Quantitative Analysis of Traditional Chinese Color

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Chinese traditional colors are an important component of traditional culture, containing profound national culture and unique aesthetic ideas. Analyzing and applying the color characteristics of traditional Chinese colors can integrate traditional color design concepts into contemporary design, implying a design path from tradition to the present, and meeting the diversified and personalized consumer needs of the market. This study examined consumers' psychological perception of traditional colors using the Natural Color System and Likert scale. Factor analysis and association tests revealed color attributes and image cognitive traits. The results reveal that blackness often degrades color image judgement. Saturation influenced Tang and Qing color perception. Red, green, and blue are the ideal hues for the Tang, Song, and Qing Dynasties, respectively. Song Dynasty culture and emotions are perfectly reflected in the green color. The Ming Dynasty's visual traits are blue, and its culture and feeling are yellow. The red color best reflects the Qing Dynasty's cultural and emotional traits, and the blue hue best matches its aesthetic traits. The study attempts to quantify customised furniture color design and improve product color design's cultural meaning and aesthetic effect.

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INTRODUCTION

Color is fundamental to Chinese traditional culture, which comprises rich national culture and aesthetic ideas. Traditional color schemes are largely based on old aesthetics and wisdom. To make them more congruent with the aesthetic cognition of current customers, it is vital to examine consumers, color preferences (Xu 2020). Traditional color has deep cultural connotations, making image transmission crucial. Design color should reflect culture.

Different intelligence algorithms rationally analyse people's color vision to evaluate color images. Perceptual engineering, Grey theory, neural network, fuzzy theory, mathematical, physical, and chemical theory, joint analysis, *etc*., are the primary methodologies. For example, Hsiao and Tsai (2004) predicted multi-color product color image evaluation using Grey clustering. Lai and others created a product shape and color evaluation model using neural network, quantitative theory, and perceptual engineering theory (Lai *et al.* 2006). Hsiao *et al.* (2006) used Grey theory and fuzzy neural network theorem to create two color evaluation models for electronic door lock design. Kirchner (2015) analyzed the law of color application in medieval Islamic culture. Llopis *et al.* (2016) used the Natural Color System to analyse a group of color design samples in 1931 and create a 3D space color combination network. Bang *et al.* (2018) examined South Korea's cultural history and suggested ways to restore architectural color. Kmita (2018) retrieved patterns and colors from cultural heritage image files. To sum up, most of the research methods of Color image are the combination of Kansei engineering and data mining. Traditional colors should not only conform to the application methods of colors, but also pay attention to their cultural integration. Color image can be the focus of traditional color research, and the evaluation of color is subjective and depends on the views and preferences of consumers, so it should be based on the willingness of users.

This study affects bespoke furniture color selection. It enhances cultural and aesthetic benefits of color design, improves designer productivity, and gives objective reference for applying traditional colors to customised furniture.

METHODOLOGY

Research Sample

The image samples considered in this work were from traditional cultural relics. Due to the specificity of the research object, color extraction cannot be directly performed on the research object, and only computer technology can be used to extract color. A large number of traditional cultural relics images were sourced from official platforms such as the Palace Museum, Taipei Palace Museum, National Museum of China, Dunhuang Research Institute, Tianjin Museum, Suzhou Museum, Liaoning Provincial Museum, *etc*. The urlibs provided by Python program were used to simulate the HTTP request behavior of the browser, and extract image links from the downloaded local webpage files (Lee and Han 2021), as shown in Fig. 1 to obtain a database of traditional Chinese color images. The four most culturally rich dynasties in history—Tang, Song, Ming, and Qing—were chosen after sifting and screening. Each dynasty’s picture data includes ceramics, art, clothes, enamel, and jewelry.

Fig. 1. The process of obtaining research samples

Because the photographs were from many sources, their format, size, and background affect color extraction results. Preprocess the image samples: (1) Python's PIL (PIL, PythonWare, python2.7, Amsterdam, Netherlands) package was used to scale down the image evenly to 200px wide; (2) The collected image materials were subjectively removed to create a foreground image with just cultural relics to highlight the research object and eliminate interference.

