6 Insights gained from naming the OSA colors

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Introduction

By the time the year 1985 rolled around, I had already been working in the realm of color vision for thirty years, with a clear focus on the psychophysiological aspects of adult human vision – the kinds of phenomena for which a genetic basis seems likely, and for which individual differences are minor. That is, I deliberately avoided working on developmental or comparative aspects of color vision, and with some exceptions I also tried to steer clear of cognitive complications. In most of my experiments, usually carried out in collaboration with graduate students or postdoctoral fellows, we used noninvasive psychophysical techniques and human subjects. (For a while I was inserting microelectrodes into monkey eyes as well.) For many years I never suspected that linguists or anthropologists had any interest in the fundamental aspects of color vision, although I was familiar with (and, I must say, unimpressed by) the Whorfian hypothesis, and it was my understanding that anthropologists considered that the naming of colors was an arbitrary affair, fully under the control of cultural influences. Perhaps most vision scientists felt that way too, because, compared to threshold measurements and matching procedures, color naming was not considered to be a very respectable psychophysical technique for getting at the fundamental aspects of color perception.

I first became aware of Berlin and Kay's *Basic Color Terms* (1969) when the monograph was mentioned in a 1973 *Annual Review of Psychology* article (Trandis, Malpass, and Davidson 1973). The account intrigued me and so, for purposes of recreational reading, I borrowed the book from the UCSD library. I found the book fascinating and delightfully easy to read. Although it was clear to me that the experimental portions of the study would not pass muster if judged according to the standards upon which experimental psychologists insist, I was somehow convinced that the major conclusions reached by Berlin and Kay were probably correct.

Despite the large number of people who have been inspired by this slim book, it has not been of much interest to most color-vision researchers with my kind of pedigree. A significant exception is Floyd Ratliff, who sent me an unsolicited copy of his 1976 review article (Ratliff 1976) published in the *Proceedings of the American Philosophical Society*. Floyd and I are old friends. We were graduate students together in Lorrin Riggs's laboratory in the Department of Psychology at Brown University around 1950. Floyd subsequently made an enormous reputation for himself in the area of spatial vision, working initially with Keffer Hartline, who had been the first person to record single-unit neural activity in any visual system. The experimental animal from which they recorded, the lowly horseshoe crab *Limulus*, does not possess any form of color vision. However, Ratliff's interests are much broader than his published experimental work might suggest, and color has been of more than passing interest for him, particularly as it relates to his deep concern with representational painting. Floyd told me recently that the Berlin and Kay monograph was also the launching pad for his interest in basic color terms, and that after he read it, he immediately began to think about the relevant underlying visual physiology. When invited to give a lecture to the American Philosophical Society, of which he is a member, he spoke on the psychophysiological basis of universal color terms, which led to his excellent paper in their journal. (Recently, Ratliff's interests in color and art have been brought together in a book [Ratliff 1992] entitled *Paul Signac and Color in Neo-Impressionism*.)

Orange and the spectral colors

Many years ago, Charles Sternheim and I published a study (Sternheim and Boynton 1966) in which we examined the color naming of monochromatic lights, from which we concluded that the category orange was unnecessary for rating the appearance of long-wavelength spectral lights, although both red and yellow categories were essential for this purpose. To my knowledge, neither the logic of our study nor the conclusion we reached has ever been challenged, and the method we developed has been employed by Fuld, Wooten, and Whalen (1981) to ask the same question about purple, with the same result. Therefore, when I learned of the Berlin and Kay work, it seemed odd to me that orange, which so obviously contains both red and yellow coextensively, could be a basic color. Obviously, this has been a source of concern for others, as is reflected, for example, by the division of chromatic basic color terms into primary and derived groups, as proposed by Kay and McDaniel (1978).

