Study on Spreading Effect of Contour Coloration in Watercolor Illusion

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Abstract: Watercolor illusion refers to the condition wherein the color at the inner contour infiltrates inwards to a closed white block when a dark outer contour is adjacent to a light inner contour. This study aims to further examine the three elements of color: hue, value, and chroma, as well as the spread effect of contour on watercolor illusion.

The study discusses hue, value, and chroma through experiments in three parts. The first part discusses the spread perception of watercolor effect in four groups based on the division of contour following Munsell’s color cycle: analogous colors (30°~90°), contrast colors (120°~150°), complementary colors (150°~180°), and neutral colors. The second part discusses the value of the contour line based on three aspects: light value, medium value, and dark value. Finally, the different chromas of the contour line into “high”, “medium”, and “low” levels to discuss the spread perception of watercolor effect. The experimental results show that: (1) the hue will influence the watercolor effect, which is particularly apparent in the matching of complementary colors, contrast colors > analogous colors, for example, purple matches yellow or blue matches orange; (2) light, medium, and dark values will all influence the watercolor effect; (3) the matching of low and medium chroma has apparent watercolor effect; and (4) among three conditions of hue, value, and chroma, the first two have apparent watercolor effect.

Key words: watercolor illusion, hue, value, chroma.

1. Introduction
Color is an important component of vision and is extensively used in life, art, and design. Color has three most important properties, namely, hue, value, and chroma [3,4,5,6,19,20]. Hue represents the color name, value is the intensity of color, and chroma is the saturation of color. In color study, colors can be regularly sorted out to maintain the order, which leads to the advent of the color order system. With the color order system, the color users can point out precisely the color that he wants. Coolorstudy in cludes color matching and its color perception, such as color psychology and color sensibility. Watercolor illusion is simply an illusion of color perception.
Watercolor illusion is the assimilation of long-range proliferation. When thin and pale color contours are inside a dark contour, the effect is color spread [11,16,18]. Past studies of watercolor illusion mentioned only dark-colored and pale-colored contours in describing watercolor illusion. In color design, it is not only classified as dark or pale; color is also composed of three properties: hue, value, and chroma. Hence, the study aims to: (1) define the effect of hue, value, and chroma on watercolor illusion, and (2) experiment on the watercolor effect of color matching.

2. Literature discussion: Three elements of color (hue, value, and chroma)

Color is composed of hue, value, and chroma. For example, in Fig. 1, two colors, red violet and yellow, have apparent differences in darkness/lightness. However, red and green have similar values. We can see that each color has different values and chroma. If only the name is defined, they cannot be compared under the same standard because their conditions are different and color cannot be specified accurately.

According to the Munsell order system: (1) the color property values are expressed simply by hue, value, and chroma; (2) the scales of hue, value, and chroma are of equal ratio, which makes it easy to feel or compare the color difference quantitatively; and (3) this color order system is the most representative internationally and is often used to express object colors and is suitable for academic color study[3,4,5,6,9,19]. Hence, this study takes the Munsell color order system as the color-representing symbols and for discussing the colors’ hue, value, and chroma.

Hue is the name of the color (e.g., red or purple). In the literature, Newton proposed seven primary colors: red, orange, yellow, green, blue, indigo, and purple. Verner proposed six primary colors: red, orange, yellow, green, indigo, and purple. Helmholtz proposed five primary colors: red, yellow, green, blue, and purple, on which the Munsell order system is based. Hering regarded red, yellow, green, and blue as the four primary colors, on which Ost-wald is based. Itten took red, yellow, and blue as the three primary colors[6,8,10]. Primary colors are mixed to get intermediate colors. The colors are then arranged in a circle to form a hue circle.

Based on the position of a color in the hue circle and the angle between adjacent colors, it can be divided to match analogous colors, that is, (1) the matching of similar hues is within 30° in the hue circle, such as 5R and 10R; (2) the matching of contrast hues is within 30°~90° in the hue circle; and (3) the matching of complementary hues is within 150°~180° in the hue circle[7,8,9,21,22], as shown in Fig. 2. The matching of colors can help color designers understand the visual effect of color use easily.
Value refers to the color’s brightness. It can be expressed by dividing colors into three tones: bright, grey, and black; the stages of value can also be divided based on their sequence. Each color order system has different steps of values. For example, Mussell’s color notation has 11 steps; Ostwald color notation has 8 steps, and PCSS has 9 steps.

