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Individual and Population Differences in Focal Colors

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RUNNING HEAD: Individual and Population Differences in Focal Colors

Introduction

Perhaps the central problem in understanding color appearance is that the only available measures are subjective. Much is now known about the neural mechanisms underlying the early encoding of color information in the human visual system, yet few clear links have been identified between these mechanisms and the perceptual organization of color experience. [For recent reviews see (Gegenfurtner & Sharpe, 1999; Mausfeld & Heyer, 2003)]. Without an objective test for “red”, studies of color appearance have instead had to rely on characterizing how observers describe the stimulus, and this has left open the debate of whether these descriptions reflect the characteristics of perceptual or linguistic processes. Arguments in this debate have hinged largely on the question of whether different individuals label spectral stimuli in similar or different ways. Comparisons of color naming across languages point to a remarkably consistent structure of color categories (Berlin & Kay, 1969; Kay & Regier, 2003). Though exceptions and counter-arguments have been noted by a number of authors (Davidoff, 2001; Davidoff et al., 1999; Gage, 1993; Jameson & D'Andrade, 1997; Lucy, 1997; Lyons, 1995; Roberson et al., 2002; Saunders & van Brakel, 1997), the observed similarities have been taken by many as strong evidence for universal tendencies in color experience that are shaped by common perceptual processes (Chapanis, 1965; Ratliff, 1976; Kay & McDaniel, 1978; Hardin, 1988; Boynton & Olson, 1990; Shepard, 1992; Kaiser

& Boynton, 1996). Yet within-language studies of color naming, and in particular of the loci of perceptually pure or unique hues, have also shown that these can vary widely from one individual to another within a given population (Kuehni, 2004), and this suggests that something about the underlying processes is highly labile. In this chapter we examine the potential sources and nature of inter-individual and inter-language variability and what these mean for the notion of universal color categories. While individual differences have been taken by some as evidence for linguistic relativity (Saunders & van Brakel, 1997), we argue that they instead suggest that the vagaries of particular languages may often place only a weak constraint on color categories, and that the factors that underlie inter-language differences may themselves show strong universal tendencies.

The World Color Survey

Berlin and Kay (1969) advanced a hypothesis of universals in cross-language color naming in a study that compared color naming across 20 languages. Naming was assessed by asking individuals to label the colors they saw in a palette of Munsell chips that varied in hue and lightness (Munsell Value) at a high saturation (Munsell Chroma; see Figure 1A). The chips chosen as the best examples of color terms by speakers of these languages were also

elicited; these clustered in small regions of the palette, leading to the proposal that color categories are similar across languages and are restricted to a set of 11 basic terms. The primary difference found among languages was in the number of basic color terms, and these varied in a consistent pattern: languages with the same number of terms tended to have terms of similar denotation. The resulting typology of basic color term systems formed an implicational hierarchy, which in turn suggested that color terms are added to the lexicon in a strongly constrained order. These results were taken to imply a strongly universal pattern in color naming.

Since Berlin and Kay (1969) there has been a large number of studies arguing both for and against the notion of color universals (see, e.g., the papers in Hardin & Maffi, 1997). Criticisms of the 1969 study included the points that in most cases only one speaker was tested for each language, that these speakers also spoke English and were living in the US, and that the languages were mostly restricted to written languages of industrialized societies. Thus the similarities in color naming might have resulted from the shared history and similar experiences of the speakers and not been representative of the world's languages. The World Color Survey (WCS) was in part undertaken to address these concerns, by collecting color naming data for a much larger sample of languages and speakers (Kay et al., 1997). The data, which are now available online at <http://www.icsi.berkeley.edu/wcs/data.html>, include color naming and focal (best example) responses for 110 unwritten languages, with an average of

24 speakers per language. The respondents were the most monolingual persons obtainable in the communities studied and were tested in their own languages and in their local communities. The 110 WCS languages represent 45 different language families (see Kay & Regier, 2003, p. 9087 for the list).

Recently, Kay and Regier (2003) analyzed the WCS data to evaluate whether the terms of different languages cluster in similar ways, that is, to perform explicit statistical tests on the evident, but primarily impressionistic, clustering observed by Berlin and Kay in a smaller sample of languages. For each speaker they calculated the centroid (i.e., the average value on each dimension) of the set of chips that were labeled with each term (after transforming the Munsell coordinates of the stimulus chips into the CIE $L^*a^*b^*$ uniform color space). Figure 1 reproduces from their paper the resulting contour plot of these centroids, which also shows the location of the corresponding naming centroids for English terms (Sturges & Whitfield, 1995). The English centroids fall at or near the peaks of the naming centroid distribution for the WCS languages. Moreover, the relatively small discrepancies between the English naming centroids and the WCS centroids are plausibly explained by the fact that English has separate terms for red, orange, yellow, green, and blue, while most WCS languages have a single term covering green and blue and also a single term covering orange and yellow. One would expect the naming centroid for a 'grue' term to fall between the centroids for separate green and blue terms (as may be observed in Figure 1).

For the same reason one would expect the centroid for a term spanning yellow and orange to fall somewhere between the centroids for distinct yellow and orange terms. (as may also be observed in Figure 1). Kay and Regier also show statistically that significantly more of the WCS speaker centroids fell on the chips representing the English foci than on the remaining chips in the palette.

Insert Figure 1 here

To test whether the centroids for different WCS languages tend to cluster, Kay and Regier first calculated the distance D between each term centroid in the WCS and the closest term centroid in each other WCS language and summed these distances. Intuitively, the smaller the value of D the greater the clustering in the WCS dataset. To perform a Monte Carlo test of the D statistic, they then created hypothetical WCS datasets by taking each WCS language, as represented by its term centroids in CIEL*a*b* space, and rotated the data for the language in the hue dimension by a randomly selected angle – the same angle for each term in a language and a different angle for each language. The D statistic was then calculated for each of the 1,000 hypothetical WCS datasets. The value of D in the actual WCS dataset was found to be lower than the lowest D value of any of the 1,000 hypothetical WCS-like datasets. This Monte Carlo test established that the WCS naming centroids are significantly clustered in color space, with $p < .001$. A similar Monte Carlo analysis showed that the WCS clusters are in fact similar to the locations for the original Berlin and Kay terms ($p < .001$), demonstrating that the clusters of

avored colors in unwritten languages of low-technology societies are close to the favored colors of the written languages of high-technology societies. On the whole, these results demonstrate that different languages tend to parse color space similarly and that written languages, including English, are not exceptional in this regard.

Individual differences in color naming

In their 1969 study Berlin and Kay also drew attention to the large individual differences within a language. In particular, they noted that the focal colors for corresponding terms from speakers of the different languages they tested were more similar than were the foci obtained in a separate study of 40 respondents from a single language (the Mayan language Tzeltal). Individual differences like these have been extensively investigated in psychophysical studies of color appearance. Most of this work has concentrated on the unique hues – the stimuli that are perceived as pure red, green, blue, or yellow, and which are assumed to represent landmarks of color coding in many models of human color vision (De Valois & De Valois, 1993; Hurvich & Jameson, 1957; Kaiser & Boynton, 1996). The loci for these hues can differ dramatically from one person to the next (Jordan & Mollon, 1995; Kuehni, 2004; Pridmore, 1999; Scheffrin & Werner, 1990; Volbrecht et al., 1997). For example, the wavelength

that observers select as unique green can vary by up to 80 nm between subjects, that is, over a quarter of the visible spectrum. Comparable differences are also large for the broader spectra characteristic of natural color signals (Kuehni, 2001; Webster et al., 2000), and thus do not simply reflect observers' inexperience with monochromatic lights. For example, Figure 2 plots the distribution in a cone-response space of hue angles chosen as unique red, green, blue or yellow for moderately saturated stimuli for 51 color-normal observers (Webster et al., 2000). The settings for unique green span a range of 60 degs, and thus include a large fraction of the color circle, and this range remains large (~45 deg) even when the settings are restricted only to the subset of subjects who set the unique hues reliably. For the remaining hues the variation is less, but still striking, in the sense that what some English speakers would call a pure yellow will be described as clearly too reddish or too greenish by others. Similar variations in perceived hue and lightness are also found for intermediate or binary hues such as orange and purple (Malkoc et al., 2002). In this chapter we consider possible sources of this variation and how it influences the focal colors measured both within and between different populations of observers.