Color naming by colorblind subjects

Horst Scheibner and I (1968) used a color-naming procedure to examine the behavior of classical dichromats (the red–green colorblind) and we were able to show, for example, that the probability of their using the name "red" increased with wavelength for equally bright monochromatic lights, whereas all of these should have appeared identical according to accepted accounts of red–green color deficiency. This led us to conclude that a weak residual red–green chromatic system was retained in most dichromats. Few believed our conclusion at first, but our interpretation has since been verified using other methods and other investigators, including two participants in the Asilomar conference (Abramov [Gordon and Abramov 1977] and Wooten [Fuld *et al.* 1981]) who have done excellent work using color-naming procedures similar to ours. As already noted, it was unusual for visual scientists of my ilk to use color-naming procedures when we began our studies. Although this early work may not bear directly on issues related to basic color terms, I mention it here because it helps to explain why, after having my curiosity piqued by reading the Berlin and Kay book, I was eventually motivated to do color-naming experiments related to their conclusions.

Color-naming experiments at University of California San Diego

Background

Prior to 1975, I had never worked with surface colors. For the most part we had used monochromatic stimuli delivered by Maxwellian view, a method that provides isolated ethereal lights that appear suspended in space and utterly devoid of any object properties even when a second channel provides a surround. As we all know, the real world of color depends importantly upon the nature of surfaces as these selectively absorb and reflect the spectral components of incident light, and the difference between the appearances of aperture and surface colors is so great that making color matches between them is virtually impossible.

Neither Berlin and Kay, nor most of those who have used a similar methodology, seem to have been concerned with the nature of the light illuminating their materials, or the possible problems introduced by chromatic context. The mechanisms of color constancy work so well that, within limits, the intensity and spectral distribution of the light used to illuminate the experimental materials make surprisingly little difference. Yet it seemed to me that these variables should be better controlled, there being no reason for them not to be if one is working in the laboratory, rather than out in the field somewhere. Contextual problems relate to the well-established fact that the chromatic appearance of any given part of the visual field depends not only upon the physical properties of the light coming from it, but also upon the surround. Therefore a focal green, say, that an informant might select from the Berlin and Kay ordered array may well be a different sample than the one that would be selected if the samples appeared in pairs, or sequentially in isolation. Berlin and Kay tended to choose the color terms to be examined a priori, rather than allowing each subject to make an independent selection, and we wished to avoid this. Other variables, including viewing time, response time, and the exact distance between the observer and the experimental materials also had not been fully controlled. So I decided to design a study to remedy these possible deficiencies (Boynton and Olson 1987, 1990).

Choice of stimuli: the OSA set

The first decision that we had to make concerned the choice of color samples. It would be possible in principle to create a set of 1 million color chips, no two of which would match if viewed side by side under good viewing conditions. There would be about 500 billion possible nonmatching pairs that could be drawn from such a set. This observation is testimony both to the exquisite sensitivity of the human visual system to small color differences, and to the impossibility of using a separate name to communicate about each discriminable color. It also means that the researcher working with a palpable set of color chips must deal with a severely restricted subset of the million or so discriminably different colors that potentially could be used, and it may well matter which set is selected for experimental purposes. I did not favor the set of Munsell colors used by Berlin and Kay. By avoiding the use of all but the most saturated chromatic colors in the set, Berlin and Kay kept the number of colors within reasonable bounds, but otherwise I could see no logical reason for doing this. Also, the cylindrical arrangement of specimens in the Munsell system guarantees that the perceptual distance between adjacent colors must vary markedly from one region to another, meaning that calculations of distances between colors in this space, which some people have done, are not very meaningful.

Ten years prior to the start of our research, the Optical Society of America had made available a new set of color chips, called the OSA Uniform Color Scales Samples (Nickerson 1981). The committee that developed this, which had supervised the relevant psychophysical observations that went into it, was attempting to produce an ordered set of colors that would sample three-dimensional color space with the requirement that the perceptual distance between each color and its nearest neighbors would be constant throughout the metric of that space. If this could be achieved, it would furnish equally spaced specimens in an isotropic color space, within which a linear distance would imply the same number of just-noticeable color steps regardless of the starting point or the direction traversed. It cannot be claimed that the final product met this criterion exactly, nor that it is even possible to achieve it exactly in Euclidean space, but it can be claimed that the OSA colors come closer to meeting this objective than do any of the other sets of color chips.

