when lightness differences are secondary among the choices available), third on Hue (when the differences on the preceding two dimensions are less than the hue differences), followed by a return to Lightness and saturation differences when Hue differences have become comparatively trivial through subdivision (i.e., Russian *Sinij & Goluboy* or English *Pink, Peach, & Salmon* – apparent lightness and saturation partitions on Blue and Red categories, respectively, occurring in the sequence after Hue partitions have been differentiated). This occurs because maximizing the perceived difference between lexically encoded categories optimizes the accuracy of the lexical code. The result is that the encoded concepts are distinct, general and carry relatively unambiguous semantic values. When two or more lexical items maximize the interpoint distances between encoded exemplars, this improves the likelihood that semantic confusions will be reduced when speakers of the language use the code to converse about color.

Thus far we have explained how Green and Blue might arise as a single category. According to the IDM Framework, if lightness how might a language come to distinguish green and blue categories? As described for within-category distinctions it may occur through successive subdi-

vision. After a Grue partition is named, followed by other lightness partitions, there is no reason why a subsequent partition based on hue cannot be imposed by borrowing terms from other languages or through social influences, as occurred with the use of woad by 6th century Celts, and in the dye industry beginning in the 12th century. It is unclear whether even the fundamental colors in today's English 'heirarchy' of color terms came to us strictly ordered according to the B&K sequence of (Bk, Wht, R, G/Y, B, Brwn, Pur/Pk/O/Gry). Diffuse descriptors for blue appearances are found in Latin. Most common was "Caeruleus" which denoted shades green, black and then blue before it was linked more solidly to blue appearances (Pastoureau, 2001 p. 26). This blue-term gap in Latin was filled by borrowing color terms for blue from two languages: Germanic "Blavus" and the Arabic "Azureus." Thus in English the word for blue appearances are inherited by way of Latin's undifferentiated blue-green-black category being subdivided and labeled by borrowed terms from precursors of German and Arabic. This supports the assertion that hue can differentiate categories in stages of development after lightness and saturation are emphasized. Indeed, Johnson, Johnson & Baksh (1986) described results for the Machiguenga (South-eastern Peru) Stage V color lexicon, which possessed separate terms for Green and Blue, plus a separate term for GRUE. This occurrence perhaps illustrates how a brightness and saturation partition of GRUE can be formed and a subsequent partition based on hue differences (green versus blue) can develop. (This is speculation however since Johnson et al. shed no light on the order of the development of the three lexical categories).

To summarize: the premises of the IDM Framework are threefold: (1) color category partitions do not arise primarily from hue dimensional salience; (2) the ordered emphasis of brightness, saturation and hue seem, in the absence of other possible influences, most general and universal as a heuristic describing the development of color lexical codes; and (3) influences on dimensional salience arising strictly from culture, language and environment can also shape a culture's color lexicon evolution. At first glance, influences of the sort given in (3) seem to be secondary to the described unfolding of lexicons that occurs when brightness and saturation features are essential, and the hue dimension carries a secondary salience.

Other non-physiologically based hue categories like GRUE exist, as seen in MacLaury's findings on the yellow-green category in Native American languages of the Pacific NorthWest. The IDM Framework provides an explanation for MacLaury's yellow-green category observations, when additional information about the relative sizes of category areas are taken into consideration. Here the uniform perceptual scaling analyses of Kuehni (2001) provide an important clarification to color research. Using analyses of OSA-NCS and Munsell perceptual scalings, Kuehni (2001) suggests that there is 1.4 times the number of unit hue differences between (1) red and blue compared to between blue and green, as well as (2) green and yellow compared to yellow and red (p. 232). In contrast, color naming research typically uses the Cartesian assumption inherent in Hering fundamental opponencies as a basis for evaluating color appearance space. If, as Kuehni suggests, there is a larger perceptual area subserved by the yellow-green area, in conjunction with the non-orthogonal orientation of the OSA or Munsell axes Keuhni describes, then by IDM standards the yellow-green area satisfies category status under the principles of category-area balance, and distributed category partitions. Further, a person's unique-color axes need not be orthogonal. The principles of the model which use symmetry and category area balance would operate equally well in a perceptual space that has orthogonal or non-orthogonal axes.

4.3.3 Applying the IDM to Individual color-naming:

Assuming the IDM accurately describes how all cultures come to name, categorize and communicate about color appearances, how do individuals developmentally acquire and use a culture's system, and what transpires when one's cultural naming system maps imperfectly into his or her personal experiential space? What determines individual perceptual salience?

In individually development, as in cultural evolution, the cognitive dimensions of brightness and saturation are proposed as the universally shared constraints (following from visual processing regularities) that provide a uniform conceptual framework across individuals and cultures. This individual learning process differs from the evolution of the cultural naming process described above in several ways.

As suggested earlier, individuals learn the normative model of color naming which is related to their individual perceptual color representation through a naming-function. Acquisition of the color terms occurs in an order dictated by (1) frequency of environmental occurrence (with more common words and perceptual categories learned earliest), (2) an awareness of color similarity and difference on the basis of the proposed IDM cognitive dimensions, (3) socio-cultural importance, and so on. Note that different observer types: Dichromats, Trichromats, Anomalous Trichromats and functional Tetrachromats, would all acquire and use (with varying efficiency) the culturally normative naming system, but they may learn them in different manners using different strategies. For example, Jameson and Hurvich (1978) suggest that dichromats learn to use and recognize normative hue terms mappings through correlation with brightness despite the inability to differentiate some hues. As described earlier, Tetrachromats may implicitly learn that the normative trichromat category tolerance permits a wider range of perceptual variants than than would be distinguished in a tetrachromat category structure. Although the same cognitive dimensions are relevant, individuals acquire the normative color-naming system under different constraints and by different means than cultures do.

Individual differences in color perception are substantial enough to produce variation in color perception representations across individuals sharing the same culture. For example, Kuehni (2001), in a study using Munsell surface samples to isolate unique hue appearances, suggests "it is apparent that when two color normal individuals look at a reflecting sample under identical conditions of viewing, they may not experience the same color. For unique hues ... the individual differences can be up to 4 Munsell 40 hue steps" (p. 63). Such results accord with individual differences in color category mappings seen in the data of MacLaury (and others who have presented individual mappings). While counter-intuitive, individual differences are not incompatible with the kinds of cultural universals put forth by the many investigators who have presented aggregated cultural mappings (as did Berlin & Kay, 1969). Because color nomenclatures are cultural artifacts, investigators have reasonably relied on aggregate analyses of category mappings in the quest for universals. However, in such mappings individual differences are averaged away and cannot be appreciated. This empirical difficulty becomes less serious if we clearly delineate which aspect of the phenomenon are individual (whether pan-human or idiosyncratic) and which are cultural (whether pan-cultural or culturally-specific). Identifying and keeping separate the individual and cultural components of the phenomena permits a more comprehensive analysis, as is attempted by the IDM Framework proposed here.

The large differences in category boundaries occurring among observers from the same culture (MacLaury, 1997) present no critical obstacle to interpersonal communication due to the linguistic

charity that follows from the fuzzy-set mapping of the color naming function (see Putnam 1988, Alvarado & Jameson, submitted; or Dedrick 1997, 154-159). Moreover, as discussed above, the category boundaries found in the cultural color map of the lexicon is simply the empirically derived aggregate, or norm of the population. In a sense, due to the highly variable properties of individual percepts reviewed here, theories of cultural color lexicons should not aim to model individual variation. They can serve, however, as a proper model of individual category-map similarity within cultures, using measures of consensus for culturally shared category maps.