Insert Figure 2 here

Before exploring this question, it is worth pausing to note the location of the stimuli that observers select for unique hues. In Figure 2 these loci are

plotted by their coordinates within a color plane whose two dimensions correspond to the two color-opponent axes that characterize color coding at early post-receptoral stages of the visual system (Derrington et al., 1984; MacLeod & Boynton, 1979). While reds tend to cluster around one of these axes, the remaining hues fall at intermediate angles in the space (Krauskopf *et al.*, 1982). It is in fact this discrepancy – between the axes defined by the subjective unique hues versus the axes defined by psychophysical and physiological measures of chromatic sensitivity – which is at the heart of the explanatory gap between the neural and phenomenological organization of color vision, a point which has been made previously with specific regard to basic color terms (Jameson & D'Andrade, 1997). That is, the stimuli that are thought to isolate pure chromatic sensations are not the stimuli that isolate the cardinal chromatic axes of early color vision, nor do the known transformations of color signals in visual cortex suggest that the unique hues are special (Lennie et al., 1990). Yet these hue sensations seem special in the phenomenological experience of color (at least to most color scientists).

Sources of variation in normal color vision

The bases for the prominent individual differences in color appearance remain unknown, and controversial. This is not surprising, because again it has not been possible to link the hue sensations to independently identifiable processes in the visual system. Speculations about the sources of normal variation include differences in the physiology, visual environment, and cultural environment of individuals. We consider each of these factors in turn, though it should be emphasized that they are frequently not separable. For example, the colors in an observer's environment are shaped by how color is used by the observer's culture, and physiological differences between observers (e.g., in how strongly their lens filters the light) depend both on their environment and their particular exposure to it (Werner, 2000). It is important to note also that to the extent that any of these factors affect differences in color appearance, they are also important for understanding the similarities or universal tendencies in color naming. For example, if differences in physiology or environment are capable of causing differences in color naming, then uniformities in color naming imply uniformities in the color-relevant aspects of physiology or environment.

Physiological differences

Differences in chromatic sensitivity among individuals with normal color vision are large. Most of these differences have been characterized at the level of the retina and the optics of the ocular media (the substructures of the eye, such as the lens, which physically affect the light striking the retina), though there is no reason to expect that important differences do not occur throughout the visual pathway. The light reaching the photoreceptors is filtered by inert screening pigments in the lens and, around the fovea (where vision is best), by the macular pigment. Both these media selectively absorb at shorter wavelengths, reducing the intensity of “blue” light available at the receptors. Individual differences in lens and macular density are pronounced (Bone & Sparrock, 1971; Van Norren & Vos, 1974; Werner, 1996), and are a primary source of normal variation in color matching (Webster & MacLeod, 1988). The spectral sensitivity of the photoreceptors can also vary in the wavelength of peak sensitivity because of polymorphisms in the genes encoding the pigments (Sharpe et al., 1999), and can vary in bandwidth because of differences in pigment density (Smith et al., 1976). Jameson et al. (2001), using a novel procedure, reported that the color experience of women who may possess more than three retinal photopigments by virtue of X-chromosome-inherited opsin gene dimorphisms may be richer than that of other humans, although other efforts to find perceptual effects of inferred human female tetrachromacy have not succeeded (e.g. Jordan and Mollon, 1993; Nagy et al., 1981). There are also striking differences in the relative numbers of the three different types of

cone receptors. For example, humans have on average twice as many L cones as M cones, yet in individual subjects this ratio has been found to vary by over a 30-fold range (Carroll et al., 2002).

These physiological differences lead to obvious differences in visual sensitivity, for example in the relative sensitivity to different wavelengths. However, it is much less obvious how they contribute to color appearance. Webster et al. (2000) compared the individual differences in unique hues to the variations that would be predicted from estimates of normal variations in the lens and macular pigment and in the cone spectra. Because these factors affect a broad range of wavelengths they should influence more than one hue in similar ways in different observers, and thus they predict high correlations across observers between the settings for different unique hues. Yet the observed variations in the unique hues are remarkably independent. The effects of these sensitivity factors on color appearance have also been assessed by studying changes in color judgments with aging. The density of the lens pigment increases with age, so that the same spectrum that is achromatic to the young eye will be greatly attenuated at short wavelengths in the older eye. Yet the achromatic locus and the unique hues instead remain surprisingly stable across the lifespan (Scheffrin & Werner, 1990; Werner & Scheffrin, 1993). Finally, a number of studies have also tested whether the unique hues can be tied to variations in the relative numbers of different cones, and recent work has established that the differences in the L:M ratio are far too large to account for

the range of individual differences in the unique hues (Brainard et al., 2000; Miyahara et al., 1998).

Despite these negative examples, there are some cases where differences in spectral sensitivity could play a role. One interesting case involves the unique hues of red-green anomalous trichromats, who have three types of cones like color normal observers but with altered photopigments so that the difference in spectral sensitivity between the L and M cones is very small. Deuteranomalous individuals set unique yellow to much longer wavelengths than normals, and this is important because it suggests there are limits to the degree to which constant color appearance can be maintained despite sensitivity differences (Neitz et al., 2002). A more controversial case is the recent proposal by Lindsey and Brown (2002) that differences in color naming may be tied to differences in lens pigmentation and retinal damage due to differences in exposure to sunlight. They observed that languages that lack a distinct ‘blue’ term tend to be spoken in areas of the world that have a high exposure to ultraviolet light, and suggested that the phototoxic effects of UV exposure might have reduced short-wavelength sensitivity to the point where blues effectively drop out of the spectrum and the color lexicon. This account was intended to explain differences between languages (those with and without a separate term for blue), and not within them, and whether it succeeds in this regard has been questioned on the basis of cross-language color naming patterns (Regier & Kay, 2004; Lazar-Meyn, 2004; see also a rejoinder by

Lindsey & Brown, 2004). A recent study casts further doubt on this explanation of the absence of ‘blue’ terms in equatorial languages and, in any case, shows it is unlikely to provide a plausible explanation for individual differences within a population. As we have noted these differences are at most weakly related to lens density. In a direct test, Hardy et al. (2004) show that older and younger observers do not differ in how blue they rate spectral stimuli, despite their large differences in lens density. Hardy et al. also show that lens density itself – which they measured directly – appears unrelated to the degree to which spectral stimuli are rated as blue.

Environmental differences

The failure to find clear correlates between color appearance and chromatic sensitivity has led a number of authors to suggest that the factors shaping color perception are in the environment rather than the observer (Shepard, 1992). For example, Pokorny and Smith (1977) and Mollon (1982) argued that unique yellow – the putative null point of the red-green opponent process – may correspond to the average illuminant in the observer’s environment. This could readily explain how individuals with very different cone ratios can have similar unique yellows (Brainard et al., 2000), or how a single observer can maintain stable color percepts despite aging (Werner & Scheffrin, 1993) or a developing cataract (Delahunt et al., in press). In each of these cases color perception could

be calibrated according to a similar pattern of stimulation. Such proposals hinge on the idea that the visual system can adapt in order to compensate for variations in the observer, and there is abundant evidence for these adaptive adjustments, beginning as early as the receptors and extending throughout the visual system (Webster, 2003).

In an elegant extension of these ideas, Yendrikhovskij (2001) used the statistical technique of cluster analysis to examine the distribution in color space of the colors that can be observed in natural images and showed that the resulting clusters – in effect, the regions of color space most often represented in natural images – fell near the foci for basic color terms. This suggests that the special status of these terms may be because they correspond to the relative frequencies of the spectral properties of objects rather than to privileged axes in the mechanisms encoding color. The analysis also provided a possible account of the relative salience of different color terms. For example, ‘red’ is the earliest chromatic color term to emerge in the evolutionary sequence for languages identified by Berlin and Kay (1969) and in individual development (Kay & Maffi, 1999), and this could be predicted by supposing that the distinctiveness of ‘red’ results because of the frequency of these stimuli and the distinctness of the cluster they form (Yendrikhovskij, 2001).

