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Influence of Different Non-color Background on Tourmaline Green

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Abstract. On the basis of uniform color space CIE 1976 L*a*b*, using Munsell color system as a contrast system, this paper discusses the influence of different achromatic backgrounds on tourmaline green through quantitative analysis of color indexes such as lightness, chroma and hue of green tourmaline, and draws the following conclusion: in the process of achromatic background lightness transformation, the lightness and chroma of green tourmaline are highly sensitive to it and have obvious changes along with it, and the two also have high synchronization; However, the hue has not changed much. At the same time, the green tourmaline itself has higher lightness and chroma, which can make the lightness of the achromatic background more effectively converted into the visual lightness and saturation of the tourmaline, but the green tourmaline with too high or too low lightness and chroma is hardly affected by the lightness of the achromatic background. This proves that the non-color background is suitable for most tourmaline green quality evaluation.

1. Introduction

Tourmaline is a kind of colored gem, whose color is rich and colorful, lively and bright, so it is known as “the rainbow falling into the world", and together with opal it is known as the birthday stone in October, symbolizing happiness and joy. The tourmaline can be evaluated from the aspects of color, clarity, cutting work and weight, of which color is the most important factor affecting its quality evaluation. Color directly affects the value of tourmaline. In the international market, except for Pallai Ba Tourmaline, usually bright red tourmaline has the highest price. However, because red tourmaline usually contains more contents, it is very difficult to have high cleanliness.

The chemical composition of tourmaline is extremely complex, and its colorful color is related to its internal trace elements. Changes in the chemical composition of tourmaline directly affect changes in its physical properties. The red color of tourmaline is related to Mn^{3+}, Mn^{2+}, Fe^{2+}, Fe^{3+}; Green is related to Fe^{2+}, Fe^{3+}, Fe^{2+}-Ti^{4+}; Brown is related to Fe^{2+}-Ti^{4+}. At present, scientific research mainly focuses on the performance of non-gem tourmaline as a mineral material [1]. However, the focus of research on gem grade tourmaline is the optimized treatment method of filling and irradiation. Although progress has been made in the research on the influence of components on color, there is still no systematic evaluation system for color.

The background color has a significant effect on the appearance of the foreground color. The influence of background color change on the color appearance of the target object is usually analyzed by binocular matching. In the field of view, different colors of adjacent areas influence each other. This phenomenon is called simultaneous color contrast, which is a research direction in psychophysics [9]. However, binocular matching method mainly relies on subjective factors of human eye observation, and lacks quantitative analysis of color changes. Because the color space CIE 1976 L*a*b* has good uniformity, it is suitable for the representation and calculation of all object colors.

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Therefore, it is widely used by countries all over the world as an international color measurement system. Nowadays, colorimetric systems are more and more widely used in gemological research [10].

Tourmaline is a high-grade single crystal gem with strong glass luster, high transparency (transparent-semitransparent) and high color saturation. It will show significant changes to the color background of alloy metals with different purity, including not only platinum and silver alloys with purity varying with lightness, but also color gold with purity varying with lightness, chroma and color. Even non-color backgrounds with different gray scales will cause significant color appearance differences due to different color characteristics. The influence of achromatic background on color appearance includes lightness, hue and chroma of target color. In addition, its own lightness will also affect the influence of background lightness on its own color. Therefore, the background can be transformed to discuss the influence of lightness, chroma and hue on the color appearance of tourmaline [14].

Because in gemology, it is known that the research on the influence of background changes on the color appearance of gemstones focuses on qualitative description rather than quantitative analysis. Therefore, this paper will take quantitative analysis method to study the influence of background changes on the appearance of gem color. The experiment is mainly carried out under non-color background, and the change of foreground color under different backgrounds is discussed, so as to quantify the specific visual characteristics of target object color. Finally, by analyzing the influence of non-color background on tourmaline color characteristics, the best neutral color background for evaluating and displaying tourmaline green was determined. Understanding the influence of background on tourmaline color is very beneficial to get rid of the subjectivity and fuzziness of color detection in the future, realize the true transmission and reproduction of color information between different media, and even realize the objectification and quantification of color evaluation and the realization of the final tourmaline color (green in this article).

