Perception, 2011, volume 40, pages 1063 – 1080

doi:10.1068/p6992

The role of spatial organization in preference for color pairs

Karen B Schloss, Stephen E Palmer
Psychology Department, University of California, Berkeley, Berkeley, CA 94720-1650, USA;
e-mail: kschloss@berkeley.edu
Received 10 April 2011, in revised form 12 August 2011

Abstract. We investigated how spatial organization influences color-pair preference asymmetries: differential preference for one color pair over another when the pairs contain the same colors in opposite spatial configurations. Schloss and Palmer (2011, *Attention*, *Perception*, *& Psychophysics* **73** 551 – 571) found weak figure – ground preference asymmetries for small squares centered on large squares in aesthetic ratings. Here, we found robust preference asymmetries using a more sensitive forced-choice task: participants strongly prefer pairs with yellower, lighter figures on bluer, darker grounds (experiment 1). We also investigated which spatial factors influence these preference asymmetries. Relative area of the two component regions is clearly important, and perceived 3-D area of the 2-D displays (ie after the ground is amodally completed behind the figure) is more influential than 2-D area (experiment 2). Surroundedness is not required, because yellowness – blueness effects were comparable for pairs in which the figure was surrounded by the ground, and for mosaic arrangements in which the regions were adjacent and separated by a gap (experiment 3). Lightness – darkness effects, however, were opposite for figure – ground versus mosaic organizations: people prefer figure – ground organizations in which smaller regions are lighter, but prefer mosaic organizations in which smaller regions are darker. Physiological, phenomenological, and ecological explanations of the reported results are discussed.

1 Introduction

When combining two or more colors in a visual display, there are two primary factors to consider: which colors to use and how to arrange them spatially. These factors are relevant for countless domains, including fine arts (eg paintings and sculptures), architecture, interior design, graphic design (eg websites, packaging, and branding), conference presentations (eg PowerPoint slide shows, posters), not to mention more ubiquitous tasks, such as selecting one's outfit in the morning. Previously, Schloss and Palmer (2011) analyzed which color pairs people like, and found that, on average, people prefer pairs with cooler colors that are similar in hue, contrasting in lightness, and contain preferred individual colors. In the present article, we investigated how the spatial organization of the two component colors influences people's aesthetic preferences for color pairs. In particular, we tested for the existence of color-pair preference asymmetries, which would occur if people systematically prefer a pair of colors in one spatial configuration to a pair containing the same two colors in the opposite spatial configuration.

Early evidence for such spatial effects comes from Bullough (1907). He demonstrated that, when participants were presented with two color pairs that only differed in their vertical arrangement, they preferred pairs in which the lower region was darker. He attributed this result to perceived color weight, positing that people prefer darker, heavier regions to be lower because they provide more gravitational stability to the image. He was adamantly opposed to statistical analysis of aesthetic judgments, however, and reported only qualitative assessments of his data.

Other previous work has focused on how balance can be achieved by adjusting the relative area among colored regions. According to Munsell's (1921/1969) principle of inverse ratios of area, color combinations are balanced or harmonious when 'stronger' colors occupy less space than 'weaker' colors. Balance is achieved when the area × value (lightness) × chroma (saturation) is equivalent in the two colored regions. Moon and Spencer (1944) proposed a similar formula, but claimed that colors were balanced when their area × distance from the adaptation point products were equal. Their formula accounts for contrast with the background (or adaptation if the colored patches are sufficiently large), whereas Munsell's formula is agnostic with respect to the background color. Moon and Spencer's (1944) and Munsell's (1921/1969) formulas are equivalent when the Munsell values of the colors are both 5, but otherwise the two formulas produce different area ratios for the same set of colors.

Several studies have investigated whether Munsell's or Moon and Spencer's formula has greater empirical validity. Granger (1953) found that participants adhered more to Munsell's rule when adjusting the relative area of colored regions to produce the most 'pleasing balance'. Morriss and colleagues reported results consistent with both Munsell's and Moon and Spencer's formulas in that participants set more saturated regions to be smaller when value was held roughly constant (Morriss et al 1982; Linnett et al 1991). When chroma was held constant and lightness varied, however, participants set regions with higher lightness contrast with the background to be smaller, which was consistent with Moon and Spencer's (1944) formula (Morriss and Dunlap 1987).

In Itten's (1961/1973) discussion of contrast of extension, defined as the relative area of color patches, he proposed that colors should be combined in a ratio that is reciprocal to their 'brilliances' or 'intensities'. This rule is similar to Munsell's (1921/1969), if one assumes the traditional use of the word 'intensity', but Itten was actually referring to Goethe's (1810/2006) order of hue-based 'light values', where yellow (9) is lightest, followed by orange (8), green (6), red (6), blue (4), and violet (3). For Itten, yellow is a '9' in light value and violet is a '3', so they should be combined in a ratio of 1 : 3. Interestingly, Goethe's order of intensities follows the order of Munsell value (lightness) of the most saturated colors in each of these six hues in Munsell's color space, and Itten uses highly saturated colors to illustrate his principle. His intensities also follow a rough ordering from yellowness to blueness and are more highly correlated with yellowness – blueness ratings of the corresponding saturated hues ($r = 0.88$) than the lightness – darkness ratings ($r = 0.52$), according to ratings from Palmer and Schloss (2010).

In previous experiments, Schloss and Palmer (2011) provided weak, but significant, evidence of preference asymmetries for color pairs organized in a figure – ground arrangement (a small square centered on a larger square). Preference ratings for 992 color pairs, rated one pair at a time, were correlated with the signed difference in coolness ($r = 0.13$) and lightness ($r = -0.14$) for ground-minus-figure, indicating that participants preferred pairs with warmer, lighter figures on cooler, darker grounds.

Schloss and Palmer's (2011) results on figure – ground asymmetries have left several important questions unanswered, two of which will be addressed in the present article. First, it is unclear whether the correlations were weak because preference asymmetries are simply marginal effects or because the previous rating task was not sensitive enough. We address this issue here by measuring preferences for color pairs presented simultaneously in a forced-choice task, where the only difference between the pairs in the comparison was the figure – ground assignment of the colors (experiment 1). Results show that preference asymmetries are robust when measured in this forced-choice method, and are strongly related to the figure – ground differences in yellowness – blueness and lightness – darkness.

Second, it is unclear which spatial aspects of the figure – ground pairs studied by Schloss and Palmer (2011) govern preference asymmetries. The figural region differed from the ground in multiple ways. Not only was it more 'figural' or object-like, in terms of figure – ground organization (Rubin 1921/1958), but also it was smaller than and surrounded by the ground, both of which contribute to its figural status. In experiments 2 and 3 we isolated which spatial factors govern preference asymmetries. In experiment 2 we show that larger differences in perceived 3-D area (after amodal completion) lead to larger preference asymmetries. In experiment 3 we show that people prefer yellower regions to be smaller irrespective of surroundedness, but they prefer lighter regions to be smaller when surrounded but larger when in a mosaic configuration.

It is important to note that the principles presented here are not aimed to instruct artists and designers on how they should construct their work. They merely describe average preferences by average viewers of generic displays which, as such, constitute default biases that can be violated to produce a desired effect. As both Munsell (1921/1969) and Itten (1961/1973) explain, there are great paintings that do not adhere to such rules of balance because imbalance can be exciting and provocative.

2 Experiment 1. Asymmetries in preference for color pairs

In experiment 1 we examined asymmetries in preference for figure – ground pairs consisting of a small square centered on a larger square. Preferences would be asymmetric if, for a given pair of colors, observers reliably preferred one color as figure and the other as ground to the opposite figure – ground arrangement.

2.1 *Methods*

2.1.1 *Participants.* Forty-eight participants (twenty-four females) from the Berkeley Color Project (Palmer and Schloss 2010; Schloss and Palmer 2011) participated. All had normal color vision (screened with the Dvorine Pseudo-Isochromatic Plates) and gave informed consent. The Committee for the Protection of Human Subjects at the University of California, Berkeley, approved the experimental protocol.