If color perception reflects an adaptation to the color statistics of the environment, then variations in these statistics could underlie differences in color judgments. Natural environments do in fact vary widely in their color

properties. For example, Webster and Mollon (1997) measured the color distributions for a range of outdoor scenes from different environments in the US and India, and showed that these distributions varied both in the mean color and in how the set of colors were distributed around the mean. In lush environments color differences within a scene tend to lie along an axis that varies signals in the short-wave sensitive cones (the vertical axis of Figure 2), while in arid environments the distributions are instead rotated toward bluish-yellowish axes (the negative diagonal of Figure 2). Webster and Mollon also showed that measures of color appearance were strongly affected when observers were adapted to the set of colors drawn from these distributions. More recently, a similar pattern of variation was found to occur within the same environments as the seasons change (Mizokami et al., 2003). One interesting aspect of this seasonal difference is that changes in vegetation cause the average color in scenes to vary along the L vs. M axis of cone-opponent space (the horizontal axis of Figure 2). This is the chromatic dimension that distinguishes ripening fruits from foliage (Regan et al., 2001), which may have been the driving force in the evolution of trichromacy in primate color vision (Mollon, 1989; Polyak, 1957). As shown in Figure 2, this is also the axis that unique reds tend to cluster along. These observations jointly make it tempting to speculate that the special salience of red may be related to the special importance of this axis for our foraging primate ancestors. That is, red may have achieved special salience for our primate ancestors because it served the uniquely important

evolutionary function of signaling ripeness. However, whatever value this speculation may have, it is not apparent how it might be reconciled with the large differences in hue settings of contemporary humans.

Cultural differences

The concordance of basic color terms across languages provides strong evidence for universal tendencies in color naming, but does not preclude all cultural or linguistic influence. This is an aspect of color naming that has been extensively debated elsewhere (e.g., Hardin & Maffi, 1997; Saunders & van Brakel, 1997). Most of this debate has focused on how linguistic or cultural differences might or might not contribute to differences between groups, and it is less obvious how they might give rise to variations within a population. However, color judgments are inherently subjective, and consequently may be susceptible to criterion effects that can be biased by individually experienced linguistic or cultural contexts. It is also possible that variability in focal hues arises because the latter are only weakly constrained by linguistic categories. For the physiological or environmental variables we considered above, we implicitly assumed that an individual's focal setting would be pinpointed by characteristics of the visual system or the world and that the differences between observers would thus be closely tied to these differences. However, to the extent that color categories are conceptual, they might also vary according

to how much information an observer has about them, and the specific prototypes this allows them to form (Rosch, 1975).

Focal color differences in Indian and United States observers

Given the large variation in color naming among individuals and the fact that these variations could plausibly arise from many different factors, it would be remarkable if the focal colors for different populations did not show some amount of nonrandom variation. Webster et al. (2002) tested for these population differences by comparing color judgments for a set of observers in India and the United States. The US observers were college students in Reno, Nevada, tested in English. The Indian participants included college students in the city of Chennai (formerly Madras) who were fluent in and also tested in English, additional urban residents of Chennai tested in Tamil, and two groups of monolingual rural farmers tested in regions of Tamil Nadu (in Tamil) or Maharashtra (in Marathi).

In one task, observers selected the best examples of the corresponding terms for 'red', 'green', 'blue', or 'yellow' (as well as the binary hues 'orange' and 'purple') from a Munsell palette that was very similar to the palette used by Berlin and Kay (1969). (See Figure 1a). In a second task, specially printed palettes were used to display a finely graded series of hues spanning a range of

reds, of greens, of blues, and of yellows, and subjects were instead asked to make a unique hue judgment for each of the four terms (e.g. by pointing to the blue that did not appear too reddish or too greenish). Figure 3 shows histograms of the focal color choices from the Munsell palette, formed by collapsing across different lightness levels to find the hue (palette column) that each observer chose for each term. The different panels are for different groups or testing conditions, with the US observers shown in the bottom two panels. There are two notable features in these results. First, the modal values of the focal hues for the different groups fall along similar columns in the palette, and in fact were identical for all groups for selections corresponding to ‘red’ and ‘yellow’. This is consistent with a strong common basis for color naming across the different groups. The second feature is that – at a finer level – the means of the distributions are not the same. For example, compared to the US observers, the Indian observers tended to choose yellows and reds that were significantly shifted toward orange, and chose blues that were even more strongly shifted toward green (although it is possible that for some of these observers, the term interpreted as a ‘blue’ term was really a ‘grue’ term). Similar differences were also found for the unique hue judgments. These differences suggest that while basic color terms are similar across the groups, their specific foci can, and probably often do, vary in real, if modest, ways across different populations.

Insert Figure 3 here

The Indian and US groups tested by Webster et al. (2002) differed along many of the dimensions we considered in the preceding section, in that they were drawn from different ethnicities, different languages, and different color environments. Thus, it is not clear what the basis of the focal color differences might be, and the aim was not to identify the source of any potential differences, but rather to maximize the chance of finding them. However, one potential factor that probably can be safely excluded is differences in the immediate testing environment. The college students in Chennai and in Reno were each tested under both natural outdoor lighting and incandescent lighting, illuminants with very different spectra [The top two panels of Figure 3 show the results for the Indian (ESO) subjects, tested in(doors) and out(doors), respectively, and the bottom two rows for the Reno (UNR) students, similarly varied by testing environment.] Within-observer group results were quite constant across changes in lighting conditions and the differences between the U.S. and India groups were thus maintained under both indoor and outdoor lighting. This suggests that whatever the bases for the differences between the two populations, they probably reflect some longer-term influences on color naming.

Focal color differences in the World Color Survey

In the preceding study, comparing focal and unique hues for Indian and US observers, the subjects were instructed to select the stimuli corresponding to what we assumed were corresponding terms across the languages. That is, they were asked to choose the best examples of ‘red’, ‘green’, ‘blue’ or ‘yellow’. Again, the results showed that these focal choices clustered within very similar regions of color space, but also that there were significant group differences in the mean foci within these clusters (e.g., in the precise location of the mean ‘red’ or ‘yellow’ for the different groups).

These results led us to explore whether there are similar patterns of within-cluster variability across the 110 languages sampled as part of the WCS. In this case the question of equivalent color terms becomes admittedly more problematic, in part because the WCS includes languages that have different numbers of basic color terms. We consider this problem below. However, for the purpose of the present analysis, we assumed that a subset of languages in the WCS data set have terms with foci that are close to the foci for the English terms *red*, *green*, *blue*, and *yellow*. This allowed us to examine individual and group differences in the foci for these nearest-neighbor terms, in the same way that we compared differences across corresponding terms for Indian and US speakers. That is, it allowed us to ask how focal colors might vary within the similar-focus clusters, and specifically, to test whether the terms that fall within

a common cluster are characterized by a common mean focal stimulus or by a range of stimuli that vary across the different populations.

The corresponding terms for each language were identified in the following steps. First, to be included in the analysis a term had to be used by more than half the speakers of the language sample. Then, for each speaker, the mean (i.e. centroid) focal point for each term was compared to the various foci for English basic color terms. The ‘closest’ English term was defined as the English term whose focal point was closest to the speaker’s mean focal chip, as given by the Euclidean distance within the palette array. (The nominal Munsell foci for the English terms were similar to the foci shown in Figure 1.) We next tallied across the speakers within a language to find the English term that was most often closest to the focus of each term in the language. To be included in a cross-language focus cluster, a term had to be closest to the same English term for more than half of the speakers. Consensus by a simple majority may seem an overly liberal criterion for defining a term as part of a focus cluster. However, in most cases consensus was in fact much higher. Finally, once a term was assigned to a cluster, the data from all speakers of the language were included in locating the cluster, whether their own individual foci were consistent with this classification or not. (Note that the procedure we used is not intended to provide a definitive measure of which WCS languages have basic color terms corresponding to the terms in English, since such measures depend on the choice of criteria. For example, some languages with a potential ‘red’

term were excluded from our analysis, because the majority of foci for the term did not fall closest to the English focal point for *red*.)

We analyzed only the sets of terms clustering near *red*, *green*, *blue* and *yellow*. The achromatic English terms (*white*, *black*, and *gray*) correspond to a small set of neutral chips, and the remaining color terms (*orange*, *pink*, *brown*, and *purple*) were the closest terms for only a small subset of the languages (Kay & Regier, 2003). Figure 4 plots the foci for the ‘red’, ‘green’, ‘blue’, and ‘yellow’ clusters, with each point showing the mean selection for speakers of a single language. This is similar to the contour plot derived for the WCS data by T. Regier (available at www.icsi.berkeley.edu/wcs/foci-20030418.html). In Figure 5, the foci have been replotted to also show the variability within each language. In this case the two panels plot the hue and lightness of the mean focal point for each language, while the error bars show the standard deviation in the foci within the language.