When individuals initially learn a color naming and categorization system, the IDM Framework proposes that brightness and saturation dimensions dominate the process. Kiel & Kelly (1987) discuss the role of a structural framework in assessing similarity relations and forming categories: “Even in the earliest stages, children do not select all the logically possible features or dimensions that could conceivably be used in a computation of overall similarity. Universally shared constraints could make some features more salient than other in organizing a domain and thus it is only within this subset of features that the shifts ... [in category membership] are occurring. In addition, broad structural constraints on conceptual structure may be at work throughout the period during which knowledge differentiates and shifts away from early exemplar-bound representations. Thus, although children who organize their concept of hand tools around characteristic features may confuse one tool with another because of overall similarity, they tend to know simultaneously that all tools share certain structural properties that cannot be violated. ... If early representations were completely based on overall similarity relations without any guiding constraints that laid down a skeletal conceptual framework, it is difficult to see how knowledge acquisition could proceed so successfully and quickly in the first place. ... therefore consider it essential that the developmental changes [and learning] ... be viewed against a backdrop of constraints and predispositions that provide a kind of trellis within which the vines of categorical structure are able to differentiate” (p. 508).

4.3.4 IDM Framework Principles Summarized:

The following principles are proposed by the IDM Framework:

1. The cognitive dimensions (ordered by importance) Lightness, Saturation, and Hue are primitives in both individual and cultural color representations. However, Lightness and Saturation are of paramount importance in the initial stages of a culture’s color naming system.
2. Cultural color naming systems and categories develop through successive partitioning of an idealized normative color appearance space on the basis of the dimensions given in (1).

Category partitions in such cultural systems strive to satisfy two equally important goals: optimization of polar symmetry and category-area uniformity and balance relative to the cognitive dimensions in (1), and responsiveness to socio-cultural-environmental pressures such as demands for representational specificity of color, demands for a non-idiosyncratic (or normative) color information code, and compatibility with existing ethno-linguistic structures.

The implementation of principles (1) and (2) results in a color naming system that is effective for the communication needs of the users of the system.

3. Individual color naming systems and categories first arise through learning a culturally normative naming system and its relation to one’s individual (personal) perceptual color appearance representation. The individual’s perceptual color representation is related to the culture’s color naming system through a color naming-function (Alvarado & Jameson in–press, Jameson

& Alvarado submitted). Over an individual's lifespan a personal naming-function evolves (e.g., new category labels are learned), which relates the culture's normative naming system to the individual's perceptual representation.

The following consequences arise from these enumerated principles of the IDM:

1. Because lexical categories are progressively assigned in ways that tend to maximize information content and minimize label-to-exemplar confusability in communications between members of a culture, the naming system developed will necessarily depend on the range of colors available, extent of each color represented, and the ordering properties (discrete or continuous) of the stimulus space to be named. These features may differ, as when belonging to two natural environments (tropical versus desert), and will differ between two scientific color-order systems (Munsell versus CIE). IDM theory suggests that a space with a non-regular distribution of items across categories (e.g., an unusual space with a large yellow stimulus region, compared to a much smaller red region) will be named in a manner that accounts for the color region 'bumps' in the space (Jameson & D'Andrade 1997) regardless of whether it is a manufactured stimulus space or a natural environmental color space.

2. Category regions, and interim category best exemplars, change as a culture's color naming system develops and successively defines new category partitions. Category focals thus shift and as a result are salient only as a function of the unfolding of the partitioning process.

3. Because the constraints of principles (1) and (2) above are universal across cultures, the evolution of color naming systems will converge somewhat, producing general features of color naming that are universal across cultures.

4. Even though color appearance representations for individuals from the same culture may differ, the individuals can share and effectively use a normative color naming system.

5. Individual color naming can reflect differences in personal color appearance representations (e.g., different category foci can be found across individuals; see the collected work of MacLaury), yet social practices of 'linguistic charity' (Putnam 1988) permit some variability in individual color naming and perhaps expect it from the probabilistic features of the gradient stimulus space (c.f., Kay & MacDaniel 1978).

6. Although the cultural development of a color naming system evolves category partitions by following the principles stated in (2) above, it may undergo successive re-partitioning in response to social pressures. (For example, a need to now differentiate blue and green separately from a previously defined GRUE category).

7. When differentiation on the basis of lightness and saturation has been optimized, successive repartitioning will proceed using principles in (2) and Hue in novel category formation.

Thus, the IDM defines color categories implicitly using (1) polar symmetry (or opponency – but not the usual chromatic opponency – Hardin 1988) and (2) pressures to regularize and balance the spatial area of category partition (see Griffin 2001). These are key to the suggestion that defining the first partition shapes the choice of subsequent partitions. These two principles, in essence, strive for a uniformly distributed category structure, consisting of separate categories that reflect partitions by an idealized perceptual specificity across the entire normative space, regardless of the number of color categories a language manifests. Applying these principles, the IDM Framework would not consider it possible to have a partitioning of the cultural space defined by a single, large, "basic" category which spanned color regions glossed by appearances of, say, *Black*, *Brown*, *Red*, *Orange* and *Yellow*, and then to have several smaller but categorically distinct

“basic” category partitions each glossed by category labels *Indigo*, *Blue*, *Aqua*, *Turquoise*, *Green*, and *Chartreuse*. The principles of the IDM suggest that such a color space structure would not represent a reasonable lexical mapping of the stimulus space. Mappings of lexicons to stimuli of this sort are not to be found in the world’s languages.

Note that the described IDM partitions of visible color space greatly depend on the stimulus domain under consideration, and that these partitions are expected to vary as the stimulus domain varies. Thus, as Jameson and D’Andrade (1997) describe for the OSA system, Yellow would be expected as the category partition after Red because of the relatively smaller Red category region and more significantly represented Yellow category in that space. By comparison, the Munsell Book of Color (MBC) is very generous in representing the purple category. These differences in the spatial extent of represented categories will produce different partitions by IDM principles for the different stimulus spaces used (c.f., Griffin, 2001). As Boynton suggests: category best exemplars and naming may well depend on which stimulus set is selected for experimental purposes (1997, p. 139).

The dynamic lexical assignment of the IDM clearly makes lexical labeling dependent on the items belonging to a stimulus domain. This feature of the IDM is similar to one of the concepts (i.e., “point of view”) described in MacLaurys “Vantage Theory” of color categories (MacLaury 1997, also reviewed by Paramei 1999), although generally speaking the two theories differ on issues of psychological processing and categorization.

Through the IDM heuristics discussed, cultures can universally reach a common solution of how to partition and label culturally-relevant color appearances. This perspective has several advantages over the perspective based strictly on a pan-human color-vision substrate. First, it additionally permits the influences of polarity and symmetry, which in this case at least, might be described as universal principles of cognitive organization (See D’Andrade 1981, 1993 for more on cognitive universals). Second, it allows for shared cultural agreement to serve the role of defining normative color categories and lexicons. Third, the perspective it is not strictly deterministic, but can accommodate shifts in cultural salience of color appearances.

To summarize, I have argued here that there exists two important universalities in color naming and categorization. First, I have argued that individuals from a given ethnolinguistic culture share a common cognitive representation (described as a “Common Cognitive Model,” by Jameson & Romney 1990). This representation differs in important ways from each individuals personal cognitive representation which in turn differs from an individuals perceptual representations. Second, I have argued that different ethnolinguistic cultures have universally “arrived” at a similar solution to the problem of how to communicate about color. The similarity of their solutions arises, in part, because color is universally accessible and comparatively constrained, unlike many other category labeling problems. I have argued that three representations of color experience exist. : These are: (1) individual perceptual representations (e.g., discrimination based); (2) individual cognitive representations (e.g., matching and tolerance based); and (3) a shared cultural representation (e.g., color lexicon based).

As an example of these separate representations, I review empirical results showing that Dichromats exhibit separate representations for perceptual discrimination and semantic representation of color. I also suggested that cognitive constructs like “matching tolerance,” in some observer groups (Dichromats and possibly Retinal Tetrachromats), must involve cognitive mapping functions that link an individual’s perceptual representation to the individuals cognitive

representations shared by different perceptual subgroups. If we argue that, for color, perceptual and semantic representations are distinct, then some cognitive mapping relation must govern the correspondence between their respective structural representations. This mapping relation is what Jameson and Alvarado (submitted, in-press) refer to as the cognitive “naming-function” of color.