There are 424 color samples in the OSA system, in which the central axis runs from near black at the bottom through grey to near-white at the top (see Figure 6.1). The two chromatic axes, orthogonal to one another and to the achromatic axis, are very roughly red–green and yellow–blue. The middle grey of the set is called 0,0,0, and the others are designated plus or minus as one moves outward, upward, or downward along the three dimensions.

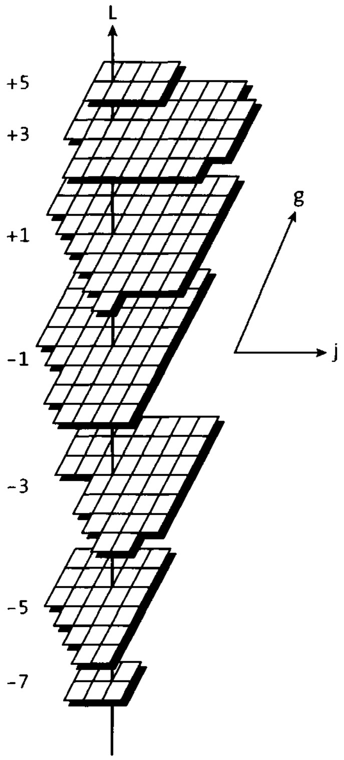

Figure 6.1 Arrangement of the OSA colors. The lightness axis "L" runs from near-black at the bottom to near-white at the top, with a neutral gray sample at each of the even-numbered lightness levels, which have been left off the diagram for clarity. At each lightness level, there are 2 chromatic axes, labeled "j" and "g", which are perpendicular to each other and to the lightness axis. Each of the 424 color chips of the system is intended to be equidistant from its 12 nearest neighbors.

Because of an interest in the relation between color discrimination and color order as these relate to color naming, I chose the OSA colors for our investigation despite knowing that doing so would complicate comparisons of our results with those of previous investigators. (Later we [Boynton, MacLaury, and Uchikawa 1989] would specify the matching samples of the OSA and Berlin–Kay Munsell sets of color chips.)

Experimental procedures

Our experimental setup was the following. The subject sat in a booth painted inside with a spectrally flat grey paint matching Munsell #5. An aperture on a slanted grey table, into which color samples could be slid from behind, was covered most of the time with a grey shutter blade. Lighting was provided indirectly by a single photoflood lamp, which produced a luminance of 40 cd/m^2 of the background grey at

3,000 K. The specular component of reflectance was negligible. Subjects were instructed to be prepared on signal to expect the shutter to open, exposing a uniform square of color. They were told to name each color using a single color term ("no modifiers or compounds are allowed") and to do so within 5 seconds. They were instructed that if they used an incorrect compound name, or delayed their response beyond the 5-second limit, they would be informed of their error and the trial would have to be repeated later, which would prolong the experimental session. These errors very seldom occurred, and no further mention of speed was made to induce time pressure. Unknown to the subjects, we recorded their response times, but we wanted the data to reflect what came naturally, rather than what they might be able to do in a hair-trigger reaction-time situation.

The experimental design was very simple. For each subject, a random order of the 424 color samples was determined. The colors were individually presented in this sequence, and the elicited names and response times were recorded for later analysis. At this point the subject's job was half completed. We continued by presenting the samples again, this time in the reverse of the initial random order. To control for possible sequential effects, each subject had his or her own random order. Our data set for each subject then consisted of 848 monolexemic color terms – 2 for each of the 424 samples, and the response times for each. Usually about 4 experimental sessions of an hour or more were needed to obtain these data.

