The role of chromatic variance in modulating color appearance

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Chromatic target patches embedded in a chromatically variegated surround appear less saturated than when they are embedded in an achromatic uniform surround (Brown & MacLeod, 1997), which can be construed as either a form of gamut expansion for targets on uniform surrounds or as a form of gamut compression for targets on variegated surrounds. Ekroll, Faul, and Niederée (2004) suggested that the difference in perceived chromaticity on the two surrounds is caused by a layered scene decomposition, wherein the increased saturation of targets on homogenous surrounds is attributed to a decomposition of a target patch into a chromatically saturated transparent layer overlying an achromatic background. Here, we report asymmetric matching data that show the perceived chromaticity difference observed on the two surrounds depends on the particular direction of chromatic variation applied to the variegated surround. If the chromatic variegated surround has the same or a similar hue to that of the target and the saturation variation of the surround is large compared to the saturation of the target the gamut expansion effect is also large. However, if the variegated surround has a different hue than the hue of the target, the perceived chromaticity difference is small and largely does not depend on the variation in saturation of the surround. These results suggest that a layered scene representation cannot fully explain the gamut expansion effect and suggest that a chromatically tuned contrast gain control mechanism may contribute to the difference in perceived color of targets on achromatic homogeneous surrounds and chromatically variegated surrounds.

Introduction

Light reflected from an opaque object depends on the spectral power distribution of the incident light and the reflectance properties of its surface. However, in the human visual system, the perceived color of an object also depends on contextual factors, including the color of the surrounding objects. This influence of color of the surrounding objects on perceived color is referred to as color induction. The perceived color of an object also depends on the color variation present in the surround, such that targets embedded in surrounds with low chromatic variance can appear more saturated than the same targets embedded in a high-chromatic-variance surround.

A typical stimulus illustrating the gamut expansion effect is shown in Figure 1. In this figure, four targets were chosen from four quadrants of the MacLeod and Boynton (MB) isoluminant chromaticity space in such a way that the contrast between the targets and the achromatic surround is approximately equal and the targets lie on the two opponent chromatic axes (MacLeod & Boynton, 1979). The chromatic samples that form the variegated surround were chosen using a Gaussian sampling distribution that attempts to compensate for the perceptual nonuniformity of the MB space. In this configuration, the target patches appear more saturated when they are embedded in a uniform achromatic surround than when they are embedded in a variegated surround composed of chromatic patches of the same luminance and mean (achromatic) chromaticity as the achromatic surround. Brown and MacLeod (1997) dubbed the perceived chromaticity difference “gamut expansion” if the perceived color of the variegated surround was taken as a standard or “gamut compression” if the perceived color of the targets on the uniform surround was taken as the standard.

Brown and MacLeod (1997) investigated gamut expansion by using three different types of variegated surrounds. In the first condition, the hue and the luminance of the variegated surround both varied; in the second, the variegated surround was formed using...
achromatic samples with different luminance values; in the third, the variegated surround was composed of isoluminant patches that varied in hue. Figure 1 illustrates a typical stimulus in which the variegated surround contains isoluminant chromatic patches. In all three conditions, the mean color of all the surround patches was achromatic. Brown and MacLeod used six target patches, including two achromatic targets with different luminance values and four isoluminant color targets. They found the largest effect (perceived chromaticity difference from the homogeneous surround) was observed for the variegated surround that varied in both hue and luminance whereas the achromatic luminance variation produced the smallest effect. In all three conditions, Brown and MacLeod chose the chromatic patches to form the variegated surround evenly from all parts of the color space. Based on the observed results, they argued that the effect occurs at a level beyond the opponent transform of the cone signals.