4.4 Why Brightness and Saturation dimensions over Hue?

While the IDM of color naming is generally in agreement with the partitioned structures of both Berlin & Kay’s original ordered hierarchy and the revised model (Kay & Maffi, 2000), the category structure derived from Kay & Maffi’s three color-appearance-based principles (i.e., Bk&W, Wa&C, and Red. See Kay and Maffi 2000) is better explained by principles of Lightness and Saturation polarity and category-area equity and symmetry, as described above. The IDM is discussed further by Jameson and Alvarado (in-press; submitted).¹⁶

The IDM Framework’s emphasis on individual brightness and saturation constructs differentiates it from theories of neurophysiological subjectivism of color (Hardin 1988), as well more objectivist approaches (Shepard, 1994, 1997), that presuppose Hering opponencies underlying color perception and categorization.

The IDM Framework overlaps conceptually, and is most in accord, with the perspectives of Dedrick (1998, 1997). Dedrick similarly suggests an intermediate level between perceptual and linguistic levels of representation (1998 pp. 133-148), incorporates the socio-cultural aspects of color naming, and generally provides very strong arguments concerning the ontology and epistemology of color experience, naming and categorization (1998). Unlike Dedrick, the IDM Framework emphasizes the cognitive dimensions of brightness and saturation over hue, and suggests a clear separation between individual and cultural naming processes; a common tendency for culture’s to solve the color-naming problem through similar, normative, mappings from convergent evolutions; and principles that predict partitions on the basis of irregularities in the color-space mapping.

The IDM’s de-emphasis of hue as subordinate to brightness and saturation dimensions is similar to alternative explanations presented for observed yellow/green and yellow/green/blue category partitions by Casson (1997; Casson & Gardner, 1992). MacLaury (1992) describes a brightness sequence composed of lightness and shininess.

The deemphasis on hue is also supported by a considerable body of results showing that average foci vary across cultures and are not strongly linked to the opponent-color unique-hue positions, for color lexicons representing early stages of the Berlin & Kay hierarchy (see Dedrick, 1997 for an evaluation of foci salience). The IDM’s emphasis on the universal cognitive dimensions of brightness and hue in both the cultural and the individual processes of color naming differs slightly from the proposals of MacLaury. He emphasizes that “every person applies a singular cognitive dynamic to a highly specific perceptual infrastructure” (2001, p. 1231). Like MacLaury, we propose that the cultural process of naming is distinct from the individual processes involved in learning and using a color naming system.

¹⁶Note that comparatively minor color perceptual non-linearities (Bezold-Bruecke and Abney Shifts) are not likely to be robust enough or systematic across individuals to be shared intraculturally and warrant linguistic denotation or hinder the use of a shared brightness or saturation construct.

Support for the IDM Framework also comes from results showing the prevalence of Basic Color Terms (BCTs) coupled with the failure of “landmark” exemplar salience, and focal/centroid salience. For example, Jameson & Alvarado (2000, in-press) tested ideas about the salience of basic color appearances and their link to basic color terms. They showed empirically that important features of the cognitive naming-function of color are highly task-dependent, and that the naming-function does not exhibit reciprocity in the empirically derived mappings that link color appearances to the color lexicon. In a study of three language groups (monolingual Vietnamese, bilingual Vietnamese-English and monolingual English speakers), they found that while BCTs are used most frequently to describe a wide array of color samples, they are not uniquely mapped to specific category exemplars across the groups. Further, while certain color samples show high agreement in naming for each group, the terms showing such agreement differ across the language groups tested. If color naming were universally determined by a neural substrate, then Jameson & Alvarado’s (In Press) findings should not occur.

When an empirical task explicitly constrains the use of terms to monolexemic assignments (c.f. Boynton & Olson 1987, 1990), then the cross-cultural variation observed by Jameson & Alvarado (In Press) will be greatly diminished or even eliminated in aggregate measures. Monolexemic naming has been a preferred paradigm in color naming research for practical reasons (see Sturges & Whitfield, 1997). The effect of such a constraint may have been to increase color-naming agreement will necessarily increase both cross-culturally and intraculturally.

With respect to the emphasis on brightness and saturation universals, Jameson and Alvarado (in-press) and Alvarado and Jameson (in-press) demonstrate empirically that despite observed differences between Vietnamese and English in terms of modifier use and monolexemic color-naming, the two language groups showed similar mappings of lightness modifiers (i.e., glosses for “light” and “dark” in both languages) and saturation modifiers (i.e., glosses for “bright,” “fresh” and “moderate” in both languages) to regions of the OSA color space. This too supports the suggestion that while hue categories and best-exemplars may vary cross-culturally, lightness and saturation may be linguistically represented more consistently across languages.

Jameson & Alvarado (in-press) empirically demonstrate the importance of Berlin & Kay’s basic color-term categories. Although the convergent solution many cultures evolve is that given in the Berlin & Kay hierarchy, we suggest that it comes about for reasons different than those originally supposed. That is, a parallel form of primacy for category best exemplar perceptual salience (even for Hering “landmark” hues) is not demonstrated, and features that appear common to the language groups tested is the way the brightness and the saturation dimensions are mapped by the different languages.

4.5 Culturally-specific linguistic influences on color naming systems

Davidoff, Davies, Roberson and colleagues raise different criticisms of the universality of the Berlin & Kay basic terms. Their research identifies cases where the 11 basic terms are not supported (in an ordered or unordered sequence). Davidoff et al. (2000) for example, demonstrated that invariance of response was strongly associated with language structure, and emphasized a need for research to acknowledge linguistic relativity in color naming. Davidoff and colleagues argue that linguistic structure and language processing are not properly considered in the widely accepted Berlin & Kay formulation, and are indeed a large component (if not the main component) affecting color naming systems cross-culturally. Other similar challenges to

basic color term universality have previously appeared and presented difficulties for the Berlin & Kay theory, prompting revision of their theory. Nevertheless, today's version is more extensive, yet similar to the original formulation in both its reliance on Hering fundamental foci, and its deficient treatment of influences of language on color naming systems (Kay, Berlin, Maffi & Merrifield 1997, Kay & Maffi 1999). The IDM Framework presented here is intended not to supplant the contemporary Berlin & Kay model, but rather it is offered as an updated alternative that builds upon the observed regularities in basic color term prevalence originally described. The proposed IDM explains the prevalence of Berlin and Kay's basic color categories as well as those cases that have historically been problematic for the Berlin & Kay theory (for example, GRUE & yellow-green category prevalence, individual variation, cultural contributions, etc.). It also accommodates the essential contributions of culture and language that Davidoff & colleagues and other cultural relativists correctly advance. These are aspects of the phenomenon that a color naming theory must take into account. The IDM further allows a renewed appreciation for MacLaury's collection of research results which illustrate within- and across-cultural variation, previously explained by Vantage Theory (MacLaury 1997). Moreover, the present suggestion that color similarity can alternatively be based on perceptual- or language-based criteria is compatible with suggestions made here and elsewhere that perceptual and linguistic representations are distinct (Dedrick 1997, Roberson, Davidoff & Braisby 1999).

Jameson and Alvarado (In Press) demonstrate the effects of culturally specific linguistic structures on color naming. They empirically show that the Boynton and Olson results which established the salience of specific category exemplars universally mapped to basic color terms, occurs only with a monolexemic naming paradigm, and disappear when the monolexemic constraint is removed. While monolexemes were originally emphasized by Berlin and Kay's theory (and have been prevalent in color-naming research due to their methodological simplicity), they do not represent the lexicon-to-appearance mappings found in the context of everyday communication in some languages. For example, Vietnamese, or other languages which rely heavily on modifier use as a general linguistic construction, appear to use more modifiers in conjunction with basic-color stem terms (see Alvarado & Jameson, in-press; Jameson & Alvarado, submitted).

4.6 Perceptually-based category focal salience

The argument supporting perceptual focal salience rests on privileged processing (salience) of a small set of basic, landmark, or focal/centroid color appearances dictated by the underlying neural substrate of color vision. In addition to Jameson & Alvarado's research showing limited utility of the focal salience construct, Roberson, Davies & Davidoff (2000) found non-universality of color focal or centroid exemplars. Sturges and Whitfield (1997) found no convincing differences between basic "landmark" hues (Hering's Black, White, Red, Green, Yellow & Blue color opponents and the other basic color categories identified as universal by Berlin & Kay (i.e., Purple, Orange, Pink & Brown). If color-opponent neurophysiology were the basis for universal color category salience and naming then it would be reasonable to predict that the landmark hues would be differentiated from the other basic hues (c.f., Kay and McDaniel, 1978); yet this does not occur in the studies cited (see also Jameson & Alvarado, in-press, submitted).