2.1.2 *Design and displays.* All pairwise combinations of the 32 chromatic colors from the Berkeley Color Project (see Palmer and Schloss 2010) were used to generate 992 color pairs. The colors included eight hues (red, orange, yellow, chartreuse, green, cyan, blue, and purple) at each of four different saturation/lightness levels (saturated, light, muted, and dark) (table A1 in Appendix), all presented on a medium-gray background (CIE $x = 0.312$, $y = 0.318$, $Y = 19.26$). The colors were translated from Munsell coordinates (Munsell 1966) to CIE 1931 values using the Munsell Renotation Table (Wyszecki and Stiles 1967). The monitors for all experiments were calibrated with a Minolta CS100 Chroma Meter to ensure accurate color presentation.

Each display contained two figure – ground color pairs, one on the left and one on the right of the monitor, separated by a 100 pixels (3.4 deg) gap. Each pair consisted of a small square figure (100 pixels, 3.4 deg × 100 pixels, 3.4 deg) centered on a large square ground (300 pixels, 10.2 deg × 300 pixels, 10.2 deg), analogous to the pairs tested in Schloss and Palmer (2011). The two pairs within a trial contained the same two colors but were reversed in figure – ground arrangement: ie if the left pair contained a figure of color A and a ground of color B (denoted pair AB), the right pair had a figure of color B on a ground of color A (denoted pair BA).(1) There were 992 trials so that each set of color-pair displays appeared twice with the spatial positions of the two displays reversed. Displays were presented on a Dell M990 monitor (18-inch diagonal) with a resolution of 1024 pixels × 768 pixels and viewed from a distance of approximately 24 inches (60 cm).

---

(1) Surroundedness and small size are two strong, well-established figure – ground cues that together predict that the small square will be seen as figure and the large square as ground (see Palmer 1999). The alternative depth interpretation of seeing a square hole in a square surround where the color of the hole is different from the color of the surround is a highly unlikely interpretation (Nelson and Palmer 2001).

2.1.3 *Procedure.* Participants indicated which pair they liked better by pressing the left arrow key if they liked the left pair better, the right arrow key if they liked the right pair better, and the down arrow key if they liked both pairs equally. Displays remained on the screen until participants responded. Trials were separated by a 500 ms inter-trial interval.

2.2 *Results and discussion*

Preferences were considered 'asymmetric' if participants preferred color pair AB to color pair BA (or pair BA to pair AB) when the only difference between pair AB and BA was the figure – ground assignment of the component colors. Figure 1 demonstrates the presence of preference asymmetries of hue in figure – ground pairs, averaged over saturation and lightness levels. Each subplot shows the data for all trials containing the hue indicated in the title above it. The square data points represent the proportion of trials on which observers preferred the pairs containing the titled hue as ground color, circular data points represent the proportion of trials on which they preferred the pairs containing the titled hue as figure color, and the gray diamond data points represent the proportion of trials on which observers reported equal preference. The three points located at each x-axis value within a subplot thus necessarily sum to 1.

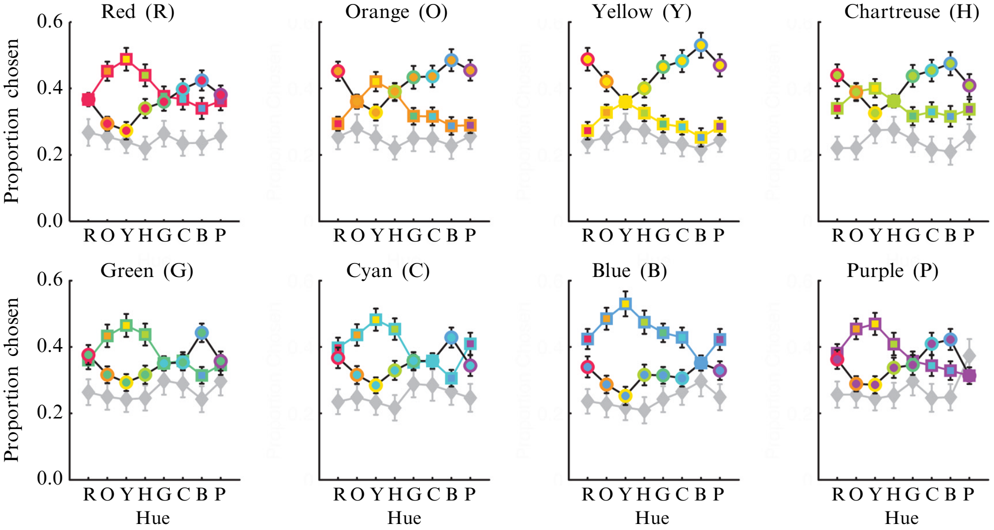

Figure 1. [In color online, see http://dx.doi.org/10.1068/p6992] Comparisons between the proportions of times each hue pair was chosen when presented in one figure – ground arrangement relative to the opposite figure – ground arrangement. Each hue subplot (indicated by subplot title) compares preference for pairs containing that hue as figure (circles) versus that hue as ground (squares) when paired with each of the other hues (x-axis). Gray diamonds show the proportion of times pairs were equally preferred. Error bars represent the standard errors of the means (SEMs).

When the figure and ground hues are the same, differing only in lightness and/or saturation (solid data points), they necessarily have the same choice probabilities because the data in figure 1 are averaged over lightness and/or saturation levels. However, the probabilities of these cases are free to vary relative to the proportion of trials on which participants indicated lack of preference (gray diamonds). Participants were more likely to like both pairs equally when the two colors within the pairs were more similar to one another, as indicated by a reliable positive correlation ($r = +0.40$, $p < 0.001$) between the proportion of times participants chose neither pair on each of the 992 trials and the same participants' similarity judgments (from Schloss and Palmer 2011) of the two colors within each pair.

Close inspection of figure 1 reveals a striking regularity in the results: participants showed preference asymmetries to the degree that the ground was bluer and the figure was yellower. This pattern is most apparent in the Yellow and Blue subplots, where participants always preferred pairs containing yellow to have yellow in the figural region (see Yellow subplot) and pairs containing blue to have blue in the ground region (see Blue subplot). The same pattern holds for pairs that do not contain yellow or blue specifically, but still differ in the yellowness – blueness dimension, such as orange and cyan (orange figure on cyan ground preferred), and chartreuse and red (chartreuse figure on red ground preferred).

To demonstrate this yellowness – blueness asymmetry more directly, figure 2a plots the proportion of trials on which each of the 992 pairs was chosen as a function of the figure-minus-ground difference in yellowness – blueness of the pair presented on the left side of the screen for each trial, such that high values indicate an aesthetic preference for the given figure – ground color pair against its figure – ground reversed version. The yellowness – blueness data and other color appearance dimensions considered below were determined by the same participants' ratings in a previous session (see Palmer and Schloss 2010). The proportion chosen was calculated by coding each participant's preference asymmetry responses so that 'left pair preferred' = 1, 'both equal' = 0.5, and 'right pair preferred' = 0, and then averaging across participants. The largest values on the x-axis correspond to yellow figures on a blue background and the smallest values to blue figures on a yellow background. There is a clear linear increase in the probability of choosing the pair on the left to the degree that its figural color is yellower and its ground color is bluer ($r = +0.63$, $p < 0.001$) with no significant additional quadratic or cubic components. To determine whether this result is significant across participants, we conducted a logistic regression on each participant's preference asymmetry data with yellowness – blueness as a predictor. This analysis showed that the resulting beta weights were significantly greater than zero across subjects ($t_{47} = 4.52$, $p < 0.001$).