Recently, Ekroll, Faul, and coworkers (Ekroll & Faul, 2012; Ekroll, Faul, & Niederée, 2004; Faul, Ekroll, & Wendt, 2008) offered a midlevel surface explanation for gamut expansion. Their explanation assumes that the perceived color of the targets in the variegated background corresponds to the “true” color of the targets and that the increase in perceived saturation of the targets embedded in the achromatic background arose from a layered scene decomposition (i.e., transparency). The concept of layered image representations can be traced back to von Helmholtz’s work on color (von Helmholtz, 1924) and found modern expression in Metelli’s model of transparency (Metelli, 1974a, 1974b), Barrow and Tenenbaum’s (1978) intrinsic image analysis, and recent claims that layered image representations may play a causal role in modulating the experience of both lightness and color (Anderson, 1997; Anderson & Winawer, 2005, 2006, 2008; Singh & Anderson, 2002, 2006; Wollschläger & Anderson, 2009). Faul et al. (2008) have argued that gamut expansion may also arise from a layered scene decomposition. The claim is that targets on a homogeneous achromatic background are decomposed into two components: an achromatic component, which forms the underlying background, and a transparent chromatic overlay. Under this logic, the decomposition into layers causes an increase in the perceived saturation of the target region because the target is being experienced as containing two components: a saturated chromatic overlay caused by the target layer itself and an achromatic background, which reduces the overall saturation of the target region. The target therefore appears more saturated because the achromatic “component” of the target region is attributed to the underlying surface rather than the target itself.

The scission explanation can be tested by manipulating the photometric and geometric conditions that must be satisfied for scission to occur. Geometrically, scission requires that the textural properties or contours present in both the background and target must continue into the overlay region. Photometrically, the contrast of any visible features in the overlay region must be lower than those in plain view. For homogeneous targets on homogeneous surrounds, it has been argued that scission will only occur when the contrast between the target and the surround is low. Note that the uniform target colored patches embedded in a variegated surround violate the conditions required for scission, and hence, homogeneous targets embedded in a variegated surround should not induce a layered scene representation. Scission should only occur when the textural properties of the target and surround match, such as when a homogeneous target is placed on a homogeneous surround or when textured targets are placed on a textured surround (Anderson & Khang, 2010; Anderson & Winawer, 2005, 2008; Wollschläger & Anderson, 2009). When homogeneous targets are placed on homogeneous surrounds, the colored target patches can theoretically be decomposed into an achromatic background and a more saturated chromatic overlay; i.e., the perceptual attribution of a shared achromatic component of the surround and the target is presumed to increase the perceived saturation of the target. Ekroll and coworkers (Ekroll et al., 2004; Faul et al., 2008) argued that gamut expansion is caused by the scission of targets embedded in the achromatic surround rather than a compression of perceived saturation of targets on the variegated

Figure 1. The four circular targets in the left and the right displays are physically identical. The four targets in the left display are embedded in an achromatic surround, and the four targets in the right display are embedded in a chromatic variegated surround formed by isoluminance samples taken from all different hues in the MB space. The saturation of the target and the surround was increased to make them visible relative to the actual stimuli used in the experiment, which substantially reduces or eliminates any of the perceived chromatic differences reported in our experiments.
surround. If this thesis is correct, then gamut expansion should be independent of the chromaticity of the variegated surround as long as the conditions for scission do not hold; i.e., the magnitude of the gamut expansion effect should not depend on the particular chromatic variation chosen for the variegated surround.

In this paper, we investigate gamut expansion in greater detail by varying the hue content of the variegated surround with respect to the target hue. To anticipate our findings, our data shows that gamut expansion depends on the chromatic content present in the variegated surround, suggesting that scission cannot provide a complete explanation for this phenomenon.

<table>
<thead>
<tr>
<th>Variation level</th>
<th>STD along L axis</th>
<th>STD along S axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0014</td>
<td>0.0111</td>
</tr>
<tr>
<td>2</td>
<td>0.0028</td>
<td>0.0222</td>
</tr>
<tr>
<td>3</td>
<td>0.0056</td>
<td>0.0444</td>
</tr>
<tr>
<td>4</td>
<td>0.0112</td>
<td>0.0888</td>
</tr>
<tr>
<td>5</td>
<td>0.560</td>
<td>0.4440</td>
</tr>
</tbody>
</table>

Table 1. Standard deviations used in creating the Gaussian distributed chromatic samples to form the variegated surrounds with different levels of variation in the direction of the L and S axes of the MB space.