Results showing cross-culturally varying focal appearance salience, when considered in conjunction with the many findings supporting Berlin & Kay's set of frequently occurring color term glosses (e.g., Jameson & Alvarado, in-press; Lin, Luo, MacDonald, & Tarrant 2001; Hardin

& Maffi 1997), support two conclusions: (1) a substrate defining perceptual salience does not determine universal color categorization and naming behaviors, and (2) the representations of perceptual color appearance and semantic color naming and categorization are distinct.

How do we account for the results of the many studies demonstrating the salience of focal colors? We do not dispute these findings but rather offer a different explanation for them. Our alternative theory suggests the possibility that many of the studies finding differential salience for focal appearances, do so through a correlation with universal linguistic salience, not through perceptual salience.

These results exemplify two important considerations for color naming and representation studies. First, color space representations are highly determined by the task used to collect the data because seemingly similar tasks may implicitly access either a perceptual-discrimination representation or a semantic, category-tolerance, representation (discussed in Bimler, 1999; Paramei & Cavonius 1999). Second, as a consequence of this, investigations aiming to define cognitive color space representations should take care to separately assess perceptual and semantic modes. Investigators must design empirical tasks and instructions which allow the two representation to be judged as independently as possible (c.f., Izmailov & Sokolov 1992).

Shepard and Cooper (1992), Marmor (1978), and Jameson and Hurvich (1978) results suggest that lexical knowledge can develop in the absence of perceptual experience. This further underscores the importance of differentiating the perceptual from the semantic representation of color (see Dedrick, 1997, for a similar discussion).

Based on the foregoing, it seems plausible that the universality observed in investigations using *language-based* categorization tasks arises from the shared cognitive representation of color (as opposed to more variable individual representations). In such cases we would not expect to see dramatic individual differences or dramatic gender differences because individual variability in color naming is absorbed by *linguistic charity* – the principle described earlier which makes interpersonal communication paramount. Thus when naming across cultures is studied much within-culture variation is obscured by the pragmatics of language use. What cross-cultural variation remains is minimized by other factors, including the empirical methods used and the uniformity of the stimulus domain. The result is an overall pattern which across cultures appears to be a pan-human universal color-naming tendency. This tendency does not arise from a common neurophysiological substrate *per se*, but through the additional cultural and cognitive mechanisms described previously.

We have suggested that investigations of color cognition, naming, and perception should carefully attend to the distinctions between perceptual representations versus individual cognitive representations versus shared lexical representations. These representations are differentiable in subtle ways in different tasks. A task that emphasizes the linguistic aspects of color (i.e., color naming or color categorization by lexical categories) will draw upon the shared cultural representation of participants. This result was among those found by Kay and Kempton (1984) where color similarity relations were in part differentiated on the basis of cross-culturally varying linguistic structure.

By comparison, a task emphasizing discrimination aspects of color vision, such as the side-by-side matching of a chromatically adjustable field to a chromatically fixed test field (minimally distinct border, MDB), will draw upon an individual's perceptual representation.¹⁷

¹⁷Note that methodologically the minimally distinct border (MDB) task and a bipartite field matching (BFM)

4.7 Evidence supporting distinct Perceptual, Cognitive and Cultural representations

We have argued that the cultural representation of color maps language onto color percepts in ways that optimize communication between individuals in the culture during social interactions. This is accomplished through a shared representation of color that need not be duplicated by any single individual's cognitive representation of color (c.f., Jameson & Romney 1990). Earlier, we reviewed evidence supporting the suggestion that judgments of color-naming and color appearance are based on distinct cognitive mechanisms (c.f. Davidoff 1991). Here we review additional evidence supporting the claim that the perceptual, cognitive and cultural representations actually differ. Neurophysiological evidence supporting the existence of distinct representations is found in populations with selective deficits for either color naming or color perception, whose capacity for color processing nevertheless remains unimpaired (e.g., Roberson, Davidoff & Braisby, 1999; also see Chao & Martin; 1999). Cases of color anomia exist where individuals can discriminate colors but not name them. In such individuals color naming is apparently dissociated from the perceptual representation of color (Davidoff 1997, Davidoff & Ostergaard 1984, Davidoff 1991). In studies of normal subjects' categorical perception of color it has been shown that although both visual and verbal codes can be employed in color recognition memory, categorical perception is only found when subjects made use of verbal coding (Roberson & Davidoff 2000). Based on these results, Roberson and Davidoff suggest that categorical color perception requires verbal codes and does not require visual codes. Such studies demonstrate instances where color perception can be found to be dissociated or represented independently from color semantics.

Another example is seen in the relational mappings of similarity for color names and color appearances for blind and color-blind and normal trichromat observers (Shepard and Cooper 1992, Marmor 1978). Both studies show that different observer groups share similar relational structures in their color language representation despite having dramatically different perceptual representations of color. (See also the findings of Johnson, Johnson & Baksh, 1986, which suggest separate semantic and perceptual representations). Consensus in the use of color lexicons among such groups with different perceptual abilities underscores the existence of a shared color language representation that differs from the divergent individual perceptual representations.

Given three levels of representation, as proposed by our perspective, what individual differences in color experience should we expect? First, we would expect to see rather large differences in perceptual and discrimination measures that capture the subtleties of the color vision idiosyncrasies experienced by dichromats, trichromats and tetrachromat observers with more than three photopigment classes (Jameson, Bimler & Wasserman submitted). Second, we would expect to see similarly idiosyncratic cognitive representation in individual color naming mappings (e.g., MacLaury, 1997) and in non-linguistic tasks involving cognitive constructs such as color match-

are functionally the same in terms of stimulus configuration. However, it is possible that the very simple variation in instructions applied to the two seemingly equivalent perceptual tasks might evoke the use different cognitive criteria. That is, the MDB task simply requires participants to adjust one field until there is no visible border between it and a fixed test field. By comparison the BFM task relies on the cognitive construct of a "match." Typical instructions are: "adjust the variable field until it *matches* the adjacent test field," or "find the best match of the adjust field to the test field." Thus the BFM task requires participants to use their matching constructs. As discussed earlier, there is no reason to expect the notion of a "match" to be a uniformly mapped construct to perceptual discrimination across the various perceptual groups of participants that exist.

ing. Such differences should be consistent with the ways dichromats are known to cognitively reconcile their own choices with the matching abilities of trichromats, and the ways we propose individuals with functional use of more than three photopigment classes might reconcile cognitive matching tolerances which do not coincide with their perceptual tolerances. Third, for the cultural representation we would expect to see linguistic influences on color naming behavior, as observed most recently by Roberson, Davies & Davidoff (2000) and Jameson & Alvarado (in-press) and Alvarado & Jameson (in-press). Finally, due to the cognitive and socio-cultural constraints discussed, we would expect the normative color-naming solutions that many languages evolve to reflect a category structure that includes the basic color categories originally proposed by Berlin & Kay (1969).

Conclusion

The suggested de-emphasis of the highly popular view of a pan-human Hering-opponent color vision substrate as the basis for color naming universality is not a return to a culturally relativistic Neo-Whorfian perspective in which language shapes perception (Whorf 1956).

Rather, the proposed perspective aims to reintroduce, in a more substantial way, the role of culture and cognitive processing into the cross-cultural study of phenomena of color naming and color categorization. The perspective described here accords with a cognitivist view of the products of shared cultural ideas (D'Andrade, 2001) and with the general approach of defining cultural meaning systems as shared cognitive representations (Romney, Boyd, Moore, Batchelder, & Brazill 1996; Romney & Moore 1998). We hope to provide a more balanced perspective that achieves a more comprehensive understanding of this complex phenomena.