Figure 2b shows a similar, but weaker, positive correlation between preference and the difference in lightness – darkness ratings, in which pairs with lighter figures were more preferred ($r = +0.47$, $p < 0.001$, $t_{47} = 1.98$, $p = 0.05$). Corresponding comparisons showed a preference for pairs with warmer figures on cooler grounds ($r = +0.38$, $p < 0.001$, $t_{47} = 2.97$, $p < 0.01$). This result is not independent of the yellowness – blueness result, however, because warmness – coolness ratings and yellowness – blueness

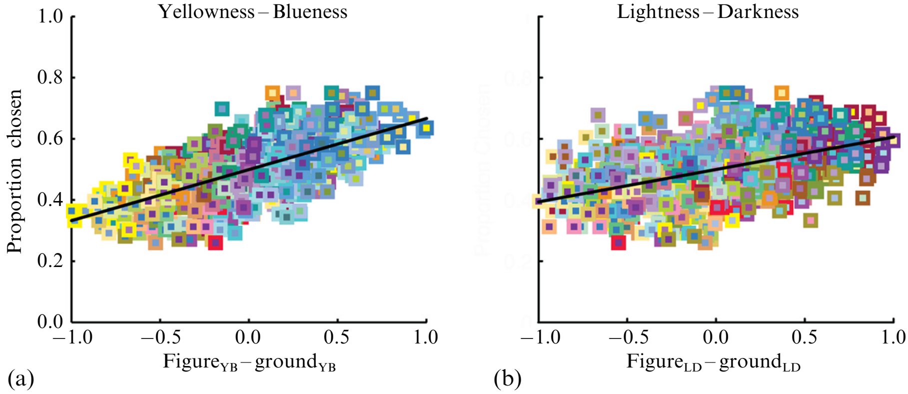

Figure 2. [In color online.] Comparisons between the proportions of times each pair was chosen as more preferred as a function of the pair's figure – ground difference in (a) yellowness – blueness and (b) lightness – darkness difference. The colors of the data points represent the colors of the pairs that were judged. The solid black line is the best fitting line as determined by a linear-regression equation.

ratings are highly correlated ($r = +0.73$, $p < 0.001$). There was also a very slight, but unreliable, preference for pairs with desaturated figures on saturated grounds ($r = -0.08$, $p < 0.01$, $t_{47} = 0.73$, $p > 0.05$), and no relation between preference and figure – ground differences in the redness – greenness of the colors ($r = 0.01$, $p > 0.05$, $t_{47} = 0.06$, $p > 0.05$).(2) A regression model including all five color appearance dimensions explained 49% of the variance, with yellowness – blueness accounting for 40% (pairs with yellower figures being preferred) and lightness – darkness accounting for an additional 9% (pairs with lighter figures being preferred). The other factors did not explain additional variance. This analysis shows that the lightness – darkness asymmetry effect is not the result of differences in lightness due to the yellowness – blueness asymmetry effect because the lightness – darkness factor accounts for additional variance after accounting for the variance due to yellowness – blueness.

Another consideration is whether color-pair asymmetries are influenced by people's preferences for the component colors. For example, Palmer and Schloss (2010) found that the same participants' preferences for single colors were strongly related to the rated yellowness – blueness of the colors, with a general preference for bluer colors. It is therefore possible that participants like bluer regions to be ground simply because they like their more preferred color in the figure – ground display to be larger. Bullough (1907) also reported that participants preferred pairs in which their more preferred color occupied more space. To test this hypothesis, we conducted another multiple linear-regression analysis that included a factor coding for component color preference as well as the color appearance dimensions described above. The component color preferences were obtained from the same participants, who were presented with all possible pairs of the 32 single BCP chromatic colors and asked to indicate which one they preferred.(3) These data were coded so that 1 = left color chosen (corresponding to the ground color of the left pair in the pair task) and 0 = right color chosen (corresponding to the figure color of the left pair in the pair task) and were then averaged across participants.

We entered the component color preference factor into the regression first to determine the extent to which people's preference for the pair BA over the pair AB could be predicted by his/her preference for color A (in the ground) over color B (in the ground). This single color preference factor explained 29% of the variance, with higher preference for pairs in which the more preferred component color occupied the larger (ground) region. Lightness difference explained an additional 22% of the variance (pairs with lighter figures being preferred), followed by yellowness – blueness explaining an additional 9% of the variance (pairs with yellower figures being preferred). The total variance explained was thus 60% (multiple-$r = 0.78$). The other factors did not account for significant amounts of additional variance. It is noteworthy that yellowness – blueness alone explains 40% of the variance, which is a large proportion of the 60% total, but the reason for this dominance appears to be its close relation with several different biases: (a) the figure – ground difference in component preferences (because bluish colors are generally preferred to yellowish ones), (b) the figure – ground difference in the lightness of the colors (because yellow is lighter than blue), and (c) the figure – ground difference in yellowness – blueness that is independent of (a) and (b).

To ensure that the effects of yellowness – blueness explained a significant amount of variance after accounting for component color preferences, we conducted two logistic regression analyses on each participant's preference asymmetry data. We first tested

(2) There were no gender differences between preference asymmetries and any of these color appearance factors, as tested both with correlations and with logistic regression on the individual participants.

(3) The 2AFC data were used, rather than the same participants' preference rating data (see Palmer and Schloss 2010), so that direct comparisons could be drawn between pair preferences and which of the two colors in each pair was more preferred singly.

how well each participant's component color preference asymmetry accounted for the participant's pair preference asymmetries. We then included the figure–ground yellowish–blueness difference to test whether yellowness–blueness explained significantly more variance than the model including only component color preferences. A χ^2 test was used to compare how well the model including component color preference alone fit the data versus how well the model with both component color preference and figure–ground blueness difference fit the data. For thirty-three out of forty-eight participants ($p < 0.01$ by a sign test), the model containing both component color preference and figure–ground yellowness–blueness difference fit their data reliably better at the 0.05 level than the model with component color preference alone. We conclude that the figure–ground yellowness–blueness effects in the preference asymmetries observed here are not simply a result of people preferring the larger (ground) color to be the more preferred color.

We also examined preference asymmetries in light of the formulations proposed by Munsell (1921, 1969) and Itten (1961/1973) and found modest support for both. Our analyses do not directly test their formulas because our particular aim is to predict the strength of preference asymmetries in color pairs of fixed ratios rather than the relative area between two colored regions. Such theories nevertheless have implications for our data because the figural region is smaller than the ground region. Following Munsell's rule, people preferred pairs in which the color of the smaller region (figure) had a higher value × chroma (V × C, or lightness × saturation) product than the larger region (ground). Indeed, 15% of the variance in preference asymmetries was explained by the figure–ground difference in the V × C product. However, Munsell's multiplicative formulation was less accurate than an additive model based on the same two factors entered as separate predictors. Value alone accounted for more variance (29% explained) than the V × C product (15% explained), with pairs containing lighter figures being preferred. When chroma was added into the model with value, it accounted for a small amount of additional variance (2% explained), with pairs containing more saturated figures being preferred.

Itten (1961/1973) claimed that the area of a region should be inversely proportional to its 'intensity' as given by Goethe (1810/2006), where yellow (9) is most intense, followed by orange (8), green (6), and red (6), blue (4), and violet (3). Because no intensity value was provided for chartreuse or cyan, we interpolated values halfway between yellow and green for chartreuse (7.5) and halfway between green and blue for cyan (5). Itten's ratios predict stronger preference asymmetries for pairs that have larger differences in intensity. Indeed, 32% of the variance in people's preference for the pair on the left can be explained by the figure–ground difference in Goethe's intensities, where people preferred more 'intense' figures (smaller region) on less 'intense' grounds (larger regions). These intensities are highly related to yellowness–blueness ($r = 0.88$), however, and the perceived figure–ground difference in yellowness–blueness actually explains more variance (40%) than the corresponding difference in Goethe's intensities (32%).