Experiments 1a and 1b: Effect of hue and saturation background variance on gamut expansion

In Experiment 1a, the gamut expansion was tested using both static and dynamic variegated surrounds. To investigate how the gamut expansion varies with variation in surround saturation, five different levels of surround variation were chosen (see Table 1) with one-dimensional Gaussian chromatic samples taken along the L axis and S axis (see Figure 2) and samples taken from a two-dimensional Gaussian distribution with parameters listed in Table 1 from MB space. In Experiment 1b, the dependence of gamut expansion on the size of chromatic patches in the variegated surround was tested for the static condition used in Experiment 1a.

Three variegated surrounds were created using isoluminance chromatic patches chosen from a Gaussian distribution with a mean at the achromatic point of MB space and standard deviations given in Table 1. To generate the chromatic samples used for the variegated surround in the L variation condition, a one-dimensional Gaussian distribution of samples was taken along the L axis of the MB space centered at the achromatic point using the standard deviation (STD) values listed in the second column of Table 1. Similarly, to form the variegated surround for the S variation condition, the STD values listed in third column of Table 1 were used to generate one-dimensional samples taken on the S axis centered at the achromatic point of the MB space. In the L&S variation condition, the standard deviations listed in the second and third columns were used to generate a two-dimensional Gaussian distribution of samples centered at the achromatic point of the MB space. Here, different standard deviations were chosen for the L and S axes in an attempt to account for the perceptual nonuniformity of the MB space with respect to just noticeable differences in CIELab space. As receptive field sizes vary along the visual pathway, the size of the effect may also vary with the spatial scale of the patches that form the variegated surround. We therefore used three different patch sizes to evaluate whether the spatial scale of the texture elements that formed the variegated surround modulates the size of gamut expansion.

Experiment 1a was designed to investigate (a) whether the magnitude of gamut expansion depends on the hue of the patches that form the variegated surround relative to the hue of the target and (b) whether the size of gamut expansion depends on the variance of the chromatic patches used in creating the variegated surround. Experiment 1b assessed whether the size of gamut expansion depends on the size of the patches that form the variegated surround. Experiments 1a and 1b were also designed to investigate whether gamut expansion depends on the particular...
color distribution of the chromatic patches that form the variegated surround. To address this question, dynamic versions of the backgrounds were constructed by generating 25 different variegated surrounds by independently choosing chromatic patches from a Gaussian distribution (parameters listed in Table 1), which were then animated as dynamic noise with a frame rate of 20 Hz.

Methods

Observers

The experimental subjects were tested for color blindness at the start of the experiment using Ishihara color plates (Ishihara, 1967). Only the participants with normal color vision were allowed to participate in the experiment. Ethics approval was obtained from the University of Sydney. The observers participated for course credit and were recruited using an online system at the School of Psychology, University of Sydney. The participants were graduate and undergraduate students. In total, 18 subjects performed the matching task for the 5 × 5 pixels of patch size condition, 36 subjects performed the matching task for the 30 × 30 pixels of patch size condition, and 15 subjects performed the matching task for the 50 × 50 pixels of patch size condition.

Stimuli

Examples of the stimuli are shown in Figures 1 and 2. In both figures, the saturation of the targets and the surrounds has been increased relative to the values used in the experiments to increase their visibility. It should be noted that this greatly reduces or eliminates the magnitude of the perceived color differences in the two conditions. One half of the stimuli were presented on an isoluminant achromatic background, and the other half contained a variegated surround formed by isoluminant chromatic patches. Four target chromaticities were chosen, two along the L axis and the other two along the S axis chosen such that they straddled the achromatic point of MB space. The color coordinates of the four targets in MB space are listed in Table 2. The first variegated surround (L&S variation) is composed of color patches chosen from a two-dimensional Gaussian distribution such that the mean of all the patches is achromatic with standard deviation given in Table 1 (see Figure 1). The second surround (L variation) was created by taking samples along the L axis of MB space that passes through the achromatic point, and the mean color of all the patches is achromatic (see Figure 3a). The third surround (S variation) was created by taking isoluminant samples along the S axis that passes through the achromatic point. The mean color of all the test patches was achromatic (see Figure 3b).