The tourmaline samples selected in this paper are oval plain samples with green hue, size of 6mmx8mm, glass luster and moderate transparency. After measurement, the refractive index of the samples is 1.62-1.65, birefringence is 0.014-0.021, and specific gravity is 3.0-3.1.

2. Tourmaline Sample Color Test

2.1. Selection of Experimental Samples

(1) The size is moderate, mainly 6mmx8mm, which meets the requirements of aperture of X-Rite SP62 colorimeter.

(2) The visual color is uniform, with strong, light, dark and light green under the naked eye. The samples are mainly in green hues, including green (yellow green) and green (slight blue) hues. There are many kinds of green, and the data are representative and convincing.

(3) Moderate transparency. Using reflection method to test, the sample with higher transparency will make the test light completely penetrate and increase the test error.

(4) Fine texture and no inclusion.

According to the above sample selection principle, the samples (73 in total) were screened to obtain the applicable samples (53 in total). First, the samples were photographed under the standard D65 light source condition, with macro mode and no flash. As the visual effect observed by human eyes, it is used to assist the analysis of instrument test results. It combines actual visual evaluation with quantitative analysis of theoretical color parameters to make the research results more reasonable and applicable.

2.2. Test Instruments

The color measuring instrument used in this paper is the U.S. X-Rite SP62 integrating sphere spectrophotometer. It is convenient to carry, has the performance and function that can meet the application of different industries, and can be used for measuring various colors. Its fixed aperture is 8mm measurement area and 13mm illumination area. It has 9 kinds of light sources including C, D50, D65, D75, A, F2, F7, F11 and F12. SCI (Specular Component Included) and SCE (Specular Component Excluded) data can be measured at the same time. Reflected signals on the sample surface are collected through integrating spheres to help analyze the influence of the sample surface structure on color.

The test conditions of this instrument are: D65 standard light source, excluding specular reflection mode (SCE mode), spectral measurement range 400 nm-700 nm, measurement time less than 2.5s, wavelength interval 10 nm, voltage 220V, current 50 Hz-60 Hz, and operating temperature controlled between 10°and 40°.

Uniform color space CIE1976L*a*b* is used as a color system for quantitative representation and analysis; Munsell Color System as Contrast System.

2.3. Sample Test Results

Each color does not exist in isolation, and the transformation of the background will have an impact on the presentation of the color of the object. In order to explore its influence results, this test selects the standard white porcelain plate carried by X-Rite SP62 spectrophotometer as the background (i.e. foreground color) of the test sample, selects CIE1976L*a*b* uniform color space, and measures the color parameters of tourmaline samples under standard light source D65, i.e. L* (lightness), a* (red and green direction coordinates), b* (yellow and blue direction coordinates), C* (chroma), h_0 (hue angle), and obtains 53 data. Among them, in order to ensure the accuracy of the experimental results, according to the test results, some samples (6 in total) with different colors are removed, i.e. 47 samples are actually used and 47 groups of data are used.

The test results show that under the standard D65 light source, the lightness value of tourmaline (green) sample is lightness L*∈(33.65, 90.25); colorimetry index a*∈(23.1,-4.39), b*∈(6.45, 41.17); chroma C*∈(5.03, 43.12); hue angle h_0∈(105.6°, 200.7°).

3. Influence of Non-Color Background on Tourmaline Green

The influence of non-color background on the green appearance of tourmaline has different degrees of reflection in lightness, chroma and hue. The lightness of the gem itself also limits the influence of the background lightness on it.

We used Munsell's gray scale card, Munsell Neutral Scale, which is the most popular Munsell system in the world (as shown in figure 3-1). Although the color card does not reflect the color degree, it clearly divides the lightness from N0.5 to N9.5 into 37 levels with a spacing of N = 0.25. Therefore, the color parameters measured under the reference background-standard white porcelain plate are regarded as the main color parameters, i.e. their own parameters. After that, N9.5, N8.5, N7.5, N6.5, N5.5, N4.5, N3.5, N2.5 and N1.5 were selected as the contrast background.

Figure 3-1. Gray Scale Card of Munsell System: Munsell Neutral Value Scale.

The color parameters of 47 samples under these 9 non-color backgrounds were tested, and the average value [15] of each parameter of the samples under each non-color background was calculated to obtain figure 3-2.