One possible explanation for the present yellowness–blueness asymmetry effects is that they are related to Berkeley participants' higher preference for Berkeley's primary color pair (gold-on-blue) to its secondary color pair (blue-on-gold) (Schloss et al 2011), given that many of the present participants were Berkeley students and nearly all of them lived in or near Berkeley. There is substantial evidence that the present results are not simply due to this 'Berkeley effect', however. First, Stanford students, whose colors are red and white, show a similar bias, preferring gold-on-blue to blue-on-gold. Second, Mexican participants, tested at the University of Guadalajara, show similar positive correlation between figure–ground differences in yellowness–blueness and their preference asymmetries ($r = +0.49$, $p < 0.001$), even though their school colors are not blue and gold. Both results imply that the blue–yellow asymmetry effects reported here are not simply due to the Berkeley effect.

The results of experiment 1 thus indicate that preference asymmetries are robust and that the two most potent colorimetric predictors are figure – ground differences in yellowness – blueness (explaining 40% of the variance) and in perceived lightness – darkness (explaining an additional 9%). We also showed that people tend to like the more preferred color to be the ground, and thus larger than the less preferred color, and that yellowness – blueness effects are still present after removing these color preference effects. Having established this much about which color appearance factors influence asymmetries in color preference for figure – ground pairs, we now consider which spatial factors influence the effects. The foregoing results suggest that the relative area between the two regions modulates preference asymmetry, but is it retinal 2-D area or perceived 3-D area that matters? And do the colors need to be in a figure – ground arrangement to elicit preference asymmetries? We address these questions in experiments 2 and 3.

3 Experiment 2. Effects of relative area on preference asymmetries

In this experiment we investigate how varying the area of the figural region relative to a constant ground region modulates preference asymmetries. Such variations necessarily change both the relative 2-D area of regions on the retina and the relative 3-D area of the surfaces that the observer perceives after the ground is amodally completed behind the figure (Kanizsa 1979). The figure's 2-D area and 3-D area will always be equivalent because the figure is always entirely visible, but the ground's 2-D area and 3-D area will always be different because the ground is always partly occluded by the figure. As the figural area increases, the ground's 3-D area remains constant because it is amodally completed, even though its 2-D area decreases. Thus, when referring to ground area we will always specify the type (2-D or 3-D), but we will not make that distinction for figural area. To ensure that the figural portion always appeared to be closer (rather than a farther region seen though a thin frame around it), the figural region was divided into numerous texture elements of the same size, all of which appeared to lie in front of the ground region (see figure 3).

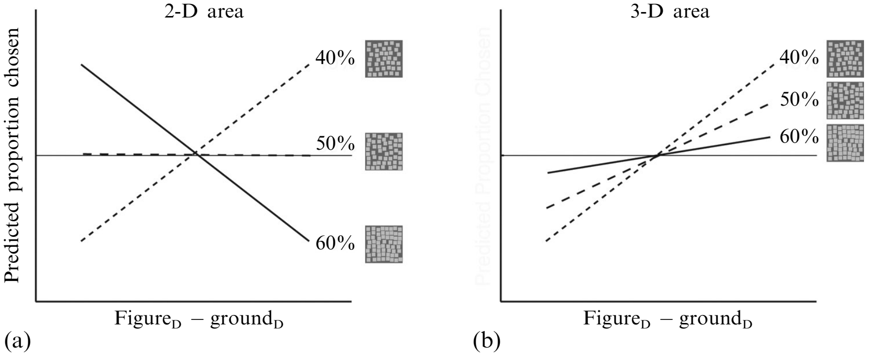

Figure 3. Predicted preferences depending on whether the relative difference in (a) 2-D area or (b) 3-D area is dominant in influencing preference asymmetries. The x-axis is the difference along a given dimension (eg yellowness – blueness, lightness – darkness) between the figure and ground colors. Separate lines represent the percentage of area the figure occupies relative to the 2-D area of the ground.

Different patterns of preference asymmetries will arise as the figural size increases, depending on whether 2-D or 3-D area governs figure – ground preference asymmetries. As shown in the predictions in figure 3, if 2-D area dominates, observers will prefer yellower, lighter figures on bluer, darker grounds when the figural area is small (40% texture), show no preference asymmetry when the figural area is equated with physical/retinal area of the ground (50% texture), and will prefer bluer, darker figures on yellower, lighter grounds when the figural area is large (60% texture). If 3-D area dominates, such that the ground is always perceived as fully completed behind the figure, observers will always prefer yellower, lighter figures on bluer, darker grounds, because the ground will always be perceived as larger. The predictions in figure 3 are drawn as linear functions because the data in experiment 1 (see figure 2) were linear.

3.1 *Methods*

3.1.1 *Participants.* The participants were thirty-two undergraduates at the University of California, Berkeley, who consented to participate in this study. All had normal color vision (screened with the Dvorine Pseudo-Isochromatic Plates). The Committee for the Protection of Human Subjects at the University of California, Berkeley, approved the experimental protocol.

3.1.2 *Design, displays, and procedure.* All participants completed three tasks in the following order: pair preference, figural size estimation, and single color preference. The pair-preference task was similar to that described in experiment 1, except that three possible spatial configurations were used for each color pair: one in which there were 40 texture squares (40% figure, 60% 2-D ground), one with 50 squares (50% figure, 50% 2-D ground), and one with 60 squares (60% figure, 40% 2-D ground). Each texture square was 30 pixels, 0.7 deg × 30 pixels, 0.7 deg and the ground was always 300 pixels, 7 deg × 300 pixels, 7 deg.(4) Each trial contained two figure–ground configurations, on opposite sides of the screen's vertical midline, separated by a 300 pixels, 7.4 deg gap. Participants were instructed to indicate which pair they preferred by pressing the left or right arrow keys. (The 'both equal' response was not available in this experiment because participants in experiment 1 simply seemed to use that response when the choice was difficult.) The pairs within a trial were always spatially identical and only varied in figure–ground assignment of the colors. All pairwise comparisons of the eight light (L) and eight muted (M) hues were tested to make a total of 240 color pairs. Colors for the saturated and dark cuts were omitted to reduce the number of trials to 720 with the three spatial configurations.

In the figural-size estimation task, participants were asked to estimate the percentage of area occupied by the textural figure relative to the 2-D area of the ground. Only one figure–ground configuration was presented per trial, which was located in the center of the screen. The four figure–ground configurations included the three just described for the pair-preference task plus an additional configuration with even less texture (30% figure, 70% 2-D ground). Participants made their ratings along a continuous response line below the configuration that had tick marks delineating 10% intervals ranging from 0% to 100%. They used a mouse to control the position of a vertical line mark on this response scale to 'compare the total area of the foreground squares with the total amount of visible area of the background square'. Participants were also told: 'Do not consider any background covered by the foreground squares when making your judgment'. Each texture configuration was presented in two color combinations: lighter gray texture squares (63.90 cd m^{-2}) on a darker gray ground (12.34 cd m^{-2}) and darker gray texture squares on a lighter gray ground. The background was the same neutral gray background (19.26 cd m^{-2}) as in all the other experiments. There were two replications of each condition to make a total of 16 trials.

In the single-color preferences task, participants were presented with each of 240 pairwise combinations of the 16 colors used in the pair-preference task (left–right balanced) and indicated which they preferred by pressing a left or right response key.

---

(4) We varied the number of same-sized texture elements rather than varying the size of the same number of texture elements because prior research has shown that when a configuration is composed of many elements, keeping the size of the elements the same and varying their number produces a display that appears more similar perceptually (cf Kimchi and Palmer 1982, 1985).

The colors were displayed as two squares (each 100 pixels, 2.5 deg × 100 pixels, 2.5 deg) on opposite sides of the screen's vertical midline.

All displays remained on the screen until participants made a response, and trials were separated by a 500 ms inter-trial interval. Displays were rendered with Presentation (www.neurobs.com) and were presented on a 20-inch iMac computer (1680 pixels × 1050 pixels resolution) viewed from a distance of approximately 24 inches (60 cm).