Chroma refers to the color’s saturation, or its purity. When a color is added with white or black, the more gray it contains, the lower chroma it will have; and vice versa. When the pure color is added with different gray colors, it will result in a series of different steps of chroma. The chroma step takes the vertical value as the longitudinal coordinates and chroma as the horizontal coordinates, as shown in Fig. 3. Both value and chroma can be expressed by numbers, or light (high), medium and dark (low), as shown in Fig. 4. The value 5R4/14 in Munsell’s color order system represents the hue of 5R, value of 4, and chroma of 14.

3. Methods

3.1 Study architecture

This study takes three elements of color: hue (analogous, contrast, complementary, and neutral), value (light, medium, and dark) and chroma (high, medium, and low) as variables to examine the spreading effect of contour coloration in watercolor illusion. Please refer to Fig. 5 for the experimental architecture.
3.1 Stimuli
The stimuli samples in this experiment take watercolor effect graphs in color assimilation described by Pinna, Brelstaff and Spillmann [16] as the basic graphs (Fig. 5). A total of 45 samples of stimuli were designed based on three variables of hue, value, and chroma and the combination of different conditions. When one color property was tested, two other properties were controlled as constants, which are described as follows:

3.2.1 Hue stimuli
This experiment divides hues into analogous, contrast, complementary, and neutral color; it also controls the value to 5 and chroma to 14. There are totally 15 stimuli (Fig. 6). The hue stimuli are as follows:
(2). Contrast colors (120°~150°): Y/R, R/B, B/Y
(3). Complementary colors (150°~180°): Y/P, YR/B, R/G
(4). Neutral colors: N2/N8, N4/N8, N6/N8

<table>
<thead>
<tr>
<th>Hue</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Analogous</td>
<td>Y/YR</td>
<td>YR/R</td>
</tr>
<tr>
<td>colors</td>
<td></td>
<td>R/P</td>
</tr>
<tr>
<td>(30°~90°)</td>
<td></td>
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</tbody>
</table>
### 3.2.2 Value stimuli

The value 8 was chosen for the outer contour, giving the inner contour values, that is, 2, 4, and 6 steps different from those of the outer contour, and the chroma was controlled to 4. Hues include R, Y, G, B and P, a total of 15 sets of color samples (Fig. 7). The value stimuli are as follows:

1. Light values: 5R6/4, 5Y6/4, 5G6/4, 5B6/4, 5P6/4
2. Medium values: 5R4/4, 5Y4/4, 5G4/4, 5B4/4, 5P4/4
3. Dark values: 5R2/4, 5Y2/4, 5G2/4, 5B2/4, 5P2/4

<table>
<thead>
<tr>
<th>Hue</th>
<th>Inner contour values</th>
</tr>
</thead>
<tbody>
<tr>
<td>5R</td>
<td>light value : 6</td>
</tr>
<tr>
<td>(5R8/4)</td>
<td>medium value : 4</td>
</tr>
<tr>
<td>5Y</td>
<td>(5Y8/4)</td>
</tr>
<tr>
<td>5G</td>
<td>(5G8/4)</td>
</tr>
</tbody>
</table>
3.3 Chroma stimuli

Chroma 14 was chosen for the outer contour, giving the inner contour a chroma, which is different from that of the outer contour by 2, 6, and 10 steps; and the value was controlled to 6. Hues include R, Y, G, B and P, a total of 15 sets of color samples (Fig. 8). The value stimuli are as follows:

(1). High chroma: 5R6/10, 5Y6/10, 5G6/10, 5B6/10, 5P6/10
(2). Medium chroma: 5R6/6, 5Y6/6, 5G6/6, 5B6/6 and 5P6/6
(3). Low chroma: 5R6/2, 5Y6/2, 5G6/2, 5B6/2, 5P6/2

<table>
<thead>
<tr>
<th>Outer contour</th>
<th>Inner contour chroma</th>
</tr>
</thead>
<tbody>
<tr>
<td>High chroma: 5R6/10</td>
<td></td>
</tr>
<tr>
<td>Medium chroma: 5Y6/6</td>
<td></td>
</tr>
<tr>
<td>Low chroma: 5G6/2</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 7: Value stimuli

Fig. 8: Chroma stimuli
3.3 Procedure

(1). This experiment was within-subjects designs. All subjects went through tests of hue, value, and chroma of watercolor effect and were shown 45 samples of stimuli.