A cultural relic image was clustered and digitally colored using K-means clustering (Yang and Yuan 2019). K clusters split the color point set in space. Each cluster centre indicates the category color. Before clustering, the computer randomly produces the first cluster center, calculates the distance from each point to the center, and iterates the new centre. The data set samples are assigned to the nearest cluster based on minimum distance to minimise the sum of distances E between all data points and their cluster centre points, using Eq. 1,

$$E = \sum_{i=1}^{k} \sum_{x \in C_i} ||x - u_i||^2 \tag{1}$$

where C_i is the i[th] cluster, x is the pixel, u_i is the i[th] initial cluster center, and K is the number of clusters. The preceding procedures were repeated using the average sample value in each cluster as the new cluster centre. All cluster centres need to be updated; otherwise the algorithm fails (Dimov *et al.* 2005). The primary color elements of the image may be retrieved when K [3, 7] colors (Chang *et al.* 2015). Typically, K = 3 is the default. The image's main, auxiliary, and ornamental colors can be identified by color proportion, and the relevant color values can be extracted for data analysis. Re-extraction of single picture color extraction result set yields typical colors from many color samples. Through repeated contrast trials and reduction of related hues, it is established that 30 colors may be grouped and extracted well. In light of this, K = 30 is configured to group hue, saturation, and brightness using the HSV color system. The final 30 typical colors were categorised using IBM SPSS Statistics 26 software's system cluster analysis. Table 1 shows 30 typical Tang, Song, Ming, and Qing dynasty colors generated by merging the clustering results of multiple color databases.

Table 1. Typical Traditional Color Samples

Dynastic Classification	Color Swatch
Tang Dynasty	
Song Dynasty	
Ming Dynasty	
Qing Dynasty	

Model for the Research

The Natural Color System is based on visual observation that was devised by Dr. Anders Hård, a color expert from the Swedish National Institute of Color Research (Hård and Sivik 1981). Six indicators represent its three-dimensional form with 6 reference colors and 2 cones joined. The indicators are whiteness (W), blackness (S), yellow (Y) hue, red (R), blue (B), and green (G); the color ring and NCS color triangle show the matching relationship of the four major reference colors (Y, R, B, and G) in the hue and the matching relationship between the solid color (C) of the hue and the black and white reference colors (Linhares *et al.* 2019). The straightforward and clear Natural Color System is essential for color design, analysis, assessment, and other study domains.

The Survey Process

By conducting literature research, searching the internet, magazines, advertising, and other means to search for descriptions, evaluations, and interviews related to the culture of the dynasty, we extract emotional vocabulary related to the style imagery of the Tang, Song, Ming, and Qing dynasties. Using the KJ method, these are classified into six groups of imagery vocabulary, each consisting of positive and negative adjectives (Chen *et al.* 2012). The Tang Dynasty successfully acquired a total of six types of picture vocabulary: gorgeous/simple, grand/implicit, comprehensive/conservative, kind/cold, mysterious/plain, and high-key/low-key. Simple/complex, elegant/vulgar, soft/vigorous, rational/romantic, lively/steady, and delicate/rough were the six categories into which the picture vocabulary of the Song Dynasty was classified. In the Ming Dynasty, there were six categories of picture vocabulary: atmospheric/implicit, simple/gorgeous, elegant/vulgar, warm/cold, slim/thick, and quiet/nimble. The six categories of image words gorgeous/plain, exquisite/crude, vivid/monotone, mysterious/plain, solemn/casual, and bold /graceful were used throughout the Qing Dynasty.

The Likert scale was used to measure the strength of the tester's attitude towards any concept, and the common Likert scales are 5, 7, and 10 (Wratten *et al.* 2022). This study employed a 7-level scale to rank conventionally used colors. Testers were instructed to score the scheme from -3 to 3 points. The generation scores near both ends signify prominent picture features, 0 is neutral, positive words on the left are positive, and negative words on the right are negative. The 20 examiners, 9 men and 11 women, were born after 1995 and knew something about Tang, Song, Ming, and Qing culture. IBM SPSS Statistics 26 programme calculated the experimental average.