3.2 *Results and discussion*

In all three texture-proportion conditions, participants preferred displays in which the textured figural region was yellower than the ground, but the difference decreased with increasing numbers of texture elements and figural area (figures 4a – 4c). There was a strong positive correlation between the proportion of times pairs were chosen as more preferred and the figure – ground difference in yellowness – blueness for the 40% ($r = +0.63$, $p < 0.001$), 50% ($r = +0.58$, $p < 0.001$), and 60% ($r = +0.33$, $p < 0.001$) conditions. To examine the statistical reliability of these effects across participants, beta weights from logistic regressions were computed for each participant's preference asymmetry data and analyzed with *t*-tests. The results show that the beta weights are reliably positive over participants in the 40% condition ($t_{31} = 3.22$, $p < 0.01$), consistent with both 2-D and 3-D predictions. Critically, however, the beta weights are also reliably positive across participants in the 50% condition ($t_{31} = 2.64$, $p < 0.05$), consistent with the 3-D prediction but not the 2-D prediction. The beta weights in the 60% condition did not reach statistical significance ($t_{31} = 1.62$, $p = 0.11$), but were clearly in the positive direction predicted by 3-D areas rather than the negative direction predicted by 2-D areas. Further specific comparisons of the beta weights across conditions showed that the yellowness – blueness effect is stronger for the 40% condition than the 50% condition ($t_{31} = 3.29$, $p < 0.01$) and is also stronger for the 50% than the 60% condition ($t_{31} = 2.82$, $p < 0.01$).

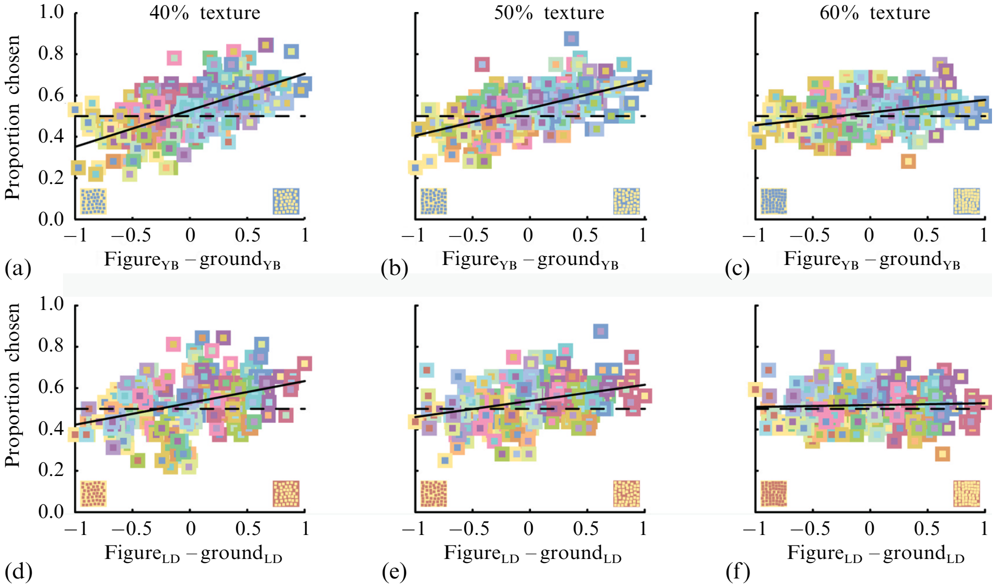

Figure 4. [In color online.] Separate plots show the proportion of times each pair was chosen as function of the yellowness – blueness difference between the figure and ground for the (a) 40%, (b) 50%, and (c) 60% texture conditions and as a function of the lightness difference between the figure and ground for the (d) 40%, (e) 50%, and (f) 60% texture conditions. Data point colors symbolize the color of the pair that was judged. Dashed black lines at a proportion of 0.5 represent 'chance'. Solid black lines represent the best-fitting regression line for each texture size condition.

As shown in figures 4d – 4f, there were similar, but weaker, correlations for the lightness – darkness dimension: 40% ($r = +0.39$, $p < 0.001$), 50% ($r = +0.35$, $p < 0.001$), and 60% ($r = +0.05$, $p > 0.05$) conditions. The beta weights obtained from logistic regressions on the individual participant's data showed that none of the beta weights reached statistical reliability across participants, however ($t_{31} = 1.44$, 1.03, 0.06, $p > 0.05$, for the 40%, 50%, and 60% conditions, respectively). Nevertheless, the beta weights for the lightness – darkness factor were reliably larger for the 40% textural condition than for the 60% condition ($t_{31} = 2.06$, $p < 0.05$), indicating that there is a weak lightness – darkness asymmetry when analyzed over participants.

Although the pattern of the present results appears to indicate that perceived 3-D area, after amodal completion, dominates 2-D area in determining which figure – ground reversed pair is preferred for the yellowness – blueness dimension, an alternative explanation is that participants tend to underestimate the amount of 2-D area covered by the figural texture relative to that covered by the background (eg perhaps the 40% texture condition looks like 30% texture, the 50% condition looks like 35% texture, and the 60% condition look like 40% texture). If so, they could simply be choosing the pair in which the yellower texture elements appeared to occupy less 2-D area than the ground. To evaluate this possibility, we asked participants to "compare the total area of the foreground squares with the total amount of visible area of the background square". They were also told "Do not consider any background covered by the foreground squares when making your judgment". As shown in figure 5, participants actually overestimated the relative amount of 2-D area occupied by the figure by substantial amounts ($F_{1,31} = 114.17$, $p < 0.001$), which undercuts the possibility that participants always chose pairs with yellower figures because they thought that the textured region had a smaller retinal area. It should also be noted that the degree to which participants overestimate the figural area increased as figural area increased ($F_{3,93} = 12.01$, $p < 0.001$). Furthermore, the overestimation is overall larger for lighter figures on darker grounds than the darker figures on lighter grounds ($F_{1,31} = 15.00$, $p < 0.01$), which is not surprising given previous work on how lightness affects perceived size [eg Münster's (1941) so-called 'irradiation' effect; but see von Békésy (1970)]. The present finding that the size of the small squares is overestimated is contrary to the Wolff illusion, in which people overestimate the size of the ground (Wolff 1934; Bonato and Cataliotti 2000). The discrepancy could be due to the nature of the present task, in which people were asked explicitly to ignore the occluded parts of the ground in judging the image-based area of the figure. It seems likely that the Wolff effect occurs with more automatic judgments of area, in which the ground is amodally completed behind the figure in a more natural surface-based percept. Further investigation of this effect is currently underway and will be reported in a subsequent article.

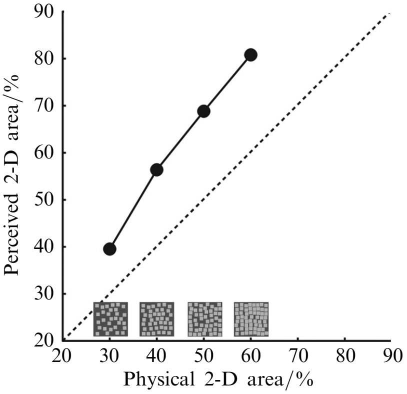

Figure 5. The estimated perceived 2-D area (filled circles) occupied by the texture relative to the visible parts of the ground for the 30%, 40%, 50%, and 60% configurations as a function of the 2-D area occupied by the texture. The dashed line represents actual percentages.

Based on these data it is clear that participants prefer color combinations to the extent that the figural region is yellower and lighter and the ground is bluer and darker. It is also clear that the perceived 3-D area of the two regions, after amodal completion due to the depth information, governs the effect. Still, it is unclear whether figure–ground organization is required to obtain these preference asymmetries. In experiment 3 we test whether the same effects exist when the component colors are not nested spatially and are separated by a gap in a side-by-side mosaic configuration that does not produce figure – ground organization.