(2). Before the experiment, the tester explained the test program and questionnaire to the subjects.

(3). Before the experiment, the subject was examined with “Color Blindness Checkup Map” to check whether his or her chromatic vision and color discrimination were normal.

(4). At the very start of the test, the subject was asked to fill out the basic data. Before the test, the tester showed hue, value, and chroma stimuli randomly. Patterns of different conditions in each test also appeared randomly.

(5). The subject chose among 1~5 in a five-point Likert Scale for each stimuli based on his or her perception of spreading effect.

(6). When all stimuli in each test were shown, the tester asked the subject to rest. After the subject had rested for an adequate period of time, he/she moved to the next test where the test period was not limited.

3.4 Facility

The experiment environment used a white ceiling fluorescent for lighting, to avoid such shortcomings as glare, reflection, and color shift. As to the color of the stimuli, the Munsell Conversion Software converted Munsell’s color signals into C, M, Y, and K and outputted them onto 80 gms white paper. Each stimulus was about 10x8 cm.

3.5 Subject

Subjects in this experiment had normal color perception. Therefore, before the test, subjects were examined on their color discrimination ability. Only qualified respondents were allowed to take the test. Subjects were 15 students in a Taiwan university, aged from 18 to 26.

4. Results

Pictures of watercolor illusion were carried out with spreading perception test on the color’s hue, value, and chroma. Survey data from the questionnaire then underwent descriptive statistics, one-way ANOVA detection, and Scheffe post-comparison with SPSS 12.0. Table 1 presents the descriptive statistics of “spreading perception” of the three variables of hue, value, and chroma. We can conclude the following intensity of the spreading perception from the table: value (M=3.5), hue (M=3.25), and chroma (M=2.32). The results of the four groups of conditional matching detected by one-way ANOVA indicate a significant difference (P=0.000<0.05). In view of the significant difference, we carried out Scheffe’s test analysis and found from the post-detection that perception of hue and value was stronger than that of chroma.

Table 1: Watercolor Illusion Hue, Value, and Chroma Variance Analysis and Scheffe Post-Comparison Abstract

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Spreading perception</td>
<td>3.25</td>
<td>3.50</td>
<td>2.32</td>
<td>62.509***</td>
<td>B&gt;A&gt;C</td>
</tr>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>1.139</td>
<td>1.11</td>
<td>1.09</td>
<td></td>
<td></td>
<td>P&lt;0.05*, P&lt;0.01**, P&lt;0.001***</td>
</tr>
</tbody>
</table>

P<0.05*, P<0.01**, P<0.001***
4.1 Experiment 1 result: Watercolor effect of different hues

Table 2 shows the descriptive statistics of “spreading perception” of different hue samples. We can see the following intensity of spreading perception from the table: matching of complementary colors (M=4.1), matching of contrast colors (M=3.8), matching of analogous colors (M=2.79) and matching of neutral colors (M=2.78). The result of four groups of conditional matching detected by one-way ANOVA indicates a significant difference (F=17.38 P=0.000<0.05). In view of the significant difference in hue matching, we carried out Scheffe’s Test analysis and found from post-detection that the matching of contrast and complementary colors delivers stronger spreading perception than that of analogous and neutral colors (Refer to Fig. 6).

Table 2. Watercolor Illusion Hue Variance Analysis and Scheffe Post-Comparison Abstract

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Watercolor illusion</td>
<td>2.79</td>
<td>1.32</td>
<td>3.8</td>
<td>1.32</td>
<td>4.1</td>
</tr>
</tbody>
</table>

P<0.05*, P<0.01**, P<0.001***

4.2 Experiment 2 result: Watercolor effect of different values

Contour values are analyzed from three levels: light, medium, and dark. We can conclude the intensity of watercolor effect from Table 3 Descriptive Statistics, that is, matching of medium values (M=3.57), matching of light values (M=3.48), and matching of dark values (M=3.43). We know from the one-way ANOVA Detection of Respondents (Table 4) that the independent variable of value (light, medium, and dark) does not reach a significant effect (F=0.237, P=0.789>0.05), and neither does the independent variable of hue (R, Y, G, B, P) (F=0.403, P=0.807>0.05). We can infer that the matching of any value, among light, medium, and dark, will not particularly influence the spreading perception of watercolor illusion (Refer to Fig. 7).