Franz Boas once suggested that *Culture*, the construct, would be crucial in debunking the ill-conceived race-based argument of differences in prosperity across different societies. Here we suggest that in view of variation in color perception behavior and diversity in the genetic basis of color perception, cross-cultural *cognitive* universals are the most likely basis for observed color-naming universality. Such universals can be appropriately used in color-naming theories as a descriptive construct which extends an unnecessarily narrow theoretical emphasis on pan-human physiological determinants of color naming. Considering cultural universals as an explanatory factor in color naming universality will provide a more comprehensive explanation of how it is that many different societies name and categorize color in a very similar way.

The account of universal color-naming and categorization proposed in this article is summarized as follows:

1. Intracultural variability of color perception is far more significant in both perceptual phenotype and phenomenological consequence than previously recognized.
2. Social and cultural forces striving to optimize interpersonal communication play an important role in the establishing the mapping relations among individuals' with varying perceptual representations of color.
3. Individual perceptual and semantic representations of color are distinct, and are described by two separate (albeit in some cases structurally isomorphic) similarity structures.
4. These two similarity structures are related by way of an additional level of cognitive representation that links perceptual and semantic structures using a cognitive naming function.

5. At the very least, the relations specified by this naming function differ for Dichromats and Trichromats. Substantial differences between retinal tetrachromats and trichromats seem plausible, but need further empirical evaluation.

6. Unlike most domains explored in naming and categorization experiments, the highly constrained and universally accessible nature of color permits very different cultures to convergently evolve similar solutions to the partitioning and lexically mapping of color experience.

7. The process by which cultures partition and name color categories in a progressively developing, common hierarchical solution (supporting Berlin and Kay's theory of color naming) is described by principles and heuristics of an Interpoint- Distance Model Framework originally proposed by Jameson and D'Andrade (1997).

8. The universalities of color experience consist of the specific cognitive constructs discussed, the shared 'normative' cultural model, and the processes by which it evolves and is maintained across cultures.

This account of color naming and categorization rests on a clear separation between processes that produce a culture's color lexicons, and processes by which individuals learn and maintain color lexical proficiency. Understanding that these aspects are distinct, while shifting the explanatory emphasis as suggested in the IDM Framework, will lead to a clearer understanding of the linkages between culture, color cognition and language, and color signal neural processing.

References

- Alvarado, N. & Jameson, K. A. (in–press). The use of Modifying Terms in the Naming and Categorization of Color Appearances. *The Journal of Cognition & Culture*.
- Anyan, W.R., Jr. & Quillian, W. W. II (1971). The naming of primary colors by children. *Child Development*, 42, 1629–1632.
- Asenjo, A. B., Rim, J., & Oprian, D. D. (1994). Molecular determinants of human red/green color discrimination. *Neuron*, 12, 1131–1138.
- Baseler, H. A., Brewer, A. A., Sharpe, L. T., Morland, A. B., Jaegle, H. & Wandell, B. A.. (2002). Reorganization of human cortical maps caused by inherited photoreceptor abnormalities. *Nature Neuroscience*, 5, 364–370.
- Berlin, B. & Kay, P. (1969). *Basic color terms: Their universality and evolution*. Berkeley: University of California Press.
- Bimler, D. (1999). Research Note: A Multidimensional Scaling Comparison of Color Metrics for Response Times and Rated Dissimilarities. *Perception & Psychophysics*, 61(8), 1675–1680.
- Bonnardel, V., Miller, S., Wardle, L. & Drew, E. (2002). Gender Differences in Colour-Naming Task. *25th European Conference on Visual Perception*. August 27, 2002. Glasgow, Scotland. *Perception*, 31, supplement, 71a.
- Boster, J. S. (1986). Can individuals recapitulate the evolutionary development of color lexicons? *Ethology*, 25(1), 61–74.
- Boynton, R. M. (1997). Insights gained from naming the OSA colors. In C. L. Hardin (Ed.) *Color categories in thought and language*. (Pp. 135–150). Cambridge, United Kingdom: Cambridge University Press.
- Boynton, R. & Olson, C. (1987). Locating basic colors in the OSA space. *Color Research and Applications*, 12, 94–105.
- Boynton, R. & Olson, C. (1990). Saliency of chromatic basic color terms confirmed by three measures. *Vision Research*, 30, 1311–1317.
- Boynton, R. M. & Scheibner, H., (1967). On the perception of red by *red-blind* observers. *Acta Chromatica*, 1, 205–220.
- Bowmaker, J. K., Jacobs, G. H. & Mollon, J. D. (1987). Polymorphism of Photopigments in the Squirrel Monkey: A Sixth Phenotype. *Proceedings of the Royal Society of London, B*, 231, 383–390.
- Brindley, G.S. (1970). *Physiology of the Retina and the Visual Pathway*. 2nd Edition. Baltimore: Williams & Wilkins.
- Casson, R. & Gardner, P. M. (1992). On brightness and color categories: Additional data. *Current Anthropology*, 33, 395–399.
- Burgess, D. Kempton, W. and MacLaury, R. E. (1983). Tarahumara color modifiers: category structure presaging evolutionary change. *American Ethnology*, 10, 133–149.

- Casson, R. (1997). Color shift: Evolution of English color terms from brightness to hue. In *Color Categories in Thought and Language*. C. L. Hardin & L. Maffi (Ed.s). Cambridge University Press: England. 224–239.
- Chang, J. J. & Carroll, J. D. (1980). Three are not enough: An INDSCAL Analysis suggesting that Color Space has Seven (+/–1) Dimensions. *Color Research & Application*, 5, 193–206.
- Chao, L. L. & Martin, A. (1999). Cortical regions associated with perceiving, naming, and knowing about colors. *Journal of Cognitive Neuroscience*, 11, 25–35.
- D’Andrade, R. G. (1987). Modal Responses and Cultural Expertise. *American Behavioral Scientist*, 31(2), 194–202.
- D’Andrade, R.G. (1993). Cultural cognition. In M.I. Posner (Ed.), *Foundations of Cognitive Science*. (Pp. 795–830). Cambridge, MA: The MIT Press.
- D’Andrade, R. G. (2001). A Cognitivist’s View of the Units Debate in Cultural Anthropology. *Journal of Cross Cultural Research*, 35(2), 242–257.
- D’Andrade, R. G. (1981). The Cultural part of Cognition. *Cognitive Science*, 5, 179–195.
- D’Andrade, R. G. & Egan, M. J. (1974). The color of emotion. *American Ethologist*, 1, 49–63.
- Dartnall, H.J.A., Bowmaker, J.K. & Mollon, J.D. (1983). Human visual pigments: microspectrophotometric results from the eyes of seven persons. *Proceedings of the Royal Society, London*. B220, 115–13.
- Davidoff, J. (1997). The neuropsychology of color. In *Color Categories in Thought and Language*. C.L. Hardin and L. Maffi (Eds.). Cambridge University Press: England. 118–134.
- Davidoff, J. & Ostergaard, A. L. (1984). Color anomia resulting from weakened short-term memory. *Brain*, 107, 415–431.
- Davidoff, J. (1991). *Cognition through Color*. Cambridge, MA: The MIT Press.
- Dedrick, D. (1996). Color language universality and evolution: On the explanation for basic color terms. *Philosophical Psychology*, 9, 497–524.
- Dedrick, D. (1998). *Naming the Rainbow: Colour language, colour science, and culture*. Kluwer Academic Publishers: Dordrecht.
- Dedrick, D. (1997). Colour categorization and the space between perception and language. *Behavioural and Brain Sciences*, 20(2), 187–188.
- De Valois, R. L., Abramov, I. & Jacobs, G. H. (1966). Analysis of Response Patterns of LGN Cells. *Journal of the Optical Society of America*, 56, 966–977.
- DeValois, R. L. and DeValois, K. K. (1993). A multi-stage color model. *Vision Research*, 33, 1053–1065.
- Derrington, A. M., Krauskopf, J. & Lennie, P. (1984). Chromatic Mechanisms in Lateral Geniculate Nucleus of Macaque. *Journal of Physiology*, 357, 241–265
- D’Zmura, M. & Knoblauch, K. (1998). Spectral bandwidths for the detection of color. *Vision Research*, 38, 3117–3128.