Insert Figures 4, 5 here

Note that the hue clusters in the upper panel of Figure 5 are similar to the focal color settings we discussed above for the Indian and US observers (Figure 3) in that the individual differences within the languages are pronounced. We again asked whether there are also significant differences between foci for different languages. To assess this, for each cluster we

compared the observed variance in the foci to the variance predicted by randomly sampling across the languages. To generate these predictions, we drew repeated random samples of 20 speakers from the entire WCS sample, which is equivalent to treating all of the WCS speakers as a single population. The predicted variance in the means was estimated from 100 random samples. Figures 6-9 replot the mean hue and lightness settings for each cluster and compare these to the predictions for a single population. To help visualize the differences across the languages, the settings have been sorted in ascending order. In all cases, the spread of focal settings is larger than that predicted by a single population. This was verified by F -tests comparing the observed variance vs. the variance predicted by sampling across the languages. The observed variation is roughly 2 to 4 times the spread that would be expected if there were no differences between the groups, a difference that in all cases is highly significant (Table 1a). Notably, the between-group differences are consistently larger (relative to the within-group variation) for the lightness than for the hue of the focal color.

Insert Table 1 here

Table 2 shows the correlations between the hue and lightness settings for the different color terms. These correlations are generally weak, and are consistent with the largely independent variations in unique hues for individual

observers reported by Webster et al. (2000) and Webster et al. (2002). This suggests that whatever factors give rise to the variations within the WCS clusters, they do not reflect global differences in how observers classify color (e.g., in the tendency to choose a higher or lower lightness for different colors).

Insert Table 2 here

One potential source of variation in the focal colors of different languages is in the number of color terms. The languages sampled in the WCS generally had far fewer basic color terms than English. For example, as noted above only a small proportion of the languages had terms with foci near ‘orange’ or ‘pink’, and thus in most cases these regions are instead subsumed within terms corresponding to ‘yellow’ or ‘red’ (Kay & Regier, 2003). It is not obvious how the best example of a color term should vary with the number or range of different terms, since it depends on whether these differences reflect perceptual or linguistic differences (Regier & Kay, 2004). One possibility is that the focal colors might lie near the center of the region labeled by a given term, because the region is treated as a single perceptual category. This would predict that in languages that lack an ‘orange’ term focal yellow might shift toward orange. A second way this shift could arise is if individual speakers chose foci near one or the other foci (e.g., near orange or yellow) or both, so that the average across speakers would again lie at an intermediate point.

Previous studies have analyzed these patterns of variation specifically for the WCS languages that lack distinct ‘blue’ and ‘green’ terms, and which thus label this region of the color space with a single ‘grue’ term. The best examples chosen for these ‘grue’ terms are bimodal, with peaks near the separate English foci for *green* and *blue* (Regier & Kay, 2004). MacLaury (1997) reported a similar pattern among Mesoamerican languages. These results are consistent with the ‘grue’ term representing a generalization over perceptually distinct blue and green regions. On the other hand, Lindsey and Brown (2004) found that the set of grue foci in the WCS were less bimodal than the distribution given for blue and green foci. They argued that this is because a subset of speakers treats grue as if it were an undifferentiated perceptual category.

Insert Figures 6,7,8,9 here

For the present analysis we did not attempt to distinguish ‘grue’ terms as such, and thus it is likely that some of the observed spread in the ‘blue’ and ‘green’ distributions resulted from including speakers that did not lexically distinguish blue and green. To assess this, however, we also examined the mean foci for the 32 WCS languages that were found to have separate terms near both ‘blue’ and ‘green’, according to the criteria we described above for identifying these terms. The foci for these languages are shown on the right side of Figures 7 and 8, and are a subset of the foci shown for the independently defined ‘blue’

or 'green' clusters plotted to the left in the figures. Restricting the terms to this subset eliminated languages near the boundary of the 'blue' and 'green' clusters. Thus the variations in the foci for 'blue' and 'green' may be partly attributable to differences in the degree to which the 'blue' and 'green' clusters are merged by the different WCS groups. (Note that because these plots show only the mean foci for each language, they do not reveal the extent to which these intermediate foci are the best examples for individual speakers.) Yet despite this factor, the cross-language variance in the 'blue' and 'green' terms remains large, and again is significantly greater than would be predicted if languages with distinct 'blue' and 'green' terms shared the focal stimuli for each term (Table 1b).

We have gone to some length to establish the fact that the foci for corresponding terms can vary across different groups. However, this finding should not overshadow the point that these differences within clusters are small compared to the differences across clusters. For example, the standard deviations of focal hues for languages within the 'red' and 'yellow' clusters were 0.67 and 0.81, respectively, while the mean hue difference between these clusters was 7.8 steps, or roughly 10 times the within-cluster variation. This is not simply an artifact of our procedure for defining clusters by nearest-neighbor terms. For example, the color category of orange falls roughly half way between the red and yellow foci, yet only one of the 110 languages included a

consensus term near orange. Similarly, despite the differences we noted for similar terms in Indian and US respondents, these differences are again small compared to the foci for different terms (Figure 3). The differences among nearest-neighbor terms are important for understanding how color naming varies across populations, but these differences reflect local dispersion within well-defined clusters and are more likely to reflect modulations of the basic color foci than categorical differences.

Conclusions

In this chapter we have approached the question of focal colors from two different traditions. Psychophysical studies of color appearance have typically started with the assumption that terms like *yellow* and *blue* correspond to special and well-defined perceptual phenomena that are shared by observers. The stimuli that elicit these states have been investigated with the aim of characterizing the visual mechanisms that might underlie these phenomena. Linguistic studies have instead focused on testing the assumption that there are corresponding color categories across languages. In the present investigation, focal colors were analyzed to determine whether they are similar enough among languages to support conclusions about universal tendencies in color naming. We have shown that at both the individual and the language level there is

variation in focal colors, with markedly greater variation in the former.

Speakers of a common language differ in the focal stimuli they choose for the same color term, and similarly, different languages show some, but noticeably less, variation in the average focal stimuli they choose for their nearest-neighbor terms. What are the implications of these differences for the psychophysics and linguistics of color?

First, the presence of large inter-individual difference within languages does not *per se* bear on the issue of cross-linguistic universals in color naming. Even if the individual language samples were random samples from a single population, the Central Limit Theorem (Feller, 1968: 229) tells us that under reasonable assumptions the standard deviation of the distribution of any statistic calculated in each of the 110 sample languages will, on average, be a little less than one tenth the standard deviation of that statistic in the population itself – and hence less than one tenth of the value expected in any particular language sample (since the variance would be reduced by a factor equal to the number of language samples, 110, and the standard deviation is the square root of the variance). Of course we know from the statistics displayed in Table 1 that in fact the individual languages of the WCS are not, with respect to focal colors, drawn from a uniform population – or, more accurately, that they are highly unlikely to be so drawn. The present point is that we need Table 1 to tell us that; the large variation of focus placement within individual languages is relevant to neither the issue of whether languages differ from each other in

focus placement nor whether there exist universal tendencies in focus placement across languages

The present analyses of the WCS data suggest that different language groups do vary in the average focal choices for nearest-neighbor terms. These group differences place some limits on universal tendencies in color naming. In particular, they suggest that to the extent there are corresponding basic color terms, these reflect constellations of similar color categories rather than a strict equivalence, and this means that there can in fact be significant contextual influences on color naming. Our analyses have not examined the possible causes of this interlingual variation: environmental, cultural or physiological. Yet, the existence of some dispersion due to any of these factors is not surprising. For example, we have noted that there are clear differences in the physical color characteristics of different environments, and it is well established that processes of adaptation will adjust the characteristics of color perception to the observer's ambient environment. These adaptation processes alone may ensure that perceived color will differ when a single person is immersed in a lush jungle or arid desert, and thus predict that color judgments will differ on average for different inhabitants of different environments (Webster et al., in press). What is surprising is perhaps how constrained these contextual influences are, for the foci for different populations remain strongly clustered in color space. This suggests that whatever factors give rise to the

large individual differences in focal colors, they may themselves have strong universal tendencies.