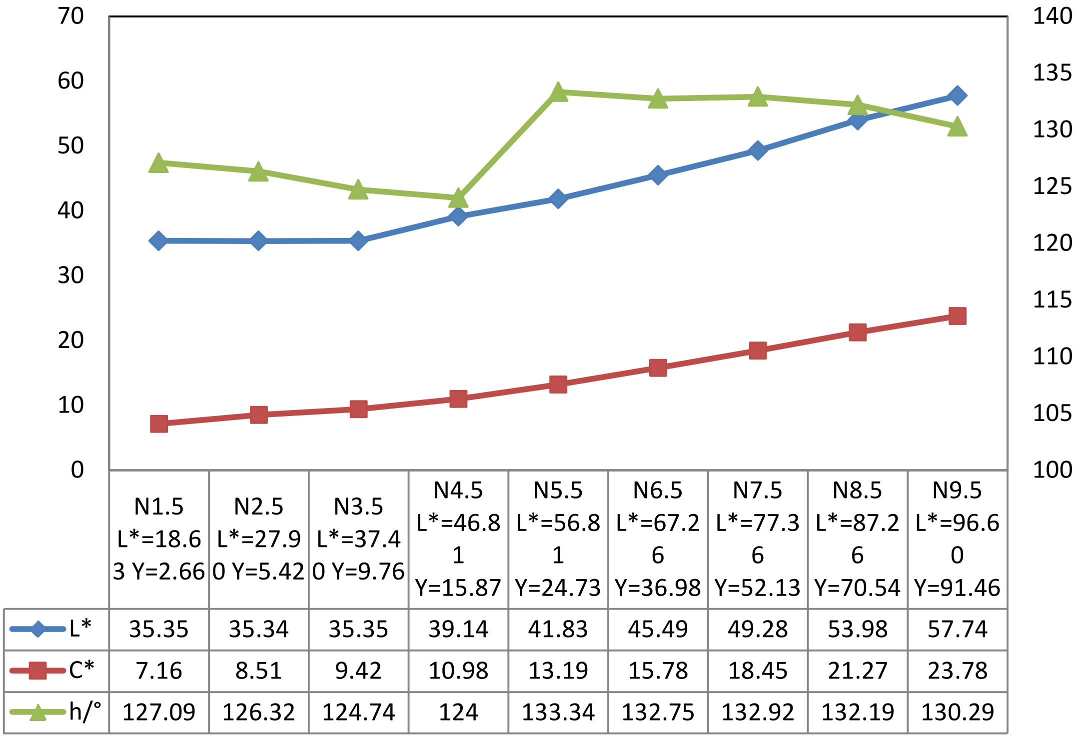

Figure 3-2. a line chart showing the change trend of sample average lightness L*, average chroma C* and average hue angle h with background lightness under 9 kinds of non-color backgrounds.

Table 3-1 shows simulated color blocks of tourmaline samples # 15, # 20, # 25 on different non-color backgrounds.

Table 3-1. Color Block Simulation of Samples # 15, # 20, # 25 on 9 kinds of Non-Color Backgrounds.

	N1.5	N2.5	N3.5	N4.5	N5.5	N6.5	N7.5	N8.5	N9.5
#15									
#20									
#25									

Under the background transformation of N9.5 to N1.5, the average visual lightness L of 47 tourmaline samples decreases as the background lightness decreases. The change trend of average visual chroma C is similar to that of average visual lightness L; The change rule of the average hue angle h is not obvious, the average hue angle hardly changes in the background transformation of N9.5-N5.5, but the average hue angle decreases to h = 124.00° under the background of N4.5, and when the background lightness further decreases, the average hue angle gradually increases to a level close to that under the background of N9.5.

In order to analyze the influence of non-color background lightness change on each color parameter, one-way variance analysis method is adopted to analyze the influence degree of background lightness on each color parameter as a whole. in variance analysis, P-value is used to indicate the influence degree of different levels of control variables on observation variables. When $P>0.05$, the variance is uniform, indicating that background lightness has no significant influence on each parameter. When $P<0.05$, the variance is non-uniform, which indicates that the background lightness has significant influence on each parameter, and the smaller the p value, the stronger the significance. Table 3-2 is obtained by calculating each color parameter and performing one-way variance analysis of background lightness respectively.