Results: use of basic color terms

All subjects, including the dichromats, used all eight basic chromatic color terms. (There are only poor examples of white and black in the OSA set of colors, and some dichromats also avoided gray [Montag and Boynton 1987].) There was no non-basic color term that was used by all subjects. The frequency of use of non-basic color terms was wildly idiosyncratic: we have had subjects who used as few as four, and others who used more than fifty. We examined the consistency of color usage, which relates to the probability that a color name, if used by a given subject on the first presentation, will be used again on the second one. No overlap was found for mean data between basic and non-basic color terms; that is, all basic color terms were used more consistently than

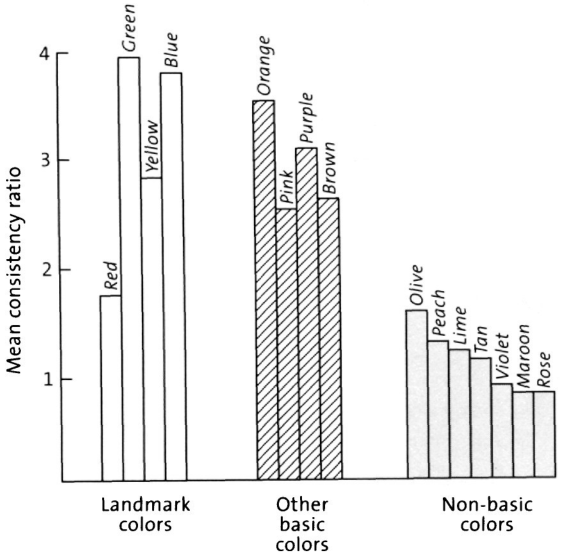

Figure 6.2 Consistency of color naming. The ordinate shows the ratio of consistent to inconsistent color naming when each of the color terms is used. The most consistently used non-basic colors are shown at the right, and the basic colors (left and center) are separated into the fundamental (landmark) and derived (other) categories. All basic colors are used more consistently than any of the non-basic ones.

any non-basic term. Moreover, the results for basic color terms were about the same for fundamental and derived basic colors. We also looked for consensus of color naming across subjects. Again, there was greater consensus for the use of all basic color terms than for any of the non-basic ones. There are some non-basic terms used by most adult subjects, such as peach, tan, and olive, but none of these was used by all of them. By contrast, we found that all color-normal adult subjects use all basic color terms. We examined one American two-year-old and two four-year-olds, one of them a Japanese child. (Only the Japanese four-year-old would tolerate the booth; the others were tested with Munsell colors lent by MacLaury.) Except for the use of the word "peach" on three occasions by the American four-year-old, and the word *mizu* (light blue) by the Japanese one, only basic color terms were used. Both four-year-olds used all of the basic color terms of their respective languages. The two-year-old never called any of the chips brown or red, although he was already fully capable of describing the colors of natural objects using these words (Boynton, *et al.* 1989).

Centroids of basic colors in the OSA space

We proceeded to examine the arrangement of basic colors in the OSA space. To do this, we calculated, both for individual and group data, the centroid location of each color. This is simply the average, across trials, for each of the three coordinate values of the color samples that elicited that color name, weighted according to the number of times it was used. Again I emphasize that such a calculation only makes sense for an isotropic space. The proper way to think about these centroids, and the color space in which they are imbedded, is the following. Take yellow as an example. The centroid is the middle of the region of color space in which the term "yellow" is used. It is not quite the same as the focal yellow, which is a bit more saturated, but it is in the region where the probability of the name "yellow" being used is greatest. The probability of any other basic color term being used in this mid-region approaches zero. Although very definite at its focus, the yellow region represents a fuzzy subset of all color chips that might be called "yellow," because the region overall lacks sharp edges. Instead, the probability of the name "yellow" being used decreases as one moves away from the middle of the region, and other basic color names begin to creep in, along with an increased use of non-basic terms. Approximately midway between the yellow and green centroid locations, for example, the two names are used with roughly equal frequency to name samples that appear coextensively yellow and green.