4 Experiment 3. Effects of area for separated regions

Thus far we have only measured preference asymmetries in displays with clear figure – ground organization. In the present experiment we tested displays containing two rectangles separated by a gap, so they appeared as a 'mosaic' of regions in the same depth plane (ie with no figure – ground organization). If the same pattern of results emerges as reported in experiments 1 and 2, then figure – ground organization and surroundedness are not prerequisites for preference asymmetries in color combination preferences. It turns out that the answer is different for yellowness – blueness than it is for lightness – darkness. We chose to use displays that were divided horizontally to determine whether participants preferred lower regions to be darker, as Bullough (1907) reported.

4.1 *Methods*

4.1.1 *Participants.* The participants were twenty-six undergraduates at the University of California, Berkeley, who consented to participate. All of them had normal color vision (screened with the Dvorine Pseudo-Isochromatic Plates). The Committee for the Protection of Human Subjects at the University of California, Berkeley, approved the experimental protocol.

4.1.2 *Design, displays, and procedure.* There were two types of spatial configurations, one with a short top region (300 pixels, 7.4 deg × 61 pixels, 1.4 deg) and tall bottom region (300 pixels, 7.4 deg × 239 pixels, 5.7 deg) and the other with a short bottom region and a tall top region (see icons below the x-axis in figure 6 for examples of short-top/tall-bottom displays). The top and bottom regions were separated by a 10 pixel, 0.2 deg gap, which was the same color as the gray background. The pairs within a trial were always spatially identical and only varied in top – bottom assignment of the colors. The two pairs

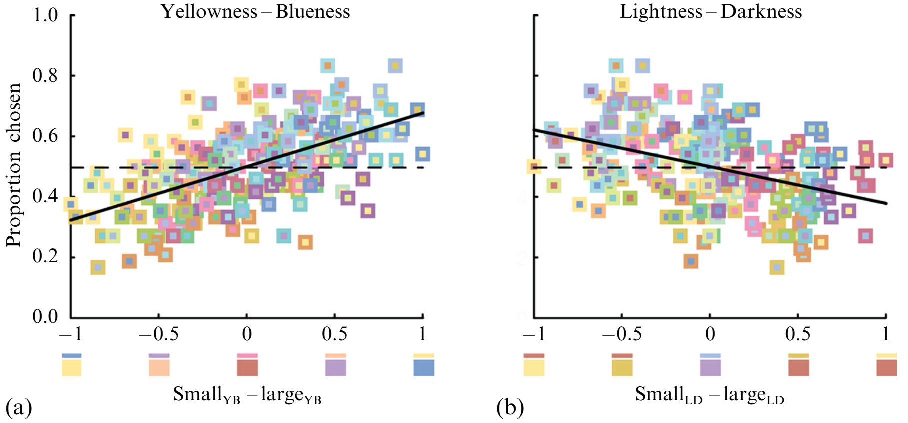

Figure 6. [In color online.] The proportion of times each pair was chosen as a function of the (a) yellowness – blueness and (b) lightness – darkness difference between the small and large regions. Data point colors represent the colors of the pairs that were judged. Dashed black lines at a proportion of 0.5 represent 'chance'. Solid black lines represent the best fitting regression line for each texture size condition.

on opposite sides of the screen's vertical midline were separated by a 300 pixel, 7.4 deg gap. All pairwise comparisons of the eight light (L) and eight muted (M) colors were tested to make a total of 240 color pairs. There were a total of 480 trials. The monitor and settings were the same as in experiment 2.

The procedure was the same as in experiment 2, omitting the size-estimation task.

4.2 *Results*

Figure 6 shows the proportion of times each pair was chosen as a function of the difference in yellowness – blueness (figure 6a) and lightness – darkness (figure 6b) between the small-region and large-region colors. These data were averaged over spatial configuration (large-bottom/small-top versus small-bottom/large-top). Regardless of the smaller region's location, participants always preferred the smaller region to be yellower than the larger region, as shown by reliable correlations and *t*-tests of the beta weights (obtained from logistic regression analyses on the individual participants' data) against zero (small-bottom: $r = +0.56$, $p < 0.001$, $t_{23} = 2.91$, $p < 0.01$; small-top: $r = +0.51$, $p < 0.001$, $t_{23} = 2.42$, $p < 0.05$). However, the beta weights also showed a weak bias toward preferring the upper region to be bluer ($t_{23} = 2.10$, $p < 0.05$).

Unlike experiments 1 and 2, there was a negative correlation between pair preference and the difference in lightness between the small and large region, but *t*-tests comparing the beta weights against zero were not significant (small-bottom: $r = -0.35$, $p < 0.001$, $t_{23} = 1.63$, $p > 0.05$; small-top: $r = -0.42$, $p < 0.001$, $t_{23} = 1.73$, $p > 0.05$). There was also no top versus bottom difference ($t_{23} = 1.45$, $p > 0.05$), which contradicts Bullough's (1907) 'color weight' hypothesis that darker, 'heavier' regions should be preferred when they are lower for (metaphorical) gravitational stability. The discrepancy between our results and Bullough's may have occurred because the two regions in our configurations were separated by a gap, as Bullough (1907) argued that the two colored regions must be perceived as part of the same 'whole' to produce the color weight effect.

Effects of relative area thus exist even without the figure – ground structure of either perceived depth/occlusion or of 2-D surroundedness, but they are not identical. Yellowness – blueness effects for mosaic displays were comparable with the figure –ground configurations studied in experiments 1 and 2. However, lightness – darkness effects for mosaic displays were reversed, such that participants preferred mosaic pairs in which the lighter regions were larger (rather than smaller, as in figure – ground displays) than the darker regions. Although the cause of this reversal is unclear, some participants commented that the mosaic displays made them think of walls and trim and they preferred displays in which the 'walls' were lighter than the 'trim'.

5 General discussion

The results of three experiments have shown that spatial organization influences people's preference for color combinations in systematic ways. People reliably prefer larger regions of color pairs to be bluer and smaller regions to be yellower, regardless of whether the regions are perceived as a figure in front of a ground (experiments 1 and 2) or as adjacent figures in the same depth plane (experiment 3). The effective sizes of the regions in figure – ground displays are determined by their relative perceived 3-D areas after the ground has been completed behind the figure rather than by their 2-D retinal areas (experiment 2). Although we found that preferences for the component colors have a reliable effect on these preference asymmetries, the yellowness – blueness effects are not solely due to such preferences because yellowness – blueness accounts for additional variance after the effects of component color preference have been removed (experiment 1). People also prefer color pairs with smaller regions to be lighter and larger regions to be darker when they are presented in a figure – ground configuration (experiments 1 and 2), but there is a trend toward preferring smaller regions to be darker and larger regions to be lighter when they are presented in a mosaic configuration of coplanar rectangles (experiment 3).

Although the pattern of preferences over different spatial organizations is reasonably clear, the reasons for it are not. Here, we will consider three types of explanations that attempt to go beyond the colorimetric descriptions given above: accounts based on physiology, phenomenology, and ecology.

A possible physiological explanation would be that people prefer yellowish colors to be smaller because the photopic visual system is most sensitive in the range of light that appears roughly yellowish, with $V(\lambda)$ peaking at 555 nm (Wyszecki and Stiles 1967), and aesthetic preference is negatively correlated with visual sensitivity (Fernandez and Wilkins 2008).(5) One problem with this low-level account is that it suggests that preference asymmetries should be governed by relative retinal area (2-D area) of the colored regions. In contrast, the results of experiment 2 show that people prefer pairs that contained yellower figures on bluer grounds, even when the yellower figures activated more retinal area than the bluer grounds. Preference asymmetries thus appear to be formed at a higher-level, after the ground has been amodally completed behind the figure, rather than the low-level of receptor activity. Furthermore, preliminary results from a study in progress (see below) suggest that the red–green dimension becomes relevant when different figural shapes are included that add different semantic meaning to the displays. Low-level mechanisms cannot account for such shape effects.