For each of the three variegated surrounds (L, S, and L&S variations), five different ranges of saturation levels were used (see Table 1). In the first level, the standard deviation of the Gaussian used to generate the surround was smaller than the distance between the achromatic point of the MB space and the two targets that fell along that axis of MB color space. In the fifth level of variation, the standard deviation was larger than the distance between the achromatic point and the

<table>
<thead>
<tr>
<th></th>
<th>L coordinate</th>
<th>S coordinate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>0.5153</td>
<td>0.3446</td>
</tr>
<tr>
<td>Green</td>
<td>0.5097</td>
<td>0.3446</td>
</tr>
<tr>
<td>Purple/blue</td>
<td>0.5125</td>
<td>0.3252</td>
</tr>
<tr>
<td>Yellow</td>
<td>0.5125</td>
<td>0.3641</td>
</tr>
</tbody>
</table>

Table 2. Coordinates of the four targets used in the experiment on the MB space.

Figure 3. Typical stimuli used in the experiment. In the left panel, the variegated surround was created by taking isoluminant samples from the L axis that passes through the achromatic point of the MB space. The variegated surround in the right-hand panel was created using isoluminant samples taken from the S axis that passes through the achromatic point. Saturation of the target and the surround were increased to make them visible relative to the actual stimuli used in the experiment, which greatly reduces or eliminates the perceived color differences in the two surround conditions.
targets that fell along that axis of MB space. Different levels of variation were used to study the effect of gamut expansion with respect to the saturation of the target. In order to control the statistical distribution of the patches that border the targets, dynamic versions of the variegated surrounds were constructed. Specifically, 25 different frames for each of the variation levels were created as described above for the static surrounds, which were then played as a movie loop with a refresh rate of 20 Hz.

To assess the influence of the spatial scale of the texture elements of the surround on gamut expansion, Experiment 1b used three different patch sizes: $5 \times 5$ pixels (0.107° visual angle), $30 \times 30$ pixels (0.429° visual angle), and $50 \times 50$ pixels (0.787° visual angle, see Figure 4). Three different chromatic variation conditions were used (L&S, L, and S variation conditions). In Experiment 1b, the variegated background was static.

The stimuli were presented on a LaCie Electron 22 Blue IV monitor running at a refresh rate of 75 Hz and with a resolution of $1280 \times 1024$. The display was controlled by a Dell Precision T3610 desktop computer running a Microsoft Windows 7 operating system (64 bits). Matlab (R2010a; Mathworks) simulation software and Psychophysics Toolbox (Brainard, 1997) were used to present the stimuli and to record the data. The display was calibrated using the method described by Brainard (1989) using spectrophotometer PR670 (PhotoResearch). Smith and Pokorny’s cone sensitivity functions in the wavelength range of 400 nm to 700 nm were used to create a MB space. The cone sensitivity functions and the individual phosphor spectra were sampled in 1-nm intervals to obtain a more accurate estimate for the transfer matrix used to convert monitor primaries to cone fundamentals. The gamma of each of the phosphors (red, green, and blue) was calibrated separately. The displays were viewed in a dark room at a distance of approximately 80 cm. The light emitted by the display monitor was the only source of light. The test and match stimuli were the same size and subtended a visual angle of 8.578°.
Results and discussion

The experimental results are shown in Figures 5 and 6. In each figure, the left-hand panel shows the results for the static background and the right hand panel shows the results for the dynamic background. In order to compare the gamut expansion effect for different chromatic variances with respect to the standard condition (L&S variation), the ratio between the size of gamut expansion effect was calculated as given in Equation 1. Normalizing the size of gamut expansion effect obtained for the L or S variation conditions by the gamut expansion observed for the L&S variation condition of the same background variation level (either static or dynamic surround) was performed to eliminate the perceptual nonuniformity of the MB space. It is known that the MB space is highly nonuniform and that a unit Euclidean distance along the S axis corresponds to a smaller perceptual difference compared to that of the L axis. Comparing the absolute size of gamut expansion effect in these two directions is therefore inappropriate. Therefore, the size of the gamut expansion was normalized by the corresponding effect obtained for the standard condition (L&S variation condition) to provide a measure that is proportional to the perceptual difference rather than the Euclidean distance along the two axes in the MB space:

\[
\text{Gamut expansion ratio} = \frac{\text{Distance from test target to match target in L or S variation}}{\text{Distance from test target to match target in LS variation}}
\]  