Need for bridges between certain basic colors.

With a few exceptions that mostly involve brown and grey, we found that the basic colors whose fuzzy sets overlap have centroids that plot less than 7.5 OSA units apart, whereas centroids for regions whose sets do not overlap are separated by distances greater than this. A very significant observation is that the red and yellow regions do not overlap at all. That is, there are no samples that are called red on one occasion and yellow on another, whereas red and orange, and yellow and orange, are frequently linked in this sense. Orange is therefore an essential bridge between red and yellow, just as yellow is an essential bridge between orange and green. This is surprising because of the derived nature of orange in contrast with the unique character of yellow: colors intermediate between red and yellow are seen as containing components of both, whereas yellow, when acting as the bridge between orange and green, does not seem to contain components of either. A bridge is also needed between red and blue.

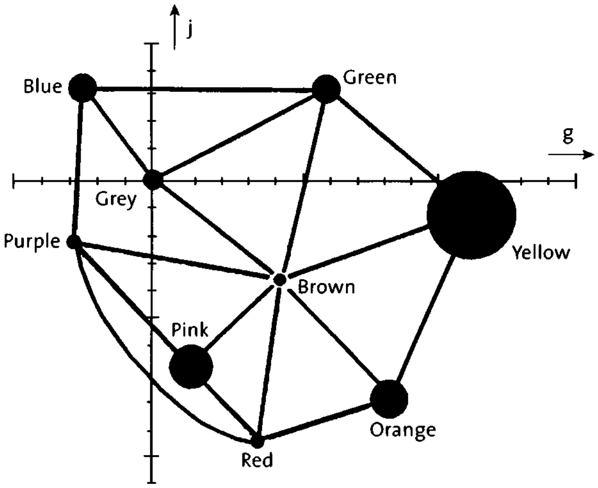

Figure 6.3 Linkages. Basic colors are said to be "linked" when there are intervening color chips that are sometimes named with one of the basic color terms, and sometimes with the other one. Connectors are shown between the centroid locations of colors linked in this sense. Note that there are no linkages between red and yellow, or between red and blue. In this diagram, the larger spheres should be visualized as being closer to the observer, representing lighter colors.

Despite their non-elementary nature, the so-called derived basic colors, in addition to meeting the criteria of consistency and consensus (and, as we will see below, short response times), serve essential bridging functions and are equally as essential for filling the basic color space as are the primary ones. (We speak of two colors as being linked or unlinked, depending upon whether or not a bridge color is necessary to move between them.) Figure 6.3 attempts to summarize the locations of and linkages among the basic colors. The lightness dimension is encoded by the size of the symbols.

No basic color exists between green and its nearest chromatic neighbors, blue and yellow, which are much closer to green than red is to yellow. There is no suggestion that a new basic color term representing a blue-green or yellow-green is needed or is likely to evolve. GRUE could describe an early cognitive stage for the two linked primary basic colors green and blue. A single term for the yellow–green region is similarly possible. Single categories embracing red and yellow, or red and blue, seem unlikely because their separation is too great, although red–orange–yellow and red–purple–blue would seem to be likely possibilities because they include the necessary bridges.

A missing basic color?

Our use of desaturated colors, as well as saturated ones, leads to an interesting result near the middle of the color space. Here there is a region, variously called "peach," "tan," and by other non-basic names (including *hada* by our Japanese subjects [Uchikawa and Boynton 1987]) that is much more than 7.5 OSA units across in any direction between flanking basic-color centroids. The one sample of the 424 which is the most difficult to name is located near the middle of this region. Basic color terms are seldom used to identify this sample and, to a progressively lesser extent, its neighbors. Response times are long; consensus and consistency are poor. This situation suggests that another basic color *ought* to exist in this region, but that for some reason it does not. If another emergent basic color sensation were to evolve, I think it ought to have its centroid here, but any physiological basis for it is apparently lacking, and it is difficult to imagine the new chromatic sensation that would elicit the use of a new basic color term for its description.