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Table 3-2. One-way ANOVA**.**

		SS	df	MS	F	P-value
lightness L*	Between-group	495.071	8	61.884	0.083	0.999
chroma C*	Between-group	296.837	8	37.105	0.859	0.579
hue angle h_0	Between-group	142.174	8	17.772	0.002	1

Significance index P=0.050

According to the analysis results, it can be seen that the change of background lightness has no significant influence on the lightness L, chroma C and hue angle h of the sample, and the significant influence on each parameter is chroma > lightness > hue angle.

In order to further analyze the influence of non-color background lightness on each color parameter, regression analysis is carried out on the change trend of each parameter respectively, and Table 3-3 is obtained.

Table 3-3. Linear Trend Line Regression Analysis of Various Parameters.

	df	SS	MS	F	R Square
lightness L*	9	538.142	59.794	115.483	0.943
chroma C*	9	271.448	30.161	271.983	0.975
hue angle h_0	9	51.375	5.708	5.807	0.453

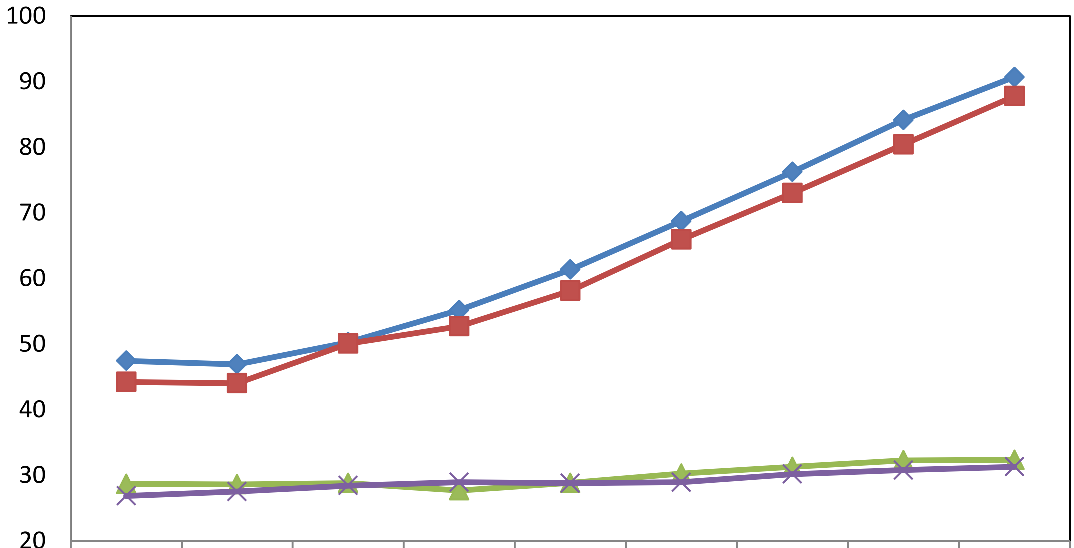
(Note: R^2 is a value indicating the fitting degree of trend line. The closer R^2 is to 1, the better the fitting degree of trend line is.)

It is found that the variation of other parameters except hue angle basically shows a good linear relationship.

To sum up, the change of non-color background lightness has certain influence on the lightness L and chroma C of sample color parameters, but has no great influence on hue angle h, therefore, the influence degree of background lightness on each color parameter can be expressed as chroma > lightness > hue angle.

3.1. Changes in Sample Lightness

The experimental results show that the visual lightness of the samples varies significantly with the background lightness and is positively correlated, with the correlation coefficient r = 0.971, i.e. the samples show higher visual lightness under the high lightness non-color background. However, when the sample itself has too low lightness, the lightness of the sample is hardly affected by the lightness of the achromatic background (as shown in figure 3-3).