RESULTS

Color Image Analysis

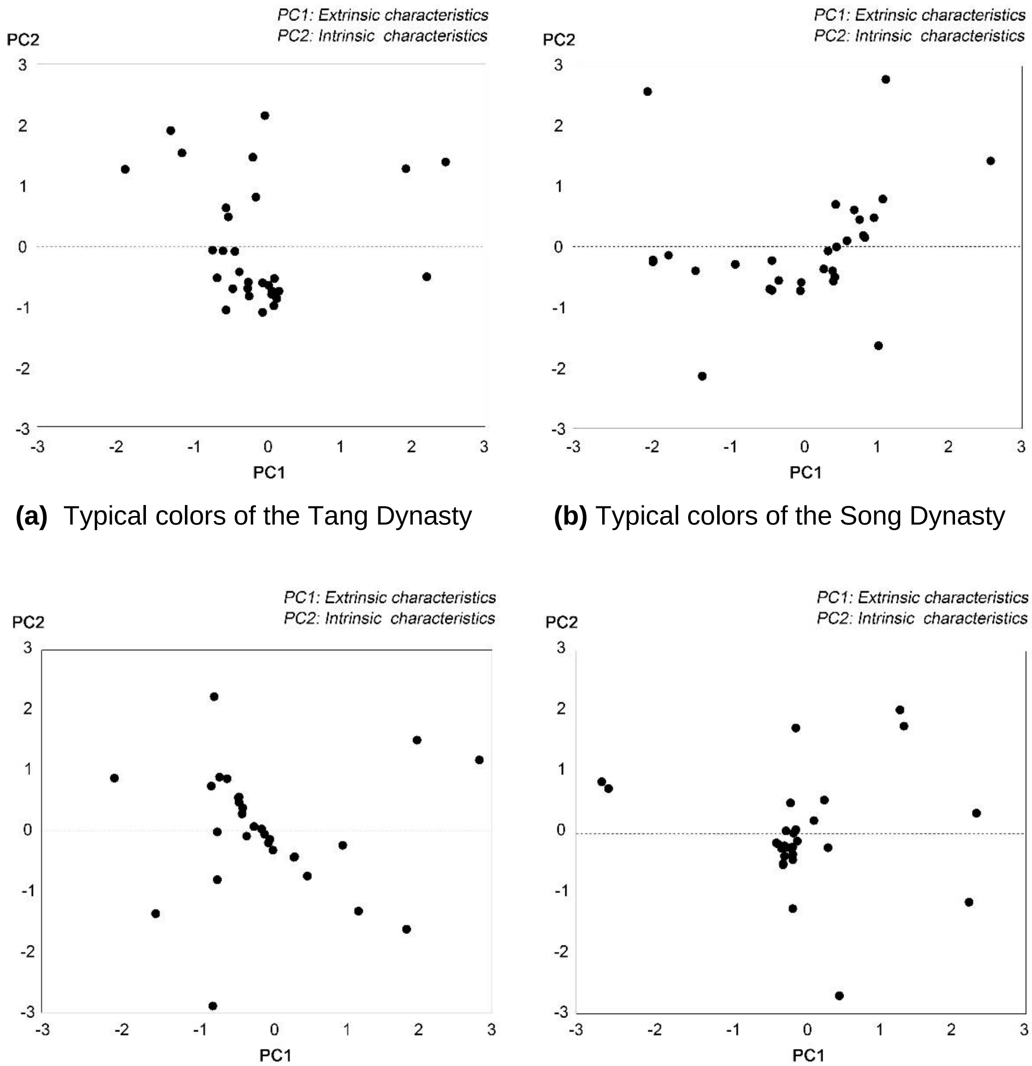
Factor analysis with IBM SPSS Statistics 26 was used to summarise and correlate images (Liu *et al.* 2022). The significance of Bartlett's ball test was (0.000) < 0.05, indicating a significant correlation between variables. Second, KMO test examines partial correlation between variables with a value of 0 to 1. Factor analysis works better when the KMO statistic is closer to 1. Factor analysis works best for statistics greater than 0.5 (Guan *et al.* 2016). The test data KMO scores are 0.681, 0.588, 0.583, and 0.561, showing that the variables have commonality and can be factored. Finally, the factor analysis results show that the top two components have cumulative contribution rates more than 80%, indicating that they better understand picture variable information. The rotated component matrix in Table 2 and factor scores in Fig. 2 show each factor's picture vocabulary scores and typical color scores.

Color images have two features, according to factor analysis. The visual components of color that may be summed up as exterior qualities, such as gorgeous/simple, grand/implicit, and high-key/low-key in the image words of the Tang Dynasty, are what the image words with a high load of absolute value in component 1 primarily reflect. The cultural and emotional aspects of color are primarily reflected in the image words with high load absolute values in component 2, which may be summed up as internal traits like comprehensive/conservative, kind/cold, and mysterious/plain in the image words of the Tang Dynasty.