Response times

As already noted, we examined response times for the use of basic color terms in comparison with those for non-basic terms. In their 1981 review article concerned with the categorization of natural objects, Mervis and Rosch (1981: 96) conclude that: "Response times are shorter for verification of the category membership of representative exemplars than nonrepresentative exemplars; these effects are robust and appear in a variety of experimental paradigms."

In Figure 6.4, the color names are again divided into three groups. The primary basic colors are at the left, the other derived or secondary basic colors are shown in the middle, and data for the six most popular non-basic colors are shown at the right. This chart, like the one for consistency in Figure 6.2, again illustrates the lack of overlap between data for basic versus non-basic colors, with all non-basic color names being used more slowly, and by the criterion of response time also there is no difference between the primary, or landmark, basic colors and the other basic colors.

Lightness locations of basic colors

It is very important not to overlook the importance of the lightness dimension in the arrangement of color centroids, because centroids alone cannot tell the full story about the shapes of the fuzzy sets they

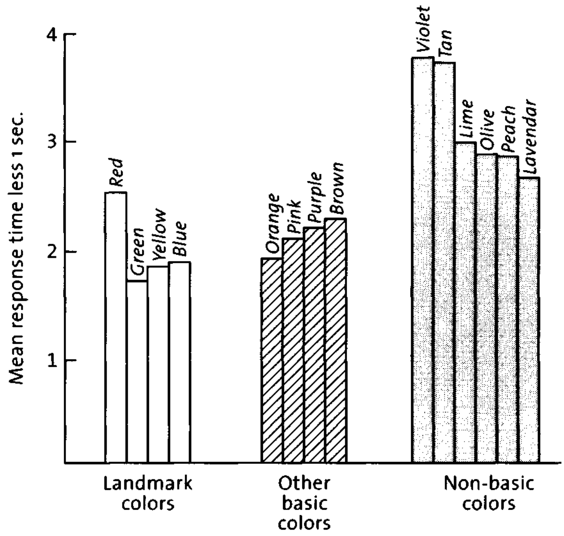

Figure 6.4 Response times. The ordinate shows the mean response time for the use of the color names depicted on the bars. Note that one second has been subtracted from the response times; this is approximately the shortest response time recorded for any individual color sample. The groupings are the same as in Figure 6.2.

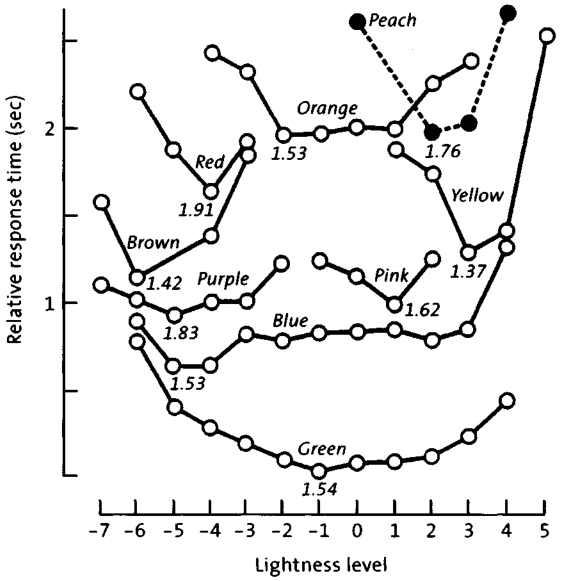

Figure 6.5 Lightness ranges. For each of the curves and at each lightness level, the shortest mean response time recorded (nine subjects combined) at that level is plotted. Where no points are plotted, the indicated color name was very seldom, if ever, employed. The plots show the range over which the basic color terms are used, and the minima of the plotted functions can be taken to indicate, by this criterion, the lightness levels for the best exemplars. The curves have been displaced arbitrarily in the vertical direction. Minimum response times are indicated for each color.