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Table 1a. Variance in the mean foci for WCS terms closest to r, g, b, or y, compared to the variance predicted by random sampling across languages.

term	#	focal hue					focal lightness				
		mean	var	pred	F	p	mean	var	pred	F	p
r	103	1.77	.46	.25	1.81	<.002	4.25	.095	.040	2.41	< e-5
g	73	18.9	3.01	.96	3.16	< e-8	4.74	.41	.099	4.12	< e-10
b	50	27.7	2.45	.93	2.56	< e-5	4.30	.46	.093	4.84	< e-10
y	86	9.46	.65	.31	2.13	<.0002	7.79	.13	.038	3.38	< e-8

Table 1b. Variance in the mean foci for WCS terms closest to g and b, for the 32 languages that included distinct b and g terms.

term	#	focal hue					focal lightness				
		mean	var	pred	F	p	mean	var	pred	F	p
g	32	18.2	1.10	.58	1.93	< .01	4.56	.29	.074	4.06	< e-7
b	32	28.3	1.22	.60	1.93	< .01	4.23	.56	.088	6.37	< e-11

Table 2. Correlations between the mean hue and lightness values for WCS languages with terms near English *red*, *green*, *blue* and *yellow*.

	r hue	r light	g hue	g light	b hue	b light	y hue	y light
r hue								
r light	-.22							
g hue	-.03	-.12						
g light	-.12	.43	-.09					
b hue	.25	-.27	-.14	-.44				
b light	-.26	.29	.04	.15	-.53			
y hue	-.13	.36	0	.22	-.17	.15		
y light	-.03	.23	-.04	.02	-.05	.04	.22	

Figure Legends

Figure 1. Contour plot, over the Munsell stimulus space (illustrated by the color panel), of the number of naming centroids in the WCS data set. Each contour represents centroids of 100 individual speakers. Filled circles represent average English focal choices observed by Sturges and Whitfield (1995).

[Adapted from Kay and Regier 2003, Figure 4b. See text for further explanation.]

Figure 2. Individual differences in unique hues for 51 observers (Adapted from Webster *et al.*, 2000, Figure 4). Points are plotted in terms of a color space whose two axes represent changes in the ratio of long- to middle-wavelength cone response (horizontal axis) and variation in short wavelength cone response (vertical axis), at constant luminance.

Figure 3. Color naming in Indian and US observers. Histograms show the number of observers that selected a particular Munsell hue (from the palette of 40 chips shown in Figure 1) as the best example of the color indicated. The different panels plot the choices for different groups of Indian and US observers. ESO-in and ESO-out: college students in Chennai tested in indoor or outdoor lighting; SM: sari merchants in Chennai; RTN: residents of rural Tamil Nadu; RM-mon and RM-win: residents of rural Maharashtra tested in monsoon

or winter seasons; UNR-in and UNR-out: US college students tested in Reno, NV under indoor or outdoor lighting. (Adapted from Webster et al. 2002, Figure 5.)

Figure 4. Location of focal colors for WCS languages that were close to the focal colors for the English terms *red* (filled circles), *yellow* (unfilled triangles), *green* (filled diamonds) or *blue* (unfilled squares). Coordinates give the location of chips in the Munsell array of Figure 1 (Kay & Regier, 2003). [See Figure 1 for the location of English focal choices. Lightness level 9 here corresponds to lightness level B in Figure 1.]

Figure 5. Color foci of Figure 4 replotted to show the separate hue and lightness levels for each language. Error bars show the range (± 1 standard deviation) of foci within each language. “Red” (unfilled circles), “yellow” (filled triangles), “green” (unfilled squares), “blue” (filled diamonds).

Figure 6. Average color foci for the WCS languages that had a term for stimuli near the English focal color for *red*, sorted in ascending order (filled circles). Predicted curves give the distribution expected if the variation in the “red” cluster is due only to the individual differences within groups (pred). The quantized steps in the predictions reflect rounding.

Figure 7. Sorted color foci for the WCS languages that had a term for stimuli near the English focal color for *green* (filled circles), compared to predictions for variations in a single population. Symbols at left plot results for all languages that included a term near “green.” The right side shows the distribution for the “green” cluster for the subset of languages that also included a separate term for “blue.”

Figure 8. Sorted color foci for the WCS languages with term near English *blue* (filled circles), compared to predictions for variations in a single population. Left plots show all languages that included a term near “blue.” Right plots are for languages that also included a term for “green.”

Figure 9. Sorted color foci for the WCS languages with term near English *yellow* (filled circles), compared to predictions for variations in a single population.