	N1.5 L*=18.63 Y=2.66	N2.5 L*=27.90 Y=5.42	N3.5 L*=37.40 Y=9.76	N4.5 L*=46.81 Y=15.87	N5.5 L*=56.81 Y=24.73	N6.5 L*=67.26 Y=36.98	N7.5 L*=77.36 Y=52.13	N8.5 L*=87.26 Y=70.54	N9.5 L*=96.60 Y=91.46
#15	47.45	46.91	50.27	55.19	61.35	68.75	76.24	84.16	90.69
#19	44.22	44.04	50.08	52.72	58.13	65.95	73.01	80.42	87.8
#61	28.69	28.61	28.82	27.7	28.84	30.26	31.29	32.29	32.34
#62	26.87	27.53	28.42	28.94	28.78	28.93	30.19	30.78	31.31

Figure 3-3. Taking samples # 15, # 19, # 61, # 62 as examples, the variation trend of sample lightness with background lightness is shown.

When the background lightness range is N5.5 to N9.5, the sample lightness shows a faster rate of increase, which is due to the large difference between the foreground lightness value of the sample and the background lightness value in this range. As the background lightness increases, the difference between the two increases continuously, thus the slight change in the background lightness will lead to a large increase in the sample lightness. When the background lightness is N3.5 to N5.5, the background lightness value in this range is similar to the foreground lightness value of the sample, so the background transformation has little influence on the sample lightness, so the sample lightness increases at a slower speed with the increase of the background lightness. However, when the background lightness is less than N3.5, the background lightness value in this range is far less than the foreground lightness value of the sample, so the lightness change of the sample is not obvious.

In the background transformation from N1.5 to N9.5, the lightness of 47 samples all increased with the increase of background lightness, which showed that the increase of background lightness could significantly improve the visual lightness of samples. At the same time, due to the different lightness of the samples themselves, the degree of influence by the lightness of the achromatic background is also different. Sample #10(L_{10}=84.46), sample #15(L_{15}=90.25) and sample #19(L_{19}=85.90) have high self-lightness values. After the non-color background lightness transformation, the visual lightness of the sample changes significantly, with larger increases, namely $_{\Delta}L_{10}$=40.46, $_{\Delta}L_{15}$=43.24, and $_{\Delta}L_{19}$ = 43.58 respectively. Sample #53(L_{53}=35.41), sample #61(L_{61}=32.34) and sample #62(L_{62}=31.31) have low self-lightness values. After non-color background transformation, the visual lightness of the samples does not change significantly, i.e., the increase is small, with $_{\Delta}L_{53}$=5.81, $_{\Delta}L_{61}$=3.65, and $_{\Delta}L_{62}$=4.44, respectively. From this, we can see that for samples with high lightness value, their lightness value is more easily affected by the lightness of non-color background. For samples with low lightness value, its lightness value is not easy to be affected by non-color background lightness.

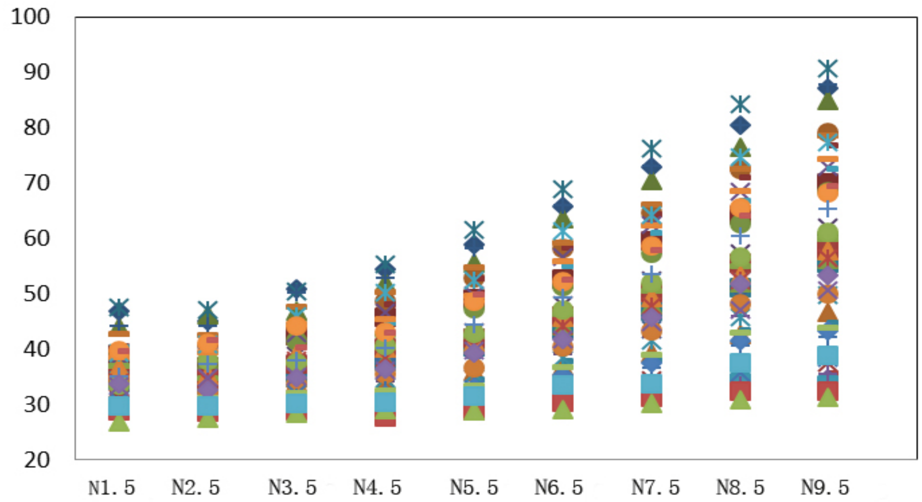


Figure 3-4. Scatter plot of lightness values of 47 samples with background lightness under non-color background.

Table 3-4. Discrete Coefficient Analysis Table of Sample Lightness under Various Backgrounds.