- Furbee, L. N., Maynard, K., Smith, J., Benfer, B. A., Jr., Quick, S. & Ross, L. (1997). The emergence of color cognition from color perception. *Journal of Linguistic Anthropology*, 6, 223–240.
- Freyd, J. J. (1983). Shareability: The social psychology of epistemology. *Cognitive Science*, 5, 121–152.
- Garner, W. R. (1974). *The Processing of Information and Structure*. Lawrence Erlbaum Associates: Hillsdale, New Jersey.
- Griffin, L. D. (2001). Similarity of Psychological and Physical Colour Space Shown by Symmetry Analysis. *COLOR Research and Application*, 26(2), 151–157.
- Hardin, C. L. (1988). *Color for Philosophers: Unweaving the Rainbow*. Indianapolis, IN: Hackett.
- Hardin, C. L. & Maffi, L. (1997). *Color Categories in Thought and Language*. Cambridge University Press: England.
- Hering, E. (1964). *Outlines of a theory of the light sense*. translation by L. M. Hurvich & D. Jameson. Cambridge, MA: Harvard University Press.
- Hurvich, L. M. & Jameson, D. (1974/75). On the measurement of dichromatic neutral points. *Acta Chromatica*, 2, 207–216.
- Ishihara, S. (1987) *Ishihara's tests for colour-blindness (Concise Edition)*. Tokyo, Japan: Kanehara & Co., LTD.
- Izmailov, Ch. A. & Sokolov, E. N. (1992). A semantic space of color names. *Psychological Science*, 3, 105–110.
- Jameson, D. & Hurvich, L. M. (1955). Some quantitative aspects of opponent-colors theory. I. Chromatic response as spectral saturation. *Journal of the Optical Society of America*, 45, 546–552.
- Jameson, D. & Hurvich, L. M. (1978). Dichromat color language: “Reds” and “Greens” don’t look alike but their colors do. *Sensory Processes*, 2, 146–155.
- Jameson, K. & Romney, A. K. (1990). Consensus on Semiotic Models of Alphabetic Systems. *Quantitative Anthropology*, 2, 289–304.
- Jameson, K. and D’Andrade, R. G. (1997). It’s not really Red, Green, Yellow, Blue: An Inquiry into cognitive color space. In *Color Categories in Thought and Language*. C.L. Hardin and L. Maffi (Eds.). Cambridge University Press: England. 295–319.
- Jameson, K. A. (1997). What Saunders and van Brakel chose to ignore in color and cognition research. *Behavioural and Brain Sciences*, 20(2), 195–196.
- Jameson, K. A., S. Highnote and L. Wasserman. (1998). Understanding Color Appearance Phenomenology: Can Variation in Photopigment Opsin Genes give rise to Individuals with Perceptual Tetrachromacy? *Perception*, 27, 173.
- Jameson, K.A. and R. G. D’Andrade. (2000). Culture, cognition, and quantitative methods: Modeling the representation of color experience. Presentation at the *29th Annual Meeting of the Society for Cross Cultural Research*. New Orleans, Louisiana.

- Jameson, K. A. & Alvarado, N. (2000). Color–Naming and Categorization in Vietnamese and English. Poster at the *Annual Meeting of the Psychonomic Society*. New Orleans, Louisiana.
- Jameson, K. A., S. Highnote and L. Wasserman. (2001). Richer color experience for Observers with multiple photopigment opsin genes. *Psychonomic Bulletin & Review*, 8(2), 244–261.
- Jameson, K. A., J. Kaiwi, & D. E. Bamber. (2001). Color– coding information with psychological– constant hue loci: Assessing alternative coding schemes using independent brightness and hue dimensions. *Journal of Experimental Psychology: Applied*, 7(2), 112–128.
- Jameson, K. A. (2001). New Findings on the Universality of Color Experience. Presentation at the *30th Annual Meeting of the Society for Cross Cultural Research*. San Diego, California.
- Jameson, K.A. & N. Alvarado. (in-press). Differences in Color Naming and Color Salience in Vietnamese and English. *COLOR Research and Application*.
- Jameson, K. A. & Alvarado, N. (submitted). The Relational Correspondence between Category Exemplars and Naming.
- Jameson, K. A., D. Bimler, & L. M. Wasserman (submitted). Re-Assessing Perceptual Diagnostics for Observers with Diverse Retinal Photopigment Phenotypes.
- Jameson, K. A., D. Bimler, & L. M. Wasserman. (2002). Assessing Color Perception in Observers with Photopigment Opsin Gene Polymorphisms. Presentation at the *33rd Annual Meeting of the European Mathematical Psychology Group*. August 23, 2002. Bremen, Germany.
- Jameson, K. A. & L. M. Wasserman. (2002). Color Appearance Variations associated with Photopigment Opsin Genotypes. Presentation *25th European Conference on Visual Perception*. August 26, 2002. Glasgow, Scotland. *Perception*, 31, supplement, 15b.
- Johnson, A., Johnson, O. & Baksh, M. (1986). The colours of emotions in Machiguenga. *American Anthropologist*, 88, 674–681.
- Johnson, E. G. (1986). The role of bilingualism in color naming. *Psychologia: An International Journal of Psychology in the Orient*, 29, 156–164.
- Johnson, E. G. (1977). The development of color knowledge in preschool children. *Child Development*, 48, 308–311.
- Johnson, C. J., Paivio, A., & Clark, J. M. (1996). Cognitive Components of Picture Naming. *Psychological Bulletin*, 120, 113– 139.
- Judd, D. B. (1973). Color in visual signaling. In *Color Vision* Proceedings of the Symposium conducted at the Spring Meeting, 1971. Committee on Vision Division of Behavioral Sciences National Research Council. National Academy of Sciences : Washington, D.C..
- Kay, P., Berlin, B., Maffi, L. & Merrifield, W. (1997). Color naming across languages. In C. L. Hardin (Ed.) In *Color Categories in Thought and Language*. (Pp. 21–56). Cambridge, United Kingdom: Cambridge University Press.
- Kay, P., & Maffi, L. (2000). Color Appearance and the Emergence and Evolution of Basic Color Lexicons. *American Anthropologist*, 101, 743–760.
- Kay, P., Berlin, B. & Merrifield, W. (1991). Biocultural implications of systems of color naming. *Journal of Linguistic Anthropology* , 1(1), 12–25.

- Kay, P. & McDaniel, C. (1978). The linguistic significance of the meanings of basic color terms. *Language*, 54, 610–646.
- Kay, P. & Kempton, W. (1984). What is the Sapir-Whorf hypothesis? *American Anthropologist*, 86, 65–79.
- Keil, F. C. & Kelly, M. H. (1987). Developmental changes in category structure. In S. Harnad & L. Maffi (Ed.), *Categorical Perception: The groundwork for cognition*. pp. 491–510. Cambridge University Press: England.
- Kuehni, R. G. (2001). Determination of unique hues using Munsell color chips. *COLOR Research and Application*, 26, 61–66.
- Krauskopf, J., Williams, D.R., Heeley, D.W. (1982). Cardinal directions of color space. *Vision Research*, 22, 1123–1131.
- Lin, H., Luo, M. R., MacDonald, L. W., & Tarrant, A. W. S. (2001). A Cross-Cultural Colour-Naming Study. Part I: Using a Unconstrained Method. *Color Research and Application*, 26, 40-60.
- Lin, H., Luo, M. R., MacDonald, L. W., & Tarrant, A. W. S. (2001). A Cross-Cultural Colour-Naming Study. Part II: Using a Constrained Method. *COLOR Research and Application* 26, 193-208.
- Maloney, L.T. (1992). Color constancy and color perception: The linear models framework. In: D.E. Meyer and S. Kornblum (Eds.), *Attention and Performance XIV: Synergies in Experimental Psychology, Artificial Intelligence, and Cognitive Neuroscience*. (Pp. 59–78). Cambridge, Mass: MIT Press.
- Marmor, G. S. (1978). Age at onset of blindness and the development of the semantics of color names. *Journal of Experimental Child Psychology*, 25, 267–278.
- MacLaury, R. E. (1991). Social and cognitive motivations of change: Measuring variability in color semantics. *Language*, 67, 34–62.
- MacLaury, R. E. (1992). From brightness to hue: An explanatory model of color category evolution. *Current Anthropology*, 33, 137–186.
- MacLaury, R. E. (1997). Color category evolution and Shuswap yellow-with-green. *American Anthropologist*, 89, 107–124.
- MacLaury, R. E. (1997). *Color and Cognition in Mesoamerica: Constructing Categories as Vantages*. Austin, University of Texas Press.
- MacLaury, R. E. (2001). Language typology and language universals. In M. Haspelmath, E. Koenig, W. Oesterreicher, & W. Raible (Ed.s), *An International Handbook*. 1227–1252. Walter de Gruyter: Berlin.
- Martinez, E., Jameson, K. A. & Wasserman, L. (1999). Behavioral Assessment and PCR Assay analysis of L-cone opsin genotypes. Poster presented at the *Annual meeting of the Association for Research in Vision and Ophthalmology*. Ft. Lauderdale, FL.
- Mausfeld, R. & Niederée, R. (1993). An Inquiry into relational concepts of colour based on an incremental principle of colour coding for minimal relational stimuli. *Perception*, 22, 427–462.