A possible phenomenological explanation is the idea that more 'intense' colors should occupy less area because people prefer the figure and ground regions to feel balanced in terms of 'intensity', thus implying that the color of the smaller, figural region should feel more intense than the color of the larger ground region. This approach is similar to Itten's (1961/1973) introspective observation that 'balanced' color pairs are produced when high-intensity colors are confined to a smaller area than lower-intensity colors. Munsell's (1921/1969) rule is based on a similar idea that balance is achieved when 'stronger' colors occupy less space than 'weaker' colors. Munsell's phenomenological 'strength' dimension, however, is defined as value × chroma whereas Itten's phenomenological 'brilliance' or 'intensity' dimension is defined by Goethe's 'light values', which are more strongly related to yellowness–blueness ($r = 0.88$) than to lightness–darkness ($r = 0.52$). Thus, the above results in terms of yellowness–blueness effects in all spatial configurations can be interpreted as supporting Itten's hypothesis.

Given that experienced color intensity also varies strongly with the lightness of a colored region, the same balanced-intensity hypothesis implies that people should like lighter regions to be smaller and darker regions to be larger. This is true for the figure–ground displays (experiments 1 and 2), but not for the mosaic displays (experiment 3). Indeed, the pattern reverses (though not significantly) for mosaic displays with lighter regions being preferred when they are larger rather than smaller. It is not clear why this should be true from a phenomenological standpoint.

Another possible phenomenological explanation for the preference asymmetries is that people prefer displays that are less visually discomforting (Wilkins et al 1984). This would make sense if color combinations with larger bluer regions are somehow visually less discomforting than combinations with larger yellower regions. Juricevic et al (2010) tested this idea by comparing people's judgments of both artistic merit and visual discomfort of Mondrian patterns that varied in color along a single axis in a variant of MacLeod and Boynton (1979) color space. Judgments of visual discomfort and artistic merit were negatively correlated, whereby people preferred color combinations that were less visually discomforting. However, they also found that, although visual discomfort was quite symmetric in terms of the amounts of blue versus yellow-orange present in

---

(5) Note that this negative correlation is contrary to Zeki's (1999) argument that aesthetic response is positively related to degree of neural activation.

the Mondrian images they studied, artistic merit (ie preference) was strongly skewed toward preferring those with more blue than yellow-orange. This result implies that visual discomfort cannot account for the blue – yellow preference asymmetries we report above.

A different kind of explanation is that strong ecological associations are responsible for the obtained spatial asymmetries in preference. There is indirect suggestive support for this hypothesis in that people prefer displays that are consistent with natural scene statistics in terms of spatial frequency (Fernandez and Wilkins 2008) and color (Juricevic et al 2010). In the color domain, colors in natural outdoor scenes tend to vary most along a yellowness – blueness dimension (Ruderman et al 1998; Webster et al 2007), and Juricevic et al (2010) found that images centered on a yellow – blue axis have higher ratings of artistic merit.

Applying this ecological hypothesis to the present experiments with a more cognitive approach, it is possible that people (consciously or nonconsciously) associate the displays with familiar objects/entities, and their preference for those objects/entities in turn influences preference for the color pairs. Palmer and Schloss (2010) found clear support for this kind of ecological account of individual color preferences, which they called the ecological valence theory (EVT): people like colors to the degree that they like the things that are those colors. Schloss and Palmer (2011) argue that if ecological associations influence single color preferences, and single color preferences influence pair preferences, as they do, then ecological associations of single colors influence pair preferences. A further implication of the EVT is that ecological associations for color pairs, as wholes, would also influence pair preferences.

There are appealing ecological facts about prototypical figure – ground relations that may account for many of the present results. For example, perhaps people like to see smaller yellower, lighter regions surrounded by larger bluer, darker regions as a generalization of the fact that most people like bright, sunny days, when they see the smaller yellow sun against the larger surrounding blue sky. Because the spatial reversal of this figure – ground combination (blue-on-yellow) has no particular ecological significance, or is perhaps an unnatural depiction of the sun-against-the-sky scenario, the yellow-on-blue organization would be strongly preferred to its reversal on the basis of ecological factors. The generalization gradient from this prototype might be strong enough that similar, though weaker, asymmetries hold for figures whose color is yellowish against grounds whose color is bluish. Another suggestive finding along these lines is the fact that people preferred the bluer region to be the upper region in mosaic organizations, consistent with the position of the sky in a landscape.

A somewhat different ecological argument can be made based on atmospheric perspective: the phenomenon in which objects that are farther away appear bluer due to the greater amount of atmosphere between the observer and the further object (see Palmer 1999). Perhaps the fact that people perceive the ground as farther away than the figure leads them to prefer the depth-consistent alternative in which the ground is bluer. However, this argument is strongly based on perceived relative depth, and there were similar yellowness – blueness effects in the mosaic configurations, where there is little, if any, perceived depth difference. Although atmospheric perspective cannot be the sole cause of the yellowness – blueness asymmetry, it might be a contributing factor in the figure – ground displays.

The corresponding preference for lighter figures surrounded by darker grounds might be a generalization of a plausible ecological preference for clear nights in which a bright moon is seen against a dark sky, as well as a bright sun against a darker sky. The reversal of this effect for the mosaic configurations with pairs containing lighter large regions and darker small regions being preferred may be due to other ecological situations being more relevant to such organizations. As mentioned above, some participants spontaneously volunteered that the mosaic displays reminded them of a wall-and-trim situation, and they preferred the walls to be lighter. This preference may occur because lighter walls tend to make rooms appear taller (Oberfeld et al 2010) and/or larger.

Although the ecological explanations just advanced are clearly ad hoc, they should not be taken lightly. The extremely close link Palmer and Schloss (2010) found between average preferences for single colors and average ratings of the degree to which people like the ecological objects that characteristically have those colors—a correlation of 0.89 using their procedures—raises the possibility that similar effects may underlie preferences for color pairs, and it is quite possible that the spatial structure of such displays plays a significant role. We are currently testing the possibility that ecological associations influence preference asymmetries by geometrical variations in figural shape, including circles and semicircles, which are reminiscent of the sun where it is high in the sky and at sunset, respectively. Preliminary results show that including these additional figural shapes causes a robust preference asymmetry in the redness – greenness dimension to appear for all shapes including squares (like the displays in experiment 1), which was entirely absent from all of the experiments presented here. Further evidence suggests that sun/sunset imagery from the circle and semicircle figural shapes is responsible for the relevance of the redness – greenness dimension. When prompted after the color preference task, a large proportion of participants reported that the displays reminded them of suns and sunsets and that they preferred pairs in which the spatial assignment of the colors was consistent with sun imagery (ie red, yellow, and orange figures on cyan, blue, and purple grounds).

The goal of the present experiments was to determine whether the spatial organization of colors influences preferences for color pairs, and if so, how. Spatial organization does indeed matter, and the perceived 3-D representation of colored surfaces (rather than the 2-D representation of colored retinal regions) is the dominant spatial factor. This new result has important implications for producing or modifying visual media by applying theoretic claims (eg Goethe 1810/2006; Moon and Spencer 1944; Munsell 1921/1969; Itten 1961/1973) and/or empirical findings about human preference for color combinations (eg Granger 1953; Morriss and Dunlap 1987, 1988; Schloss and Palmer 2011). For example, effective use of the robust yellowness – blueness asymmetry to optimize the aesthetic impact of websites requires the graphic designer to consider the perceived depth relations among the areas in question and the sizes of the corresponding perceptually completed surfaces rather than their 2-D pixel-based areas. Similar considerations arise in other applications whose aim is modifying color to enhance aesthetic appearance (eg Cohen-Or et al's 2006 photograph 'harmonization' algorithm). More generally, the present results imply that aesthetic preferences operate on high-level representations of surfaces in depth rather than on low-level representations of image structure.

Acknowledgments. We would like to thank two anonymous reviewers for their helpful comments. We thank Joseph Austerweil, Christie Nothelfer, Rosa Poggesi, Madison Zeller, Lily Lin, Lilia Prado León, Patrick Lawler, Laila Kahn, Cat Stone, Divya Ahuja, and Jing Zhang for their help with this research. The project was supported by the National Science Foundation (Grant No 0745820) and a Google Gift to SEP, as well as by a generous gift of product coupons from Amy's Natural Frozen Foods (Santa Rosa, CA) to KBS, with which we 'paid' many of our participants. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation, Google, or Amy's Natural Frozen Foods.