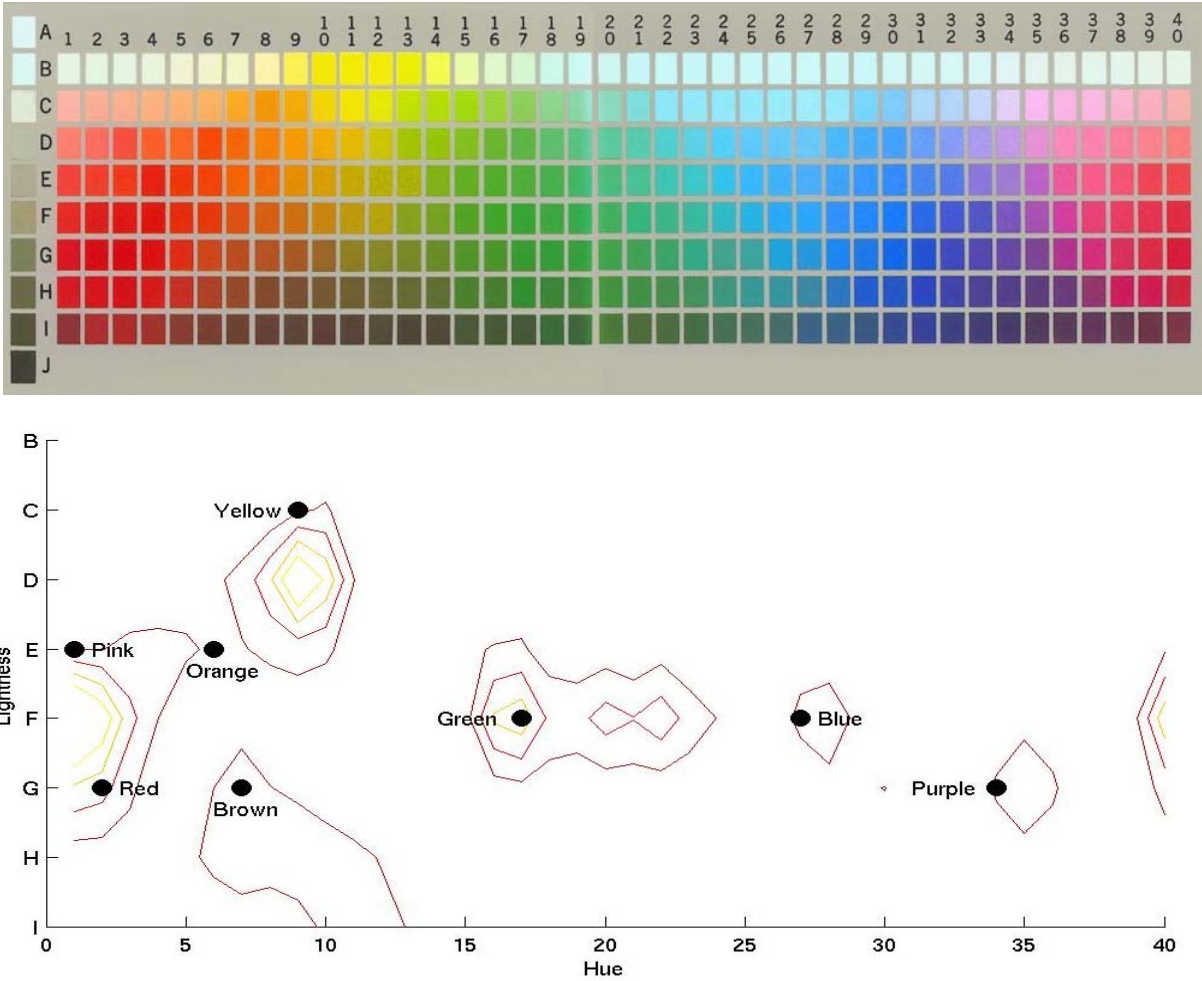


Figure 1

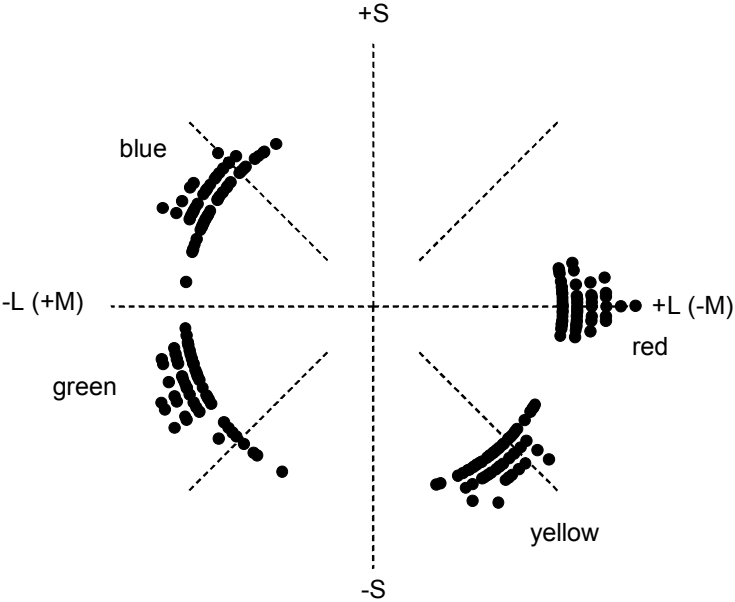


Figure 2

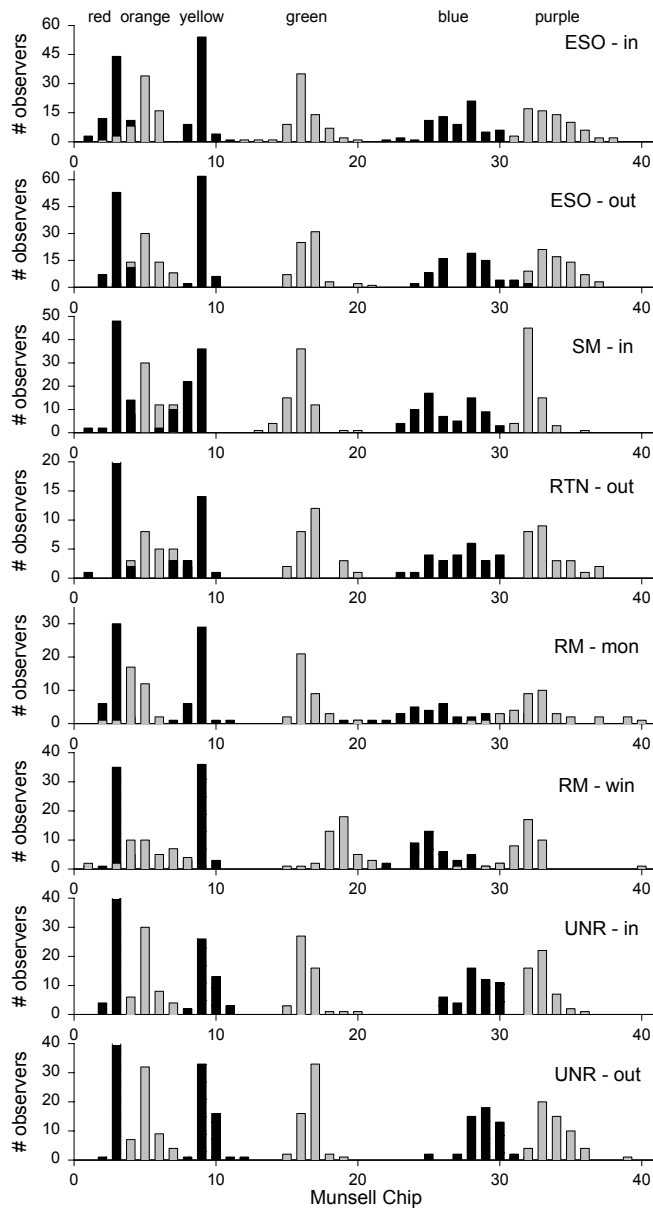


Figure 3