	N1.5	N2.5	N3.5	N4.5	N5.5	N6.5	N7.5	N8.5	N9.5
Standard deviation	4.87	5.12	6.38	7.48	8.83	10.70	12.73	14.58	16.40
Mean value	35.35	35.34	35.35	39.14	41.83	45.49	49.28	53.98	57.74
Coefficient of dispersion	0.14	0.15	0.18	0.19	0.21	0.24	0.26	0.27	0.28

In order to further explore the influence of non-color background lightness on sample lightness, we made a scatter plot of sample lightness with the change of background lightness (as shown in figure 3-4). It was found that the data span range of sample lightness was smaller when the background was N1.5, indicating that sample lightness was similar and difficult to distinguish. With the increase of background lightness, the data span was continuously increasing, that is, the discrimination degree of sample lightness was continuously increasing, and reached the maximum when the background was N9.5.

In order to confirm the above conclusion, the discrete coefficients of sample lightness under various backgrounds are obtained, and Table 3-4 is obtained. From the data results, it is not difficult to see that with the increase of background lightness, the dispersion coefficient also gradually increases, which represents that under the background condition of high lightness, the difference of lightness of samples themselves will be more and more obvious, and the discrimination between samples will be higher and higher. Meanwhile, background N9.5 has better effect on the exhibition of sample lightness and is more conducive to quality evaluation.

3.2. Changes in Chroma of Samples

The experimental results show that the visual chroma of the sample is significantly affected by the background lightness. The sample can show higher visual chroma only under the non-color background with high lightness, and when the sample's own chroma is too low, the sample chroma is basically not affected by the lightness of the non-color background. (figure 3-5)

In the background transformation from N1.5 to N9.5, the chroma of 47 samples all increased with the increase of background lightness, which showed that the increase of background lightness significantly increased the visual chroma of samples, and the correlation coefficient was 0.987. The significance of chroma change is slightly higher than that of lightness change, and the change can be perceived by naked eyes. At the same time, the chroma of the sample itself is different, and the

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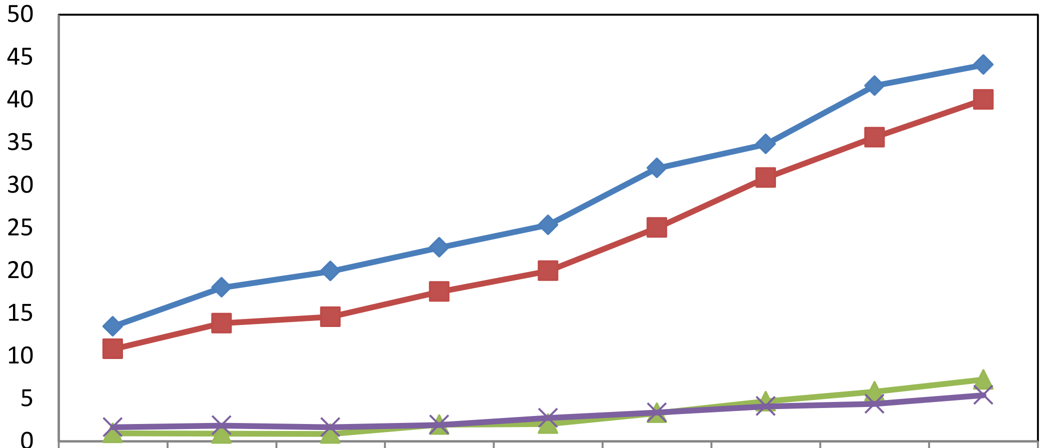
influence of the lightness of the achromatic background is also different, which is consistent with the effect of the different lightness of the sample caused by the transformation of the achromatic background. Sample #16(C_{16}=43.12), sample #22(C_{22}=38.25) and sample #25(C_{25}=31.92) have high chroma values themselves. After the transformation of the non-color background lightness, the chroma of the sample changes greatly, namely $_{\Delta}C_{16}$=30.65, $_{\Delta}C_{22}$=28.82 and $_{\Delta}C_{25}$=29.20. Sample #61(C_{61}=6.30), sample #62(C_{62}=5.03) and sample #71(C_{71}=7.36) have low chroma values themselves. After the conversion of non-color background lightness, the chroma of the sample has not changed much, namely $_{\Delta}C_{61}$=6.28, $_{\Delta}C_{62}$=3.76 and $_{\Delta}C_{71}$=6.35. Therefore, for the samples with high chroma, the visual chroma is more sensitive to the change of background lightness. However, for the samples with low chroma, the chroma is not easily affected by the change of background lightness.