The unique picture vocabulary score for each factor can be used to get the score for each color on many factors. While the color with a higher score on component 2 more clearly demonstrates the cultural and emotional traits of the associated dynasty, the color with a higher score on component 1 is more appropriate for the visual qualities of the corresponding dynasty. Suggestions for color design can be made based on the idea that factors with higher scores should be considered. They are: color samples T1, S20, M7, Q17, and Q28, which have the highest component 1 scores and the best effects; color samples T14, S6, M2, and Q30, which have the highest component 2 scores and the most obvious intrinsic cultural characteristics of color.

Table 2. Factor Analysis Results of Color Image

Color Classification	Component Matrix After Rotation[a]						
	part	Sum of Squares of Rotating Loads			Imagery	Component	
		Total	Percent Variance	Accumulation (%)		PC1	PC2
Tang Dynasty Typical Colors	1	2.91	48.42	48.42	gorgeous/simple	0.69	0.59
	2	2.35	39.17	87.59	grand/implicit	0.78	0.52
	3				comprehensive/ conservative	0.21	0.92
	4				kind/cold	-0.01	0.84
	5				mysterious/plain	-0.05	0.97
	6				high-key/low-key	0.79	0.53
Song Dynasty Typical Colors	1	3.02	50.26	50.26	simple/complex	0.98	-0.01
	2	2.58	42.93	93.19	elegant/vulgar	0.86	0.30
	3				soft/vigorous	0.93	0.26
	4				rational/romantic	0.19	0.97
	5				lively/steady	0.49	0.82
	6				delicate/rough	0.43	0.90
Ming Dynasty Typical Colors	1	2.85	47.44	47.44	atmospheric/ implicit	0.87	0.47
	2	1.92	32.04	80.48	simple/gorgeous	0.88	-0.23
	3				elegant/vulgar	-0.07	0.78
	4				warm/cold	-0.21	0.81
	5				slim/thick	0.96	0.14
	6				quiet/nimble	-0.58	0.61
Qing Dynasty Typical Colors	1	3.05	50.85	50.85	gorgeous/plain	0.75	0.58
	2	1.77	29.57	80.42	exquisite/crude	0.93	-0.02
	3				vivid/monotonous	0.89	0.43
	4				mysterious/plain	0.07	0.64
	5				solemn/casual	-0.26	0.91
	6				bold /graceful	-0.05	0.88



(a) Typical colors of the Tang Dynasty **(b)** Typical colors of the Song Dynasty

(c) Typical colors of the Ming Dynasty **(d)** Typical colors of the Qing Dynasty

Fig. 2. Score of specific image words of each factor

Correlation Analysis of Color image and NCS Color Elements

To investigate the hue, lightness, and chroma characteristics of colors with particular semantic perception, a correlation analysis between color image level (Z) and hue variables (Y, R, B, and G), blackness variable (S), and chroma variable (C) was performed.

Data should be normalised before correlation analysis. IBM SPSS Statistics 26 offers Kolmogorov Smirnov and Shapiro Wilk normalcy tests (Araveeporn 2022). The Kolmogorov-Smirnov test is suitable for assessing data normality in big samples with more than 50 rows. Shapiro Wilk test method was used for the normality test because it is appropriate for small sample data analysis with less than 50 rows (Mudholkar *et al.* 1995).

Most of the significance test P values of typical color image variables and color elements are less than 0.05, which does not follow the normal distribution and meets Spearman correlation coefficient correlation test requirements. Pearson linear correlation coefficient is usually called Spearman correlation coefficient (Sedgwick 2014). Assume that the original data x_i and y_i are arranged in the order from big to small, and record that x'_i, y'_i are the original x_i, and yi is the position of the data after arrangement, then x'_i, y'_i are called the rank of variables x'_i, y'_i, and $d_i = x'_I - y'_i$ is the difference between the rank of x_i and y_i. If there is no same rank, the Spearman correlation coefficient r_s can be calculated by Eq. 2. If the same rank exists, the Pearson linear correlation coefficient between ranks needs to be calculated, as shown in Eq. 3 (Hanxiao *et al.* 2022):

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{2}$$

$$r_s = \frac{\sum_i (x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_i (x_i-\bar{x})^2 \sum_i (y_i-\bar{y})^2}} \tag{3}$$

Spearman correlation coefficient applies to non-linear and non-normal data. Stronger linear correlations produce Spearman correlation coefficients closer to 1 or -1, indicating positive or negative connection (Cao *et al.* 2022).