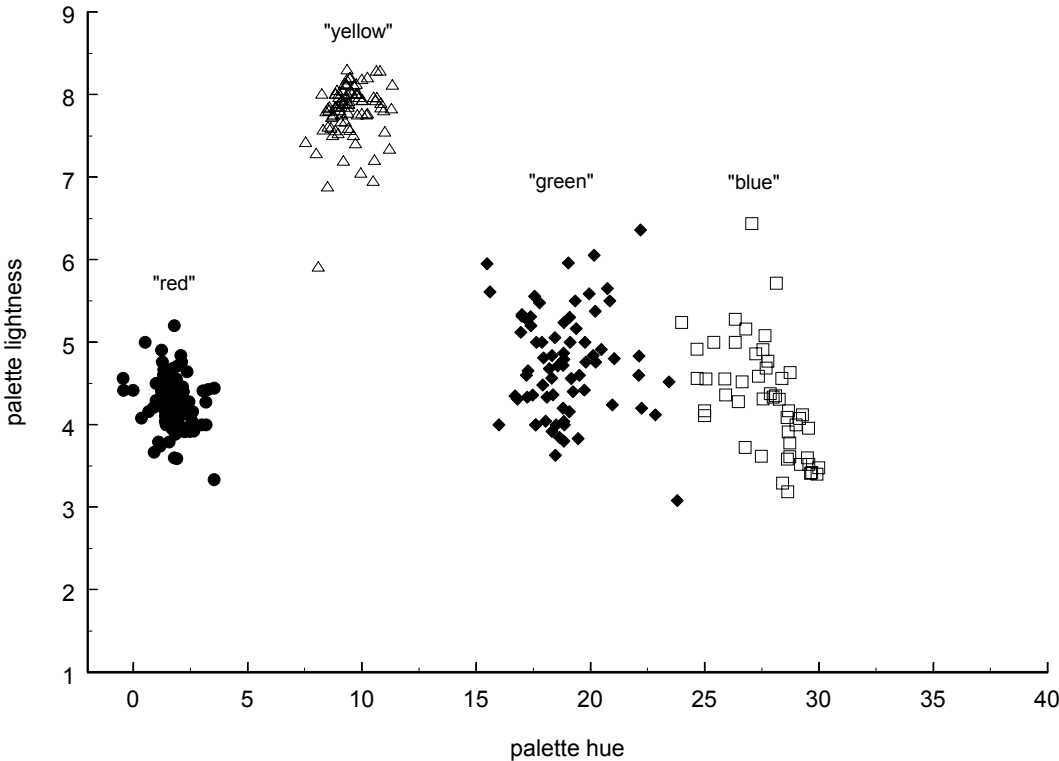


Figure 4

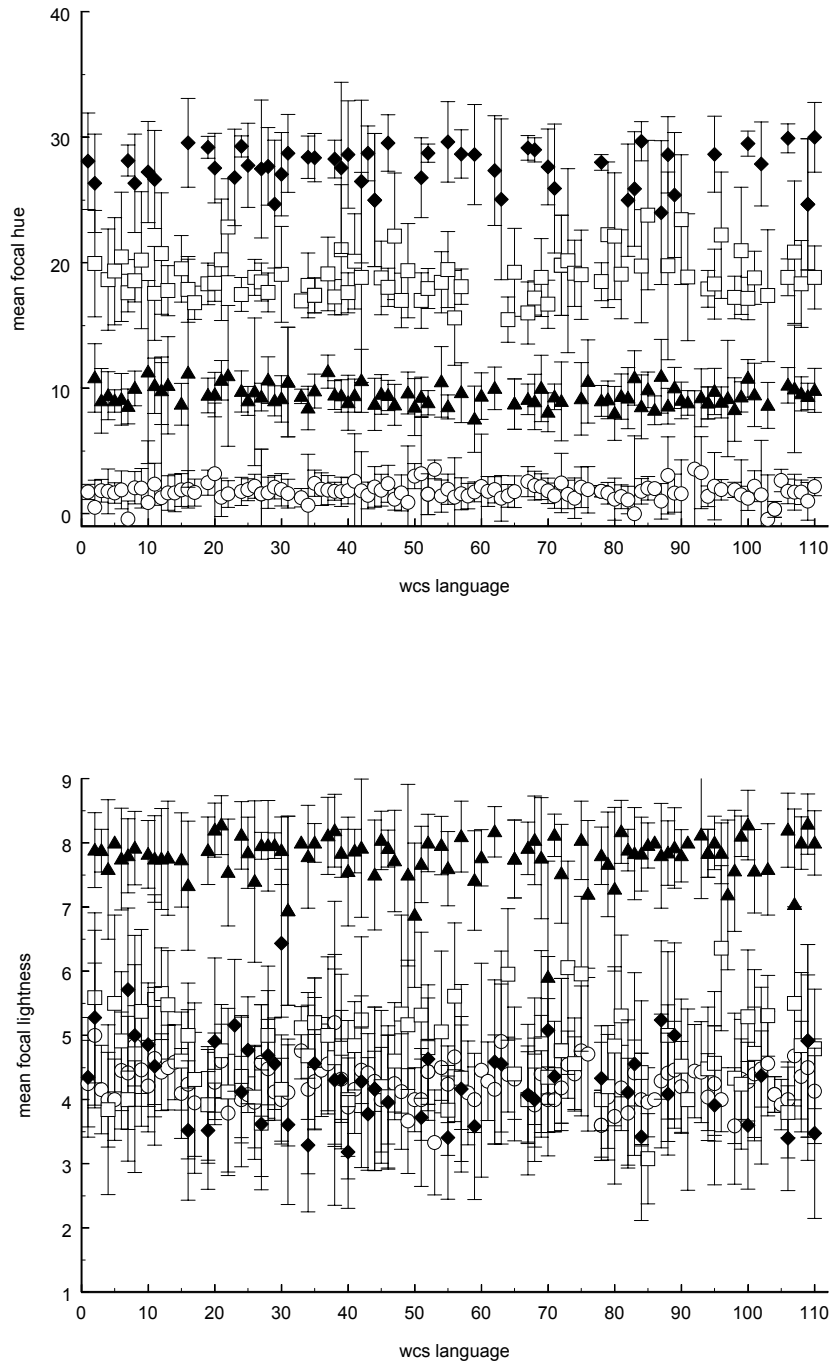


Figure 5

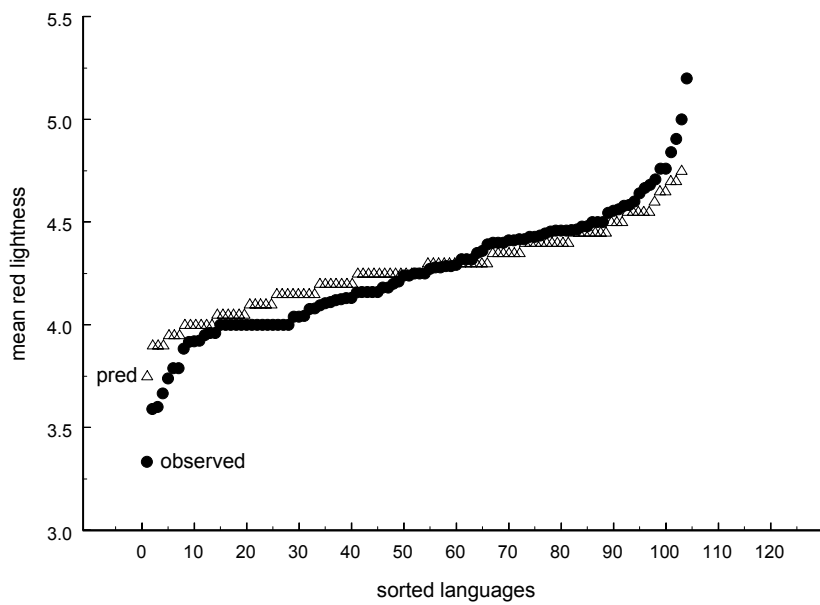
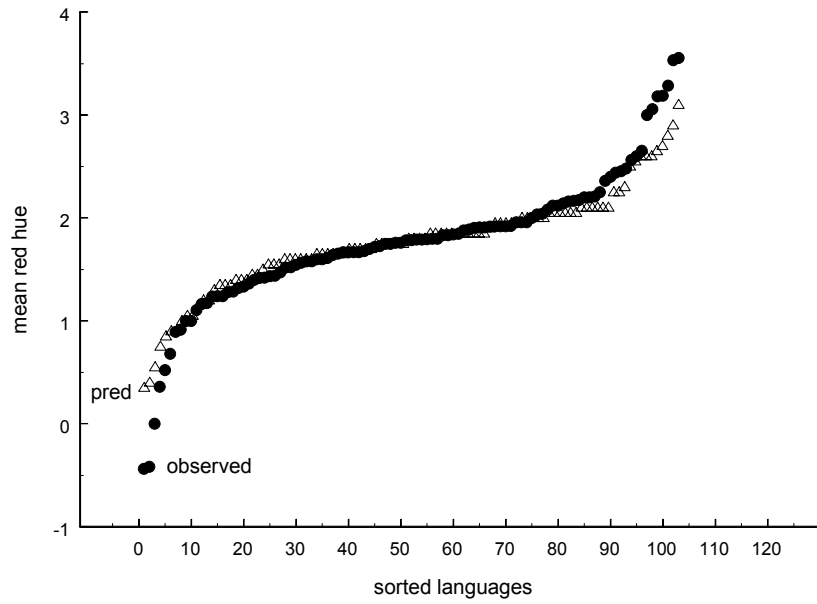