	N1.5 L*=18.63 Y=2.66	N2.5 L*=27.90 Y=5.42	N3.5 L*=37.40 Y=9.76	N4.5 L*=46.81 Y=15.87	N5.5 L*=56.81 Y=24.73	N6.5 L*=67.26 Y=36.98	N7.5 L*=77.36 Y=52.13	N8.5 L*=87.26 Y=70.54	N9.5 L*=96.60 Y=91.46
#16	13.45	18.01	19.92	22.69	25.34	31.99	34.81	41.65	44.1
#25	10.81	13.84	14.59	17.53	19.96	25.02	30.87	35.62	40.01
#61	0.96	0.9	0.87	1.94	2.04	3.31	4.68	5.83	7.24
#62	1.65	1.85	1.65	1.93	2.73	3.38	4.11	4.39	5.41

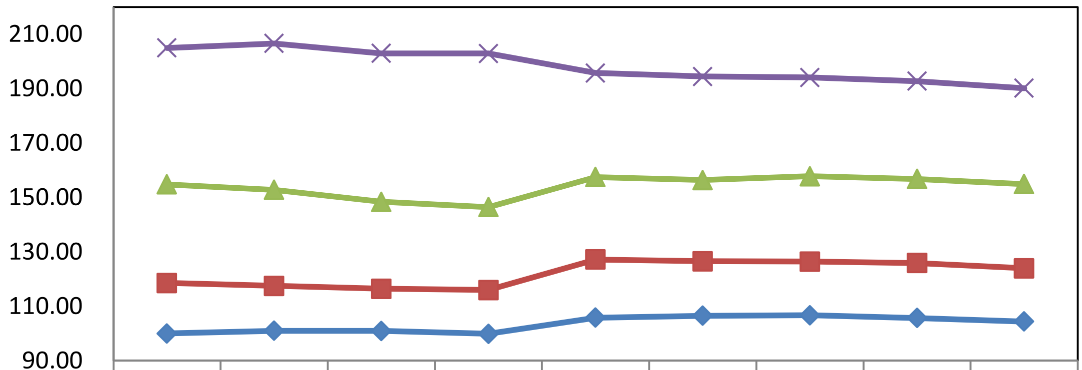
Figure 3-5. Taking samples # 16, # 25, # 61, # 62 as examples, the variation trend of sample chroma with background lightness is shown.

When the background lightness changes from N1.5 to N4.5, the sample chroma slightly increases, which is due to the increase of the background lightness, the background color transits from black to gray but still belongs to dark color system, which makes the sample lightness slightly increase and the light transmission degree also increases, thus improving the sample chroma but the amplitude is not large. When the background lightness is in the range of N4.5 to N9.5, the chroma of the sample increases obviously. This is because the background lightness increases and the background color changes from gray to white, i.e. from dark to light. The lightness of the sample increases rapidly and the light passing degree increases obviously, thus the chroma of the sample is better displayed, i.e. the chroma of the sample is greatly increased. When the background lightness reaches N9.5, the chroma value of the sample reaches the maximum. From this, it is not difficult to find that the overall change trend of sample chroma with background lightness is consistent with the change trend of sample lightness affected by background, and the lightness and chroma of the sample decrease to the lowest synchronously in the change of background lightness from N2.5 to N1.5, while the lightness and chroma of the sample increase to the highest synchronously when the background lightness is N9.5, which shows that the two have certain correlation in the experiment of non-color background lightness transformation.

It is worth noting that sample #15(L_{15}=90.25, C_{15}=41.32) has higher lightness and chroma according to the comparison results of lightness and chroma. Therefore, its visual lightness and chroma are most affected by the lightness of achromatic background (ΔL_{15}=43.24, ΔC_{15} = 26.13); However, sample #61(L_{61}=34.13, C_{61}=6.30) and sample #62(L_{62}=33.65, C_{62}=5.03) have low lightness and chroma, so their visual lightness and chroma are least affected by the lightness of the achromatic background (ΔL_{61}=3.65, ΔC_{61} = 6.28; ΔL_{62}=4.44, ΔC_{62}=3.76). In addition, the quadratic coefficient of the quadratic polynomial of the sample's visual chroma fitting with the achromatic background lightness is 0.083, which is lower than the sample's visual lightness coefficient fitting with the achromatic background lightness (0.269). Therefore, the change rate of the sample's chroma is lower than the change rate of the sample's lightness, which indicates that the sensitivity of the sample's chroma to the change of the background lightness is lower than the sensitivity of the sample's lightness to it.