(1)

In each panel in Figure 5, two sets of colored bars (red and green, purple and yellow) illustrate the gamut expansion ratio of the targets in the L or S variation conditions, respectively. The color of the bars denotes the color of the target in each figure, and the height of the bars shows the size of gamut expansion effect with respect to the L&S variegated surround condition. If the type of surround variation did not affect the magnitude of gamut expansion, then the height of each bar should be equal to one. A bar height smaller than one means the size of the gamut expansion effect for the given condition is smaller than that of the L&S variation condition. Similarly, a bar height larger than one means that the relative size of gamut expansion effect is larger than the magnitude of the effect observed with the L&S condition. In this experiment, Bonferroni-corrected alpha values of 0.0125 per t test was applied to assess the statistical significance of gamut expansion effects in the L and S variation conditions.

The main finding of this experiment is that the gamut expansion is relatively large when the variegated surround contains patches that have similar hue and greater saturation than the target. However, if the hue of the surround patch is different from the target, gamut expansion is relatively small, and the effect slightly reduces with saturation of the surround. It is also apparent that gamut expansion is somewhat smaller for the dynamic condition than for the static condition. The gamut expansion for both the L and S variation conditions are normalized using the corresponding L&S variation condition, so it is expected that the normalized gamut expansion should be the
same for the corresponding static and dynamic conditions. However, the difference between the gamut expansion observed in the static and dynamic conditions may simply be a consequence of temporal averaging. The data for both static and dynamic conditions show that the amount of gamut expansion is proportional to the saturation of the colors in the variegated surround that have the same hue as the target. However, when the noise of the surround is sampled along the full two dimensions of hue, temporal averaging will produce a smaller decrease in the saturation of the colors shared with the targets than will occur for the surrounds that vary only along the chromatic direction of the targets. Thus, the difference between the size of gamut expansion observed with dynamic and static surrounds may simply reflect a

Figure 5. Results for Experiment 1a for background variation level 1 to 5 with 30 × 30 pixels patch size for static and dynamic backgrounds. In variation level 1, the standard deviation used to create the chromatic patches to form the variegated surround is smaller than the distance between the achromatic point and the targets in both axes in MB space. The color of the bars denotes the color of the targets, and the height of the bars shows the mean of the relative size of gamut expansion of the targets with respect to that obtained for the L&S variation condition. Standard error is marked on each bar as an indication of the consistency between subjects. A single star indicates that $p < 0.05$, and a double star indicates that $p < 0.01$. (a–b) Results for variation level 1: For static background in the L variation condition, none of the $t$ tests resulted in a $p$ value smaller than 0.01, and in the S variation condition, all four tests resulted in a $p$ value smaller than 0.001. For the dynamic background with the L variation condition, the difference between red-purple, red-yellow, and green-purple $t$ tests resulted a $p$ value smaller than the alpha value. In the S variation condition, the difference between green-yellow and green-purple $t$ tests resulted in a $p$ value smaller than 0.001. (c–d) Results for variation level 2: For static background in both L and S variation conditions, all the $t$ tests resulted in a $p$ value smaller than 0.01. For the dynamic background condition in both the L and S variation conditions, all the $t$ tests resulted in a $p$ value smaller than 0.01. In the S variation condition, the difference between green-yellow and green-purple $t$ tests resulted in a $p$ value smaller than 0.001. (e–f) Results for variation level 3: For the static background condition in both L and S variation conditions, all the $t$ tests yielded a $p$ value less than 0.01. For the dynamic background condition in both L and S variation conditions, all the $t$ tests resulted in a $p$ value smaller than 0.001. Single star means $p < 0.05$, and double star means $p < 0.01$. (g–h) Results for variation level 4: For the static background condition in both L and S variation conditions, all the $t$ tests resulted in a $p$ value smaller than 0.01. For the dynamic background condition in both L and S variation conditions, all the $t$ tests resulted in a $p$ value smaller than 0.001. Single star means $p < 0.05$, and double star means $p < 0.01$. (i–j) Results for variation level 5: For the static background condition in both L and S variation conditions, all the $t$ tests resulted in a $p$ value smaller than 0.001. Single star means $p < 0.05$, and double star means $p < 0.01$. (g–h) Results for variation level 4: For the static background condition in both L and S variation conditions, all the $t$ tests resulted in a $p$ value smaller than 0.001. Single star means $p < 0.05$, and double star means $p < 0.01$. (i–j) Results for variation level 5: For the static background condition in both L and S variation conditions, all the $t$ tests resulted in a $p$ value smaller than 0.001. Single star means $p < 0.05$, and double star means $p < 0.01$.
difference in the effective saturation of the two surround types. Indeed, the results in Figure 5a and b show that if the saturation variation in the surround is smaller than the saturation of the target, the observed gamut expansion is relatively small (i.e., the difference in perceived hue of the targets on the homogeneous surround is not much different than the perceived hues of the targets on the variegated surround). The size of observed gamut expansion increases with the relative saturation in the variegated surround, but only if the variegated surround has a similar hue as the target patch. If the variegated surround contains different hues than the target, the saturation of the surround has little effect on gamut expansion.