represent. Of all the plots we have created to represent our results, Figure 6.5 is my favorite. Each curve shows the shortest response time for any color sample used in each of the categories of chromatic basic color naming, plotted as a function of lightness level. There are points on a given curve only for lightness levels at which that color name was used at least ten times by the nine subjects included in the analysis, so for all practical purposes each name was used only over the range plotted. (Note that the separate curves have been arbitrarily displaced vertically from one another.) These curves summarize the important facts about basic colors as a function of lightness level, which are the following:

(a) Unlike the other colors, green and blue are seen at virtually all lightness levels. The darker blues appear to be slightly more prototypical, yielding the shortest response times. The best greens are seen at the middle lightness levels.

(b) Red, brown, and purple are reported only at the lower lightness levels. Optimal brown is the darkest, followed by purple and then red.

(c) Next to blue and green, the use of orange covers the broadest range of lightnesses, optimally so at intermediate levels. The lightness of the best pink is intermediate between those for the best orange and the best yellow.

It is interesting to speculate concerning why the centroid locations of the basic colors are where they are. Looking down on the array from the top, and ignoring the achromatic spindle, it is clear that each centroid occupies a unique location when projected to the chromatic plane. This is not surprising because it reflects the relative excitations of the L-, M-, and S-cones of the visual system which are fundamental to chromatic variation. However, the important proviso must be added that there is no chromatic plane at any lightness level that includes all of the basic colors. Yellow, orange, and pink simply do not exist at the lower levels, and purple, brown, and red are absent at the lighter ones. Brown requires a lighter surround for its very existence. The low-lightness position of the centroid for red, unlike that for brown, is dependent instead upon the nature of reflecting pigments. To get a good red, all but the longest wavelengths of incident white light must be absorbed. The remaining long wavelengths are ones to which the eye is relatively insensitive, and it is for this reason alone that the red centroid plots at low lightness. A source that emits long-wavelength light and which appears red does not lose its redness at high brightness levels, even without any surround (as we all know from our experience with red stop lights at night). Brown signal lights, on the other hand, are impossible to produce, even though brown is as useful as any other basic color for coding purposes in reflecting displays.

Some other color-naming studies at San Diego

We have used our color-naming method to examine a number of other areas that I have not mentioned because they do not bear directly on the issues under discussion in this volume. These include the color rendering of light sources (Boynton and Purl 1989; Boynton, Fargo, and Collins 1990), color memory (Boynton, Fargo, Olson, and Smallman 1989), the influence of surrounds (Uchikawa, Uchikawa, and Boynton 1989a), color constancy (Uchikawa, Uchikawa, and Boynton 1989b), and the role of basic colors in visual search (Smallman and Boynton 1990).

Final remarks

In thinking about basic colors, as these relate to the kinds of concerns that seem to motivate anthropologists, I would suggest that it would be much more useful to consider our color space than to refer to opponent-color diagrams, and that one should accept our conclusion that there are no differences between primary and derived basic colors except for the compound sensory aspect of the latter, which really does not seem to matter. I would argue that all eleven basic colors are perceptual fundamentals, and that the concept of fundamental neural responses, as defined by Kay, Berlin, and Merrifield (1991), should be expanded to include all eleven. Their appeal to the early research of DeValois and his 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 units (see Boynton 1979: 234–236).

We simply do not yet know what kind of activity in the brain generates our color sensations. I feel it reasonable to suppose that there may be eleven categorically separate varieties of activity, corresponding to each of eleven kinds of color sensations that are identified by the eleven basic color terms. It might be productive, I think, to consider these as the pan-human perceptual fundamentals, and to keep their fuzzy-set locations in mind when speculating about the cultural evolution of basic color terms. I also feel hopeful that physiologists or physiological psychologists may eventually find the basis in the brain for the eleven basic color sensations. Some progress in this regard has been made by Yoshioka, Dow, and Vautin (1996).