4.3 Experiment 3 result: Watercolor effect of different chroma

Contour chroma is analyzed from three levels: high, medium, and low. We can conclude the intensity of watercolor effect from the descriptive statistics in Table 5, that is, matching of low chroma (M=2.74), medium chroma (M=2.39), and high chroma (M=1.84). The result of three groups of conditional matching detected by one-way ANOVA shows a significant difference (F=14.56 P=0.000<0.05). We can see from the Respondent Effect Detection (Table 6) that the independent variables of chroma (high, medium, and low) have reached a significant difference (F=14.56 P=0.000<0.05) and the independent variables of hue (R, Y, G, B, P) have no significant effect (F=0.9693, P=0.43>0.05). In view of the significant difference in the matching of chroma, we conducted Schefè’s Test analysis and found from the post-detection that the matching of low and medium chroma has stronger spreading perception than that of high chroma (Refer to Fig. 8).

Table 5. Chroma Variable Analysis and Scheffe Post-Comparison Abstract

<table>
<thead>
<tr>
<th>High chroma[A]</th>
<th>Medium chroma[B]</th>
<th>Low chroma[C]</th>
<th>One-way ANOVA</th>
<th>Scheffe’s Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>spreading perception</td>
<td>1.84</td>
<td>0.92</td>
<td>2.39</td>
<td>0.99</td>
</tr>
</tbody>
</table>

P<0.05*, P<0.01**, P<0.001***
Table 6. Chroma Property Respondent Effect Detection Abstract

<table>
<thead>
<tr>
<th>Resource of variance</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chroma low/medium/high hue (R, Y, G, B, P)</td>
<td>31.262</td>
<td>2</td>
<td>15.631</td>
<td>14.559</td>
<td>.000***</td>
</tr>
<tr>
<td>Chroma low/medium/high*</td>
<td>6.427</td>
<td>8</td>
<td>.803</td>
<td>.748</td>
<td>.649</td>
</tr>
</tbody>
</table>

P<0.05*, P<0.01**, P<0.001***

5. Conclusions

Watercolor effect was proposed by Pinna in 1987. He pointed out that the contour of dark and light hue matching will produce watercolor illusion. The color features of watercolor illusion are as follows: (1) effect can still be seen but will be weakened if two lines are of the same color; (2) the effect when the purple and orange lines are juxtaposed is the most apparent; (3) all colors can produce a coloration effect; (4) color spread does not have a scope; and (5) watercolor illusion also occurs in colored and black background[1,2,7,12,15,16,17,18]. We cannot conclude that the above results are obtained from measuring or summarizing three properties, which is possibly because the darkness/lightness is not properly defined from the aspects of hue, value, and chroma. We found from this experiment that value, in contrast to hue and chroma, has the strongest influence. This study proposes that light value implies expansion and dilation [4,6,7,8,9,19]. Each stimulus has a light-valued outer contour to match with the light, medium, and dark inner contour. Because of the diffusivity of light value, value is the top factor in watercolor effect. Hence, we surmise that the matching of purple and orange, and dark and light proposed by Pinna has confused hue with value.

This study has discussed the influence of color matching (between complementary and contrast colors and between low and medium chroma) on watercolor effect, which is similar to the result of watercolor effect triggered by purple and orange, blue and yellow, and red and green as proposed by Pinna, Brelstaff, and Spillmann[16].

This study has manipulated hue, value, and chroma as independent single variables. Future studies can manipulate two factors: hue and value, value and chroma, and hue and chroma to examine the differences in results from matching two properties or one property, and conduct a complete research on watercolor effect.

Footnote

1. Munsell Conversion Software is developed by WallkillColor and can convert Munsell’s color code to C, M, Y, K, such as 5R/8/6, equivalent to C=0, M=27, Y=30, K=0.

References