The results in Figures 5 and 6 show that for the surround with L variation, the two targets along the L axis exhibit more gamut expansion than the two targets along the S axis. Similarly, for the variegated surround with S variation, the size of the effect is large for the targets chosen along the S axis compared to that of the targets chosen along the L axis. It is also noteworthy that the size of the gamut expansion effect increases with the amount of saturation variation in the variegated surround relative to the saturation of the target.

From the results presented in Figures 5 and 6, it can be seen that, in most cases in which the surround varied along the L-axis, the red target exhibits a slightly larger size of effect compared to that of the green target. It is unclear what is responsible for this effect. It may reflect a perceptual nonlinearity along the L axis of the MB space. Similarly, the size difference observed in the yellow and purple targets in many of the S variation conditions could also be the effect of perceptual
The data also reveal that the standard errors of matches on the dynamic background are smaller than matches made on the static background. Although the mean color of the variegated surround is achromatic in both the dynamic and static surrounds, the spatial distribution of color bordering the targets in the static surround would be more variable than the dynamic surrounds, which may increase the amount of variability in individual matches in the static surround condition.

From the results presented in Figures 5 and 6, it can also be seen that as the saturation of the variegated surround increases, the amount of gamut expansion observed becomes progressively smaller for targets on surrounds with hues along the color axis orthogonal to the target (i.e., the induction size ratios are all less than one and decrease as saturation increases). There are two noteworthy aspects of this decrease. First, although the induction size ratio decreases, it is not completely abolished. If gamut expansion is caused solely by gain control mechanisms oriented along the same axis as the target, then no gamut expansion should be observed for surrounds that contain colors orthogonal to the target colors (i.e., the color of the target on the orthogonal surrounds should be indistinguishable from the targets on the homogeneous achromatic surrounds). This suggests that any gain control processes that arise along the two axes are not entirely independent or that the gamut expansion effect cannot be solely due to gain control processes. Second, the fact that the gamut expansion effect is larger when the targets and surrounds are along the same color axis suggests that the gamut expansion effect cannot be solely a consequence of scission or transparency mechanisms (Ekroll & Faul, 2013; Ekroll et al., 2004). Once the texture of the surround becomes clearly visible, it should not be possible to decompose the target into a transparent overlay and an underlying surface because the target and the surround do not share the same textural properties. This suggests that the gamut expansion cannot be fully explained as a consequence of color transformations induced by scission or transparency. We will return to these issues in the General discussion.