- McGuinness, D. (1976). Away from a unisex psychology: Individual differences in visual sensory and perceptual processes. *Perception*, 5, 279–294.
- McGuinness, D. & Lewis, I. (1976). Sex differences in visual persistence: Experiments on the Ganzfeld and afterimages. *Perception*, 5, 295–301.
- McMahon, M. J. & MacLeod, D. I. A. M. (1998). Dichromatic Color Vision at High Light Levels: Red/Green Discrimination using the Blue-Sensitive Mechanism. *Vision Research*, 38(7), 973–983.
- Mollon, J. D. (1992). Worlds of difference. *Nature*, 356, 378–379.
- Mollon, J. D. (1995). Seeing Color. In: T. Lamb and J. Bourriau (Eds.), *Colour, Art & Science*. (Pp. 127–150). Cambridge: Cambridge University Press.
- Moore, C. C., Romney, A. K., & Hsia, T.-L. (2000). Shared Cognitive Representations of Perceptual and Semantic Structures of Basic Colors in Chinese and English. *Proceedings of the National Academy of Science*, 97(9), 5007–5010.
- Morgan, M. J., Adam, A. & Mollon, J. D. (1992). Dichromats detect colour-camouflaged objects that are not detected by trichromats. *Proceeding of the Royal Society of London B*, 248, 291–295.
- Nagy, A. L. & Boynton, R. M. (1979). Large-Field Color Naming of Dichromats with Rods Bleached. *Journal of the Optical Society of America*, 69, 1259–1265.
- Nathans, J. (1997). The genes for color vision. In A. Byrne and D. R. Hilbert (Eds.), *Readings on Color, Volume 2: The Science of Color*. Cambridge, Massachusetts: The MIT Press.
- Nathans, J., Thomas, D., & Hogness, D. S. (1986). Molecular genetics of human color vision: The genes encoding blue, green, and red pigments. *Science*, 232, 193–202.
- Neitz, J. & Jacobs, G.H. (1986). Polymorphism of the long-wavelength cone in normal human color vision. *Nature*, 323, 623–625.
- Neitz, M., Kraft, T. W., & Neitz, J. (1998). Expression of L cone pigment gene subtypes in females. *Vision Research*, 38, 3221–3225.
- Neitz, M., Neitz, J. & Jacobs, G.H. (1995). Genetic basis of photopigment variations in human dichromats. *Vision Research*, 35, 2095–2130.
- Neitz, J. & Neitz, M. (1994). Colour vision defects. In: A.S. Wright and B. Jay (Eds.), *Molecular Genetics of Inherited Eye Disorders*. Chur: Harwood Academic Publishers.
- Neitz, M. & Neitz, J. (1998). Molecular genetics and the biological basis of color vision. In: W.G.K. Backhaus, R. Kliegl and J.S. Werner (Eds.), *Color Vision: Perspectives from Different Disciplines*. (Pp. 101–119). New York: Walter de Gruyter.
- Niederée, R. (1993). Continuity considerations in colour perception: Why already in center-surround stimuli colour appearances cannot be coded three-dimensionally. *Technical Report, Psychologisches Institut, Universitaet Bonn*. Germany.
- Nowaczyk, R. H. (1982). Sex-related differences in the color lexicon. *Language and Speech*, 25, 257–265.

- Otake, S. & Cicerone, C. M. (2000). L and M cone relative numerosity and red-green opponency from fovea to midperiphery in the human retina. *Journal of the Optical Society of America, A*, 17, 615–627.
- Paramei, G. V., (1996). Color space of normally sighted and color-deficient observers reconstructed from color naming. *Psychological Science*, 7, 311–317.
- Paramei, G. V., Bimler, D. L. & Cavonius, C. R. (1998). Effects of luminance on color perception of proanopes. *Vision Research*, 38, 3397–3401.
- Paramei, G. V., Bimler, D. L. & Mislavskaya, N. O. (2000). Color perception in twins. *Journal of Higher Nervous Activity*, 50, 819– 832. [in Russian language].
- Paramei, G. V. & Cavonius, C. R. (1999). Color Spaces of Color–Normal and Color–Abnormal Observers Reconstructed from Response Times and Dissimilarity Ratings. *Perception & Psychophysics*, 61(8), 1662–1674.
- Paramei, G. V. (1999). Book Review (In Russian language): “Color and Cognition in Mesoamerica: Constructing Categories as Vantages,” by R. E. MacLaury. Published 1997. Austin: University of Texas Press. *Voprosy Psikhologii*, 3, 116–117. English translation available at <http://www.sas.upenn.edu/maclaury/paramei.htm>.
- Paramei, G. V., Bimler, D. L. & Cavonius, C. R. (2000). Color–Vision Variations Represented in an Individual–Difference Vector Chart. *COLOR Research and Application, Supplement*, 26, S230–S234.
- Paramei, G. V., & Bimler, D. L. (2001a). Is color space curved? A common model of color-normal and color-deficient observers. In W. Backhaus (Ed.), *Neuronal coding of Perceptual Systems*. (Proceedings of the International School of Biophysics, Casamicciola, Napoli, Italy, 12-17 October, 1998). *The Series of Biophysics and Biocybernetics of the Istituto Italiano per gli Studi Filosofici*, vol. 9, (pp. 102–105. World Scientific: Singapore, New Jersey, London, Hong-Kong.
- Paramei, G. V., & Bimler, D. L. (2001b). Vector coding underlying individual transformation s of a color space. In C. Musio (Ed.), *Vision: The Approach of Biophysics and Neurosciences*. (Proceedings of the International School of Biophysics, Casamicciola, Napoli, Italy, 11-16 October, 1999). *The Series of Biophysics and Biocybernetics of the Istituto Italiano per gli Studi Filosofici*, vol. 11, (pp. 429–436. World Scientific: Singapore, 2001.
- Pastoureau, M. (2001). *Blue: The History of a Color*. Princeton University Press: Princeton.
- Pérez–Carpinell, J., Baldoví, R., de Fez, M. D., & Castro, J. (1998). Color Memory Matching: Time Effect and Other Factors. *COLOR Research and Applications*, 23(4), 234– 247.
- Philip, B. R. (1938). Sex differences in the perception of color mass. *American Journal of Psychology*, 51, 398–404.
- Putnam, H. (1988). *Representation and Reality*. Cambridge, MA: The MIT Press.
- Rapoport, A. & Fillenbaum, S. (1972). An experimental study of semantic structures. In A. K. Romney, R. N. Shepard & S. B. Nerlove (Ed.s) *Multidimensional Scaling (Volume II): Applications*. pp. 93–131. Seminar Press: New York.