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References

Berlin, B., and P. Kay 1969. *Basic Color Terms: Their Universality and Evolution*. Berkeley: University of California Press. 1st paperback edn. 1991, with bibliography by Luisa Maffi.

Boynton, R. M. 1979. *Human Color Vision*. New York: Holt, Rinehart, and Winston.

Boynton, R. M. and C. X. Olson 1987. Locating basic colors in the OSA space. *Color Research and Application* 12(2): 94–105.

1990. Salience of chromatic basic color terms confirmed by three measures. *Vision Research* 30(9): 1311–1317.

Boynton, R.M., and K. F. Purl 1989. Categorical color perception under low-pressure sodium lighting with small amounts of added incandescent illumination. *Lighting Research and Technology* 21: 23–27.

Boynton, R. M., L. Fargo, and B. L. Collins 1990. Categorical color rendering of four common light sources. *Color Research and Application* 165: 222–230.

Boynton, R. M., R. E. MacLaury, and K. Uchikawa 1989. Centroids of color categories compared by two methods. *Color Research and Application* 14: 6–15.

Boynton, R. M., L. Fargo, C. X. Olson, and H. Smallman 1989. Categorical effects in color memory. *Color Research and Application* 14: 229–234.

Fuld, K., B. R. Wooten, and J. J. Whalen 1981. The elemental hues of short-wave and extraspectral lights. *Perception and Psychophysics* 29(4): 317–322.

Gordon, J., and I. Abramov 1977. Color vision in the peripheral retina II. Hue and saturation. *Journal of the Optical Society of America* 67: 202–207.

Kay, P., and C. K. McDaniel 1978. The linguistic significance of the meanings of basic color terms. *Language* 54(3): 610–646.

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

Mervis, C. B., and E. Rosch 1981. Categorization of natural objects. *Annual Review of Psychology* 32: 89–115.

Montag, E., and R. M Boynton 1987. Rod influence in dichromatic surface color perception. *Vision Research* 27: 2153–2162.

Nickerson, D. 1981. OSA color scale samples: a unique set. *Color Research and Application* 6: 7–33.

Ratliff, F. 1976. On the psychophysiological basis of universal color terms. *Proceedings of the American Philosophical Society* 120(5): 311–330.

1992. *Paul Signac and Color in Neo-Impressionism*. New York: Rockefeller University Press.

Scheibner, H. M. O., and R. M. Boynton 1968. Residual red–green discrimination in dichromats. *Journal of the Optical Society of America* 58: 1151–1158.

Smallman, H. S. and R. M. Boynton 1990. Segregation of ten basic colors in an information display. *Journal of the Optical Society of America A* 7(10): 1985–1994.

Sternheim, C. E., and R. M. Boynton 1966. Uniqueness of perceived hues investigated with a continuous judgmental technique. *Journal of Experimental Psychology* 72(5): 770–776.

Trandis, H. C., R. S. Malpass, and A. R. Davidson 1973. Psychology and culture. *Annual Review of Psychology* 24: 355–378.

Uchikawa, K., and R. M. Boynton 1987. Categorical color perception of Japanese observers: comparison with that of Americans. *Vision Research* 27(10): 1825–1833.

Uchikawa, H., K. Uchikawa, and R. M. Boynton 1989a. Influence of achromatic surrounds on categorical perception of surface colors. *Vision Research* 29: 881–890.

1989b. Partial color constancy of isolated surface colors examined by a color naming method. *Perception* 18: 83–91.

Yoshioka, T., B. M. Dow, and R. G. Vautin 1996. Neuronal mechanisms of color categorization in areas V1, V2, and V4 of Macaque monkey cortex. *Behavioural Brain Research*. 76: 51–70.