3.3. Changes in Sample Hue

Based on the measured data and GemDialogue color card comparison results, 47 samples were divided into 4 groups according to hue, namely yellow group (Y), yellow-green group (GY), green group (G) and cyan group (BG). The average value of each group of data is taken as its trend chart with the change of background lightness for analysis. (figure 3-6)



	N1.5 L*=18.63 Y=2.66	N2.5 L*=27.90 Y=5.42	N3.5 L*=37.40 Y=9.76	N4.5 L*=46.81 Y=15.87	N5.5 L*=56.81 Y=24.73	N6.5 L*=67.26 Y=36.98	N7.5 L*=77.36 Y=52.13	N8.5 L*=87.26 Y=70.54	N9.5 L*=96.60 Y=91.46
Y	99.98	101.00	100.96	99.87	105.85	106.55	106.73	105.68	104.40
GY	118.55	117.48	116.43	115.96	127.17	126.52	126.45	125.91	123.95
G	154.81	152.77	148.39	146.46	157.49	156.36	157.79	156.77	154.91
BG	204.93	206.57	202.93	202.87	195.73	194.43	194.10	192.70	190.13

Figure 3-6. Line chart of change trend of average hue angle of 4 groups of samples with background lightness under non-color background.

The experimental data show that when the background lightness is in the range of N1.5 to N4.5, the average hue angle trend of the four groups of samples is stable, indicating that the hue of the four groups of samples has no significant change. However, when the background lightness changes from N4.5 to N5.5, the data of the four groups all change: the average hue angle of the samples of the green group, the yellow-green group and the yellow group increases slightly, while the average hue angle of the samples of the blue-green group decreases slightly. According to the CIE color system, the best display lightness of the green hue is around N5, and lightness coincidence occurs in the background transformation of N4.5-N5.5. Therefore, the background lightness in this range plays an auxiliary role in the display of the green hue, and the best display lightness of the blue hue is about N4, so the background lightness in this range weakens the display effect of the blue hue to a certain extent. When the background lightness is in the range of N4.5 to N9.5, the continuous increase of the background lightness has no great influence on the hue of the sample, because the gray level in the hue of the sample itself is slightly larger whether it is cyan group, green group, yellow-green group or yellow group, but the average hue angle of the four groups of samples also shows some slight decrease, which indicates that for the samples of green group, yellow-green group and yellow group, the background lightness in the range of N5.5-N6.5 is more favorable for displaying the foreground scenery, and for the samples of cyan group, or the background lightness is n. It is worth noting that the yellow group is less sensitive to the change of background lightness than the other three groups, and the hue hardly changes with the change of background lightness. Therefore, the conversion of the lightness of the achromatic background can slightly change the visual hue of the sample.

4. Conclusion

The change of the lightness of the achromatic background has a significant effect on the lightness L*, chroma C* of the sample color parameters, but has no significant effect on the hue angle h_0. There is a significant positive correlation between the visual lightness change of the sample and the background lightness change. For the sample with higher lightness value, it is more vulnerable to the influence of the non-color background lightness, and the lightness of the sample itself is different, and the degree of influence by the non-color background lightness is also different. However, when the sample itself has too low lightness, the sample lightness is almost not affected by the non-color background lightness. Although the sensitivity of the sample's visual chroma to the change of background lightness is slightly lower than the sample's visual lightness, it can also be seen that there is an obvious positive correlation between the change of visual chroma and the change of background lightness. The chroma of the sample itself is different, which is affected by different background lightness. A lower background lightness will lead to a lower visual chroma. However, when the lightness and chroma of the sample itself are too low, the visual lightness and chroma are basically not affected by the lightness of the achromatic background. The conversion of non-color background lightness can slightly change the visual hue of the sample.

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