Experimental results for the asymmetric color matching task for the three conditions with different patch sizes (Experiment 1b) are shown in Figure 7. Panel (a) shows the results for the patch size of 5 × 5 pixels, (b) shows the results for the patch size of 30 × 30 pixels, and (c) shows the results for the patch size of 50 × 50 pixels. In each panel, two sets of four bars show the asymmetric matching results for the L and S variation conditions normalized by the L&S variation condition. The height of the bars shows the mean of the relative size of gamut expansion effect of the targets with respect to the effect size observed for the L&S variation condition. Standard error is shown as an indication of consistency between subjects. For the 5 × 5 pixels patch size background condition with the L variation condition, only the green-purple difference t test resulted in a p value smaller than the alpha, and for the S variation condition, none of the t tests resulted in a p value smaller than the alpha. For the 30 × 30 pixels and 50 × 50 pixels test cases for both L and S variation conditions, all the t tests resulted in a p value smaller than 0.001. Single star means p < 0.05, and double star means p < 0.01.
The main purpose of these experiments was to test whether or not gamut expansion could be understood as a consequence of scission. The scission explanation of gamut expansion proposed by Ekroll and coworkers (Ekroll et al., 2004; Faul et al., 2008) predicts that the size of the effect should be the same for all targets when the conditions for transparency are not satisfied for the variegated surrounds. This prediction arises from the assumption that the difference in the perceived chromaticity of targets on the two surround types (achromatic homogeneous and variegated) reflects an increase in perceived saturation of the targets on the homogeneous surrounds caused by scission rather than a decrease in the perceived chromaticity of targets on the variegated surround. The presumption is that the textural differences between the homogenous target and the variegated surround violate the conditions for scission whereas the low contrast of the homogeneous surround and the homogenous targets cause the targets to be decomposed into a saturated transparent layer overlying an achromatic surround. The results of our experiment reveal that the difference in the perceived saturation of targets on the two surrounds depends on the hue of the variegated surround relative to the hue of the target, the saturation of the variegated surround relative to the saturation of the target, and the size of the patches that form the variegated surround. These dependencies mean that scission cannot be solely responsible for the perceived color differences induced by the two types of surrounds and that at least some of the perceived color difference may be more appropriately construed as a form of gamut contraction of the targets placed on the variegated surround. The perceived difference in color gamut is progressively reduced for targets on surrounds with hues along the color axis orthogonal to the target, which suggests that the chromatic differences may arise from a form of chromatic gain control that is specific to the particular chromaticities present in the image.

It is, however, unclear whether gain control mechanisms can fully account for the pattern of results we obtained. If the contrast gain control processes along the two axes of MB color space were independent, then there should be no difference in the perceived color gamut of targets on the homogeneous achromatic surrounds and those on variegated surrounds that only contain colors orthogonal to the chromatic axis of the targets. This is not what we observed; the targets on variegated surrounds with hues orthogonal to the chromatic axis of the targets were perceived as less saturated than the corresponding targets on the homogeneous surround. This suggests that either the gain control mechanisms putatively responsible for the gamut compression of targets on the variegated surround are not completely independent (i.e., the axes of MB space do not represent the chromatic axes involved in the hypothesized gain control processes) or that the gamut expansion effect cannot be simply the consequence of gain control processes.

It should be noted that the mean color of all of our surrounds was achromatic, and thus any proposed gain control mechanism cannot be one that is driven by the mean color of the surround. Rather, our results can be better understood by a model in which the chromatic responses are decomposed into a statistical mean (DC) component and a contrast (AC) component that captures the variance around the mean. Models of this kind have been proposed previously to explain adaptation to temporally modulated surrounds (Webster & Mollon, 1995) and spatially variegated surrounds (Webster & Mollon, 1993). In the latter, the authors investigated the adaptation to the luminance and chromatic contrast in the measurement of luminous efficiency function. Our findings are broadly...
consistent with this explanation. Consider the L&S variation condition, which was used to normalize the amount of gamut expansion along the two hue axes of our targets. The hue components along the axes of the targets in the L&S condition (RG and BY) had approximately equal perceptual variance. However, when the contrast variation in the surround is restricted to a single chromatic axis, then the total contrast variation along that axis will be greater than the conditions in which the surround contains the full range of hues. Thus, any contrast gain control mechanisms should decrease the perceived saturation of the targets that are aligned with the chromatic variance of the surround, generating greater gamut expansion. However, as noted, this cannot account for the gamut expansion observed for the targets along the orthogonal axis of the surround color variation. This suggests either that the contrast normalization of the two axes of MB color space are not fully independent or that there is some genuine expansion of the targets on the homogenous achromatic surround, consistent with the scission thesis proposed previously (Faul et al., 2008).

**Keywords:** gamut expansion, color induction, color perception

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**Acknowledgments**

This research was supported by grants from the Australian Research Council (ARC) to B. L. Anderson.

Commercial relationships: none.
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**References**