- Ratliff, F. (1976). On the physiological bases of universal color terms. *Proceedings of the American Philosophical Society*, *120*, 311–330.
- Rich, E. (1977). Sex-related difference in color vocabulary. *Language and Speech*, *20*, 404–409.
- Roberson, D., Davidoff, J., & Braisby, N. (1999). Similarity and Categorization: Neurophysiological Evidence for a Dissociation in Explicit Categorization Tasks. *Cognition*, *71*, 1–42.
- Roberson, D. & Davidoff, J. (2000). The Categorical Perception of Colors and Facial Expressions: The Effect of Verbal Interference. *Memory & Cognition*, *28(6)*, 977–986.
- 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(3)*, 369–398.
- Roberts, J. (1987). Within Culture Variation: A Retrospective Personal View. *American Behavioral Scientist*, *31(2)*, 194–202.
- Romney, A. K., Weller, S. & Batchelder, W. (1986). Culture as Consensus: A Theory of Informant Accuracy. *American Anthropologist*, *88(2)*, 313–338.
- Romney, A. K., Batchelder, W. H., & Weller, S. (1987). Recent Applications of Cultural Consensus Theory. *American Behavioral Scientist*, *31(2)*, 163–177.
- Romney, A. K. (1994). Cultural Knowledge and Cognitive Structure. In *The Making of Psychological Anthropology II*, M. Suárez-Orozco, G. Spindler and L. Spindler (Ed.s). Pp. 254–283. Fort Worth, TX: Harcourt Brace.
- Romney, A. K., Boyd, J. P., Moore, C. C., Batchelder, W. H., & Brazill, T. J. (1996). Culture as Shared Cognitive Representations. *Proceedings of the National Academy of Science*, *93*, 4699–4705.
- Romney, A.K., Moore, C.C. & Rusch, C.D. (1997). Cultural universals: Measuring the semantic structure of emotion terms in English and Japanese. *Proceedings of the National Academy of Sciences*, *94*, 5489–5494.
- Romney, A. K. & Moore, C. C. (1998). Towards a Theory of Culture as Shared Cognitive Structures. *Ethnos*, *26(3)*, 314–337.
- Romney, A.K., Moore, C.C., Batchelder, W. H. & Hsia, T.-L. (2000). Statistical Methods for Characterizing Similarities and Differences between Semantic Structures. *Proceedings of the National Academy of Sciences*, *97(1)*, 518–523.
- Sacks, Oliver W. (1997). *The Island of the Colorblind and Cycad Island*. New York : Alfred A. Knopf, Publishers.
- Saito, M. (1994). A cross-cultural study on color preference in three Asian cities: Comparison between Tokyo, Taipei and Tianjin. *Japanese Psychological Research*, *36*, 219–232.
- Saito, M. (1996a). Comparative studies on color preference in Japan and other Asian regions, with special emphasis on the preference for white. *COLOR Research and Application*, *21*, 35–49.
- Saito, M. (1996b). A comparative study of color preferences in Japan, China and Indonesia with emphasis on the preference for white. *Perceptual and Motor Skills*, *83*, 115–128.

- Sapir, E. (1921). *Language*. New York: Harcourt, Brace.
- Saunders, B. A. C. & van Brakel, J. (1997). Are there nontrivial constraints on colour categorization? *Behavioral and Brain Sciences*, 20, 167–228.
- Scheibner, H. M. O. & Boynton, R. M. (1968). Residual red-green discrimination in dichromats. *Journal of the Optical Society of America*, 58, 1151–1158.
- Sharpe, L. T., Stockman, A., Jaegle, H. & Nathans, J. (1999). Opsin Genes, Cone Photopigments, Color Vision, and Color Blindness. In *Color Vision: From Genes to Perception*. Gegenfurtner, K. & Sharpe, L. T. (Ed.s). (p. 3–52).
- Shepard, R. N. (1994). Perceptual–cognitive universals as reflections of the world. *Psychonomic Bulletin & Review*, 1(1), 2–28.
- Shepard, R. N. (1997). The perceptual organization of colors: An adaptation to regularities of the terrestrial world? In A. Byrne & D. Hilbert (Eds), *Readings on Color: Volume 2, The Science of Color* (pgs. 311–356). Cambridge, MA: The MIT Press.
- Shepard, R. & Cooper, L. (1992). Representation of colors in the blind, color–blind, and normally sighted. *Psychological Science*, 3, 97–103.
- Shevell, S. K. & He, J. C. (1995). Interocular difference in Rayleigh matches of color normals. In B. Drum (Ed.), *Colour Vision Deficiencies XII*. pp. 185–191. Kluwer Academic: Dordrecht.
- Simpson, J. & Tarrant, A. W. (1991). Sex- and age-related differences in colour vocabulary. *Language & Speech*, 34, 57–62.
- Sjoberg, S.A., Neitz, M., Balding, S.D. & Neitz, J. (1998). L–cone pigment genes expressed in normal colour vision. *Vision Research*, 38, 3213–3219.
- Sleight, C. & Prinz, P. M. (1982). Children’s color vocabulary. *Language & Speech*, 25, 75–79.
- Smallman, H.S. & Boynton, R.M. (1990). Segregation of basic colors in an information display. *Journal of the Optical Society of America, A*, 7(10), 1985–1994.
- Smallman, H.S. & Boynton, R.M. (1993). On the usefulness of basic colour coding in an information display. *Displays*, 14(3), 158–165.
- Smith, V. C., Porkorny, J. & Swartley, R. (1973). Continuous hue estimation of brief flashes by deuteranomalous observer. *American Journal of Psychology*, 86, 115–131.
- Stockman, A., Sharpe, L. T. & Fach, C. C. (1999). The spectral sensitivity of the human short-wavelength-sensitive cones derived from thresholds and color matches. *Vision Research*, 39, 2901–2927.
- Sturges, J. & Whitfield, T.W.A. (1997). Salient Features of Munsell Colour Space as a Function of Monolexic Naming and Response Latencies. *Vision Research*, 37(3), 307–313.
- Swaringen, S., Layman, S. & Wilson, A. (1978). Sex differences in color naming. *Perceptual and Motor Skills*, 47, 440–442.
- Saunders, B. A. C. & van Brakel, J. (1997). Are there nontrivial constraints on colour categorization? *Behavioral and Brain Sciences*, 20, 167–228.
- Thomas, L. L., Curtis, A. J. & Bolton, R. (1978). Sex differences in elicited color lexicon size. *Perceptual and Motor Skills*, 47, 77–78.

- Thompson, E., Palacios, A. & Varela, F. J. (1992). Ways of coloring: Comparative color vision as a case study for cognitive science. *Behavioral and Brain Sciences*, *15*, 1–74.
- Thompson, E. (1995). *Colour Vision: A study in cognitive science and the philosophy of perception*. Routledge: London & New York.
- Uchikawa, K. & Boynton, R.M. (1987). Categorical color perception of Japanese observers: Comparison with that of Americans. *Vision Research*, *27*, 1825–1833.
- Weller, S. (1987). Shared Knowledge, Intracultural Variation and Knowledge Aggregation. *American Behavioral Scientist*, *31*(2), 178–193.
- Whorf, B. L. (1956). Science and linguistics. In *Language, Thought and Reality*. J. B. Carroll (Ed.). Cambridge, MA.
- Winderickx, J., Lindsey, D. T., Sanocki, E., Teller, D. Y., Motulsky, A. G., & Deeb, S. S. (1992). Polymorphism in red photopigment underlies variation in color matching. *Nature*, *356*, 431–433.
- Wyszecki, G. & Stiles, W. (2000). *Color Science: Concepts and Methods, Quantitative Data and Formulas (Third Edition)*. New York: Wiley.
- Yendrikhovskij, S. N. (2001). A computational model of colour categorization. *COLOR Research and Application, supplement*, *26*, s235–s238.
- Young, F. W. (1975). Scaling replicated conditional rank-order data. *Sociological Methodology*, *6*, 129–170.
- Zaidi, Q. (2001). Is there a perceptual color space? Book Review of *Geometrical Representations of Perceptual Phenomena*, (1995). R. D. Luce, M. D’Zmura, D. Hoffman, G. J. Iverson, & A. K. Romney (Ed.s). *COLOR Research and Application*, *26*, 325–328.