Figure 6

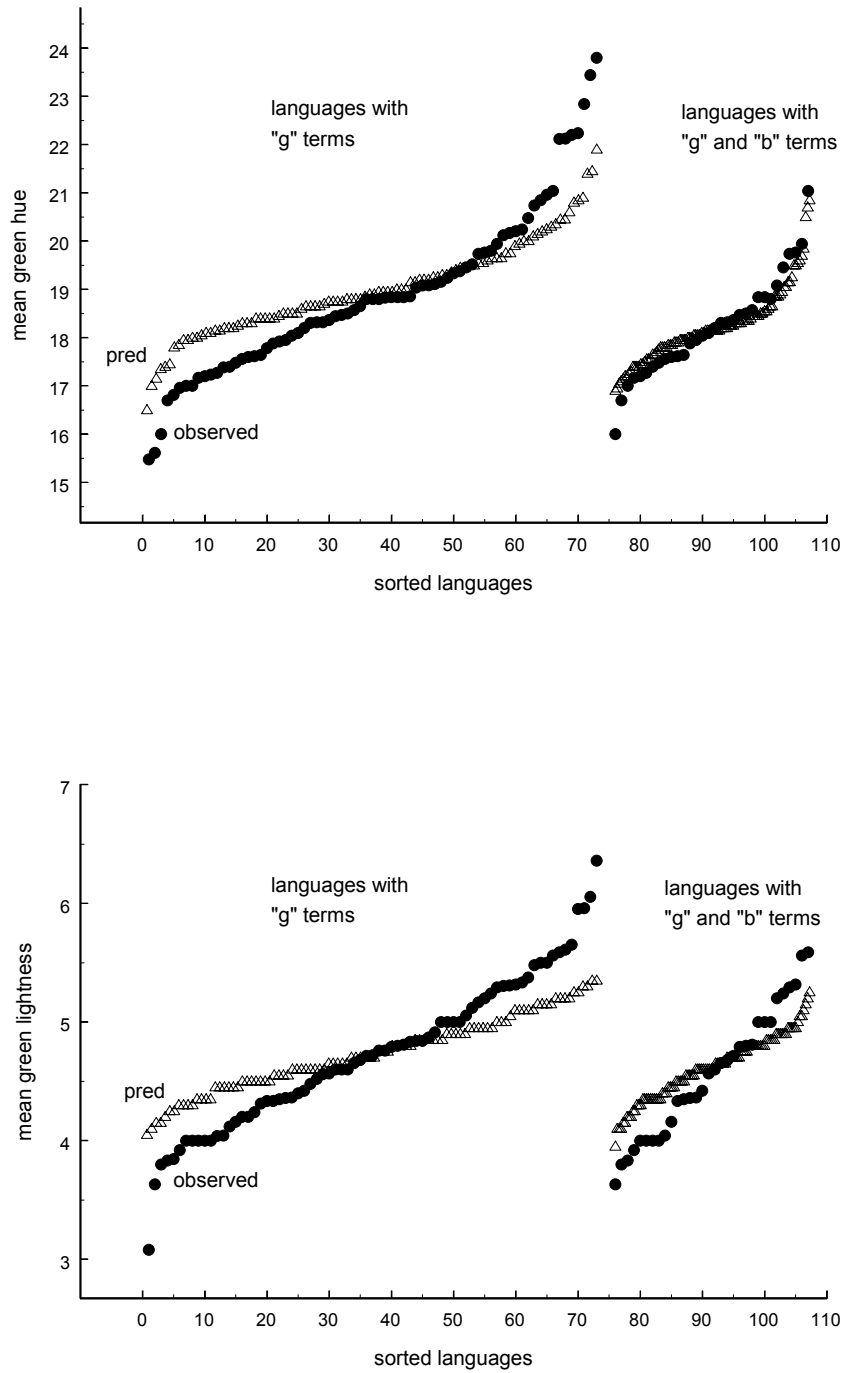


Figure 7

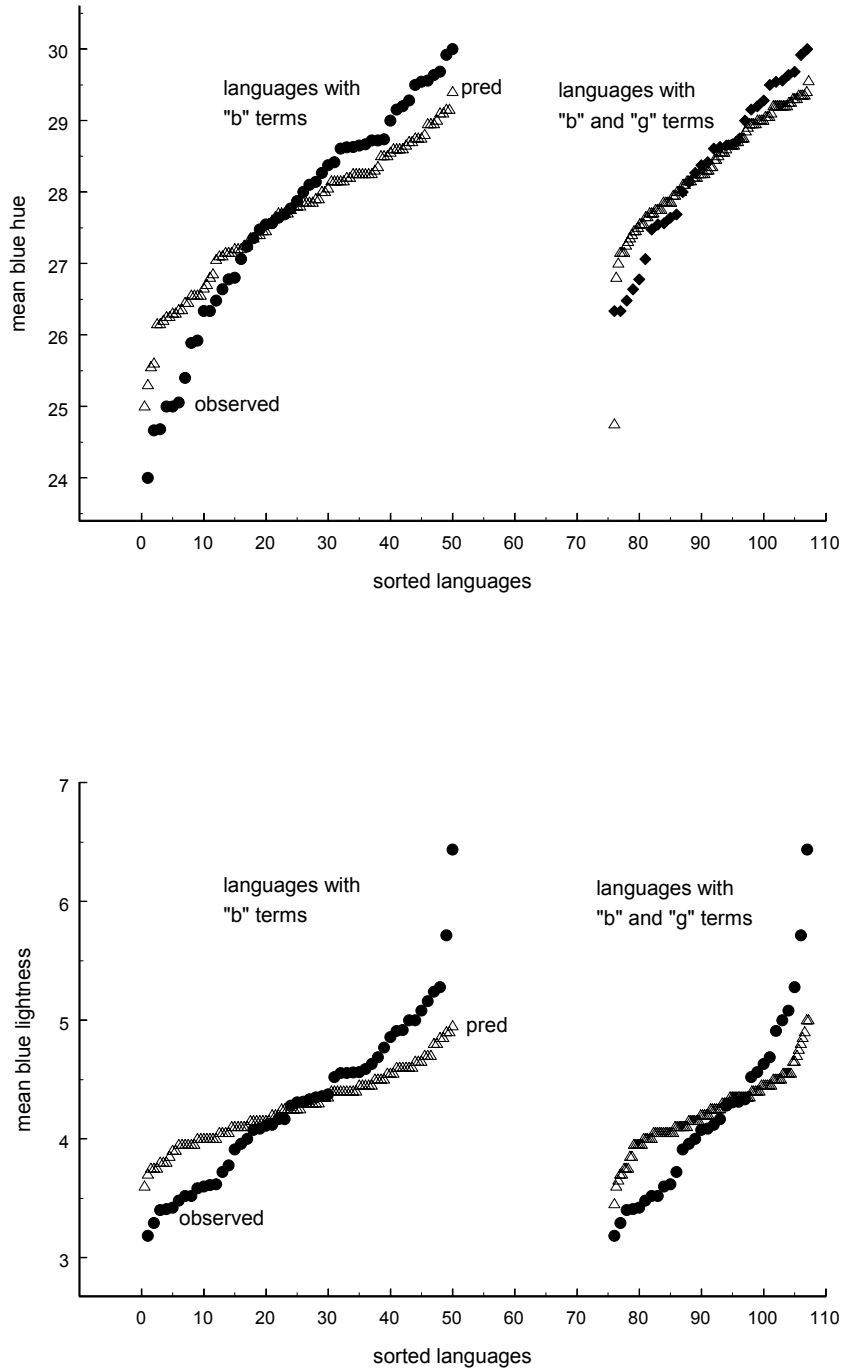


Figure 8

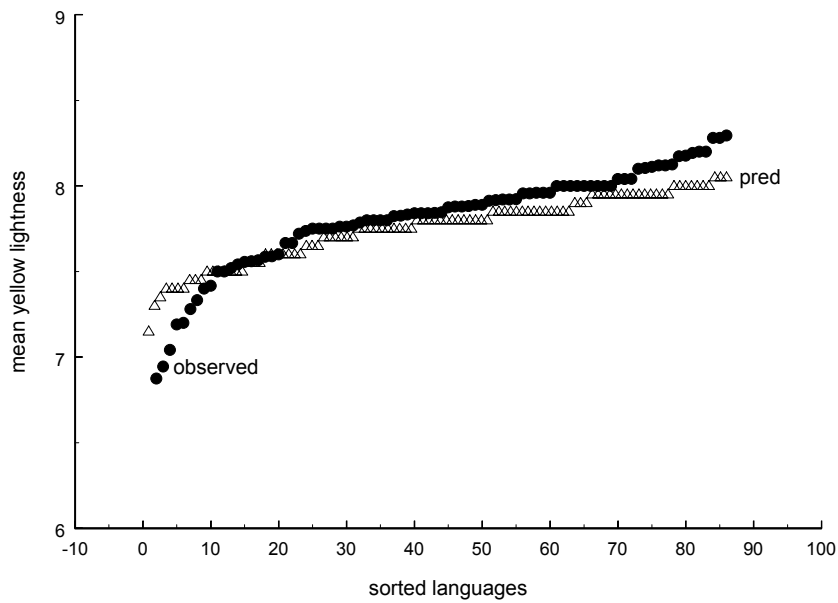
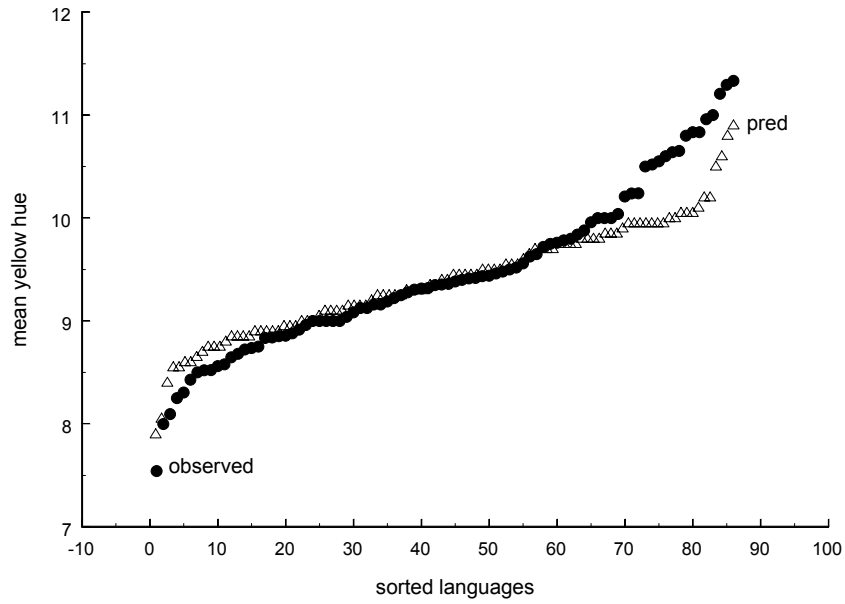


Figure 9