References

Békésy G von, 1970 "Apparent image rotation in stereoscopic vision: The unbalance of the pupils" *Perception & Psychophysics* **8** 242 – 247

Bonato F, Cataliotti J, 2000 "The effects of figure/ground, perceived area, and target saliency on the luminosity threshold" *Perception & Psychophysics* **62** 341 – 349

Bullough E, 1907 "On the apparent heaviness of colours" *British Journal of Psychology* **2** 111 – 152

Cohen-Or D, Sorkine O, Gal R, Leyvand T, Xu Y, 2006 "Color harmonization", in *ACM SIGGRAPH 2006 Papers* (New York: ACM) pp 624 – 630

Fernandez D, Wilkins A J, 2008 "Uncomfortable images in art and nature" *Perception* **37** 1098 – 1113

Granger G W, 1952 "Objectivity of color preferences" *Nature* **170** 778 – 780

Granger G W, 1953 "Area balance in color harmony: An experimental study" *Science* **117** 59 – 61

Goethe J W, 1810/2006 *Theory of Colours* translated by C L Eastlake (1840) from *Farbenlehre* of 1810 (Cambridge, MA: MIT Press)

Itten J, 1961/1973 *The Art of Color* (New York: Van Nostrand Reinhold)

Juricevic I, Land L, Wilkins A, Webster M A, 2010 "Visual discomfort and natural image statistics" *Perception* **39** 884 – 899

Kanizsa G, 1979 *Organization in Vision: Essays on Gestalt Perception* (New York: Praeger)

Kimchi R, Palmer S E, 1982 "Form and texture in hierarchically constructed patterns" *Journal of Experimental Psychology: Human Perception and Performance* **8** 521 – 535

Kimchi R, Palmer S E, 1985 "Separability and integrality of global and local levels of hierarchical patterns" *Journal of Experimental Psychology: Human Perception and Performance* **6** 673 – 688

Linnett C M, Morriss R H, Dunlap W P, Fritchie C J, 1991 "Differences in color balance depending upon mode of comparison" *Journal of General Psychology* **118** 273 – 283

MacLeod D I, Boynton R M, 1979 "Chromaticity diagram showing cone excitation by stimuli of equal luminance" *Journal of the Optical Society of America* **69** 1183 – 1186

Morriss R H, Dunlap W P, Hammond S E, 1982 "Influence of chroma on spatial balance of complementary hues" *American Journal of Psychology* **95** 323 – 332

Morriss R H, Dunlap W P, 1987 "Influence of value on spatial balance of color pairs" *Journal of General Psychology* **114** 353 – 361

Morris R H, Dunlap W P, 1988 "Influence of chroma and hue on spatial balance of color pairs" *Color Research and Application* **13** 385 – 388

Moon P, Spencer D E, 1944 "Area in color harmony" *Journal of the Optical Society of America* **34** 93 – 103

Munsell A H, 1921/1969 *A Grammar of Color* Ed. F Birren (New York: Van Nostrand Reinhold)

Munsell A H, 1966 *The Munsell Book of Color—Glossy Collection* (Baltimore, MA: Munsell Color Company)

Münster C, 1941 "Über den Einfluss von Helligkeits unterschieden in beiden Augen auf die stereoskopische Wahrnehmung" *Zeitschrift für Sinnesphysiologie* **69** 245 – 260

Nelson R, Palmer S E, 2001 "Of holes and wholes: The perception of surrounded regions" *Perception* **30** 1213 – 1226

Oberfeld D, Hecht H, Garner M, 2010 "Surface lightness influences perceived room height" *Quarterly Journal of Experimental Psychology* **63** 1999 – 2011

Palmer S E, 1999 *Vision Science: Photons to Phenomenology* (Cambridge, MA: MIT Press)

Palmer S E, Schloss K B, 2010 "An ecological valence theory of human color preference" *Proceedings of the National Academy of Sciences of the USA* **107** 8877 – 8882

Rubin E, 1921/1958 "Figure and ground", in *Readings in Perception* Eds D C Beardslee, M Wertheimer (New York: Van Nostrand Reinhold) pp 194 – 203

Ruderman D L, Cronin T W, Chiao C C, 1998 "Statistics of cone responses to natural images: implications for visual coding" *Journal of the Optical Society of America* **15** 2036 – 2045

Schloss K B, Palmer S E, 2011 "Aesthetic response to color combinations: Preference, harmony, and similarity" *Attention, Perception, & Psychophysics* **73** 551 – 571

Schloss K B, Poggesi R M, Palmer S E, 2011 "Effects of university affiliation and 'school spirit' on color preferences: Berkeley versus Stanford" *Psychonomic Bulletin & Review* **18** 498 – 504

Webster M A, Mizokami Y, Webster S M, 2007 "Seasonal variations in the color statistics of natural images" *Network: Computation in Neural Systems* **18** 213 – 233

Wilkins ..., 1984

Wolff W, 1934 "Induzierte Helligkeitsveränderung" *Psychologische Forschung* **20** 159 – 194

Wyszecki G, Stiles W S, 1967 *Color Science: Concepts and Methods, Quantitative Data and Formulas* (New York: John Wiley)

Zeki S, 1999 "Art and the brain" *Journal of Consciousness Studies* **6** 76 – 96

Appendix

Table A1. CIE 1931 values and Munsell values for the 32 chromatic colors (from Palmer and Schloss 2010).

Color		*x*	*y*	*Y*	Hue	Value/chroma
Red	saturated	0.549	0.313	22.93	5 R	5/15
	light	0.407	0.326	49.95	5 R	7/8
	muted	0.441	0.324	22.93	5 R	5/8
	dark	0.506	0.311	7.60	5 R	3/8
Orange	saturated	0.513	0.412	49.95	5 YR	7/13
	light	0.399	0.366	68.56	5 YR	8/6
	muted	0.423	0.375	34.86	5 YR	6/6
	dark	0.481	0.388	10.76	5 YR	3.5/6
Yellow	saturated	0.446	0.472	91.25	5 Y	9/12
	light	0.391	0.413	91.25	5 Y	9/6.5
	muted	0.407	0.426	49.95	5 Y	7/6.5
	dark	0.437	0.450	18.43	5 Y	5/6.5
Chartreuse	saturated	0.387	0.504	68.56	5 GY	8/11
	light	0.357	0.420	79.90	5 GY	8.5/6
	muted	0.360	0.436	42.40	5 GY	6.5/6
	dark	0.369	0.473	18.43	5 GY	4.5/6
Green	saturated	0.254	0.449	42.40	3.75 G	6.5/11.5
	light	0.288	0.381	63.90	3.75 G	7.75/6.25
	muted	0.281	0.392	34.86	3.75 G	6/6.25
	dark	0.261	0.419	12.34	3.75 G	3.75/6.25
Cyan	saturated	0.226	0.335	49.95	5 BG	7/9
	light	0.267	0.330	68.56	5 BG	8/5
	muted	0.254	0.328	34.86	5 BG	6/5
	dark	0.233	0.324	13.92	5 BG	4/5
Blue	saturated	0.200	0.230	34.86	10 B	6/10
	light	0.255	0.278	59.25	10 B	7.5/5.5
	muted	0.241	0.265	28.90	10 B	5.5/5.5
	dark	0.212	0.236	10.76	10 B	3.5/5.5
Purple	saturated	0.272	0.156	18.43	5 P	4.5/17
	light	0.290	0.242	49.95	5 P	7/9
	muted	0.287	0.222	22.93	5 P	5/9
	dark	0.280	0.181	7.60	5 P	3/9

ISSN 0301-0066 (print) ISSN 1468-4233 (electronic)

PERCEPTION

VOLUME 40 2011

www.perceptionweb.com