Table 3. Correlation Analysis Results of Color Elements

Indicator Variable		Correlation Coefficient: r_s					
Color Characteristics Color Element		Blackness	Chroma	Y Hue	R Hue	B Hue	G Hue
Tang Dynasty	Extrinsic characteristics	0.24	0.30	-0.29	0.34	0.15	-0.26
	Intrinsic characteristic	-0.42	0.83	0.28	-0.35	-0.57	0.61
Song Dynasty	Extrinsic characteristics	-0.50	-0.26	0.16	-0.52	0.45	0.32
	Intrinsic characteristic	-0.49	0.36	-0.18	-0.55	0.13	0.59
Ming Dynasty	Extrinsic characteristics	0.03	-0.21	-0.34	-0.02	0.40	-0.03
	Intrinsic characteristic	-0.17	0.18	0.64	0.11	-0.74	0.10
Qing Dynasty	Extrinsic characteristics	-0.70	0.64	-0.08	0.36	0.33	-0.21
	Intrinsic characteristic	0.02	0.54	-0.01	0.38	0.00	-0.28

According to the correlation analysis results of image characteristics and color elements in Table 3, color perception rules of testers were as follows:

1. External characteristics of color: Tang dynasty colors are known for their “magnificence,” “atmosphere,” and “publicity” qualities. Blackness is uncorrelated with exterior traits. Color darkness does not impact the tester's color perception. Chroma improves vision. The Song Dynasty’s colors are simple and elegant, characterised by “simplicity,” “elegance,” and “softness.” Red is the dominant hue. The tester’s visual assessment of Song Dynasty color was adversely linked with blackness and chroma. Ming period colors have a strong sense of hierarchy, characterised by “atmosphere,” “simplicity,” and “delicacy.” Song porcelain culture is strongly associated with blue color. Blackness and chroma are unrelated to appearance. The Qing Dynasty's lovely, elegant color is described as “gorgeous,” “exquisite,” and “vivid” by testers. Chroma positively correlates with interior traits, while blackness strongly negatively correlates with outward features. Qing Dynasty testers prefer red and blue hues and bright characteristics.

2. Intrinsic characteristics of color. Tang dynasty colors are atmospheric and inclusive, with “openness,” “friendliness,” and “mystery.” Blackness severely affects internal traits and color culture. Chromaticity strongly correlates with interior traits. Most testers think Tang Dynasty colors should be vivid. The Song Dynasty's pure artistic view of color emphasises “rationality,” “lightness,” and “delicacy,” with cultural and emotional

aspects being green. Blackness lowers the tester's assessment of Song Dynasty colors' culture and emotions. The tester prefers colors with color sense but low chromaticity. Ming dynasty colors are dignified and graceful, with "elegance," "warmth," and "silence" as their key traits. In the Ming Dynasty, internal color properties were unaffected by darkness and chroma. Yellow matches its internal culture; Qing dynasty colors inherited heritage and minority culture, with "mysterious," "solemn," and "bold" traits. Blackness does not change intrinsic traits. Chroma improves internal qualities and red color is recognised.

CONCLUSIONS

1. Blackness is adversely correlated with the assessment of color image style among the characteristics influencing the evaluation of traditional Chinese color picture. Chroma influences how positively people in the Tang and Qing dynasties see color.
2. The Tang dynasty's aesthetic aspects lean towards the red hue in terms of tone, while its culture and emotions are best captured by the green color. Blue hue best reveals the visual characteristics of the Ming dynasty, yellow hue corresponds to the culture and emotion of the Ming dynasty, and red hue may best convey the culture of the Qing dynasty. Green hue accurately depicts the culture and feeling of the Song dynasty, while the blue hue best adheres to its aesthetic qualities.

Based on research findings, it is possible to effectively evaluate the imagery of traditional Chinese colors, express the relationship between external and internal characteristics of colors and color elements, and assist designers in obtaining design solutions for traditional colors more quickly to meet the needs of target consumer groups. The flexible application of traditional colors in design practice can not only enhance people's aesthetic perception of products, but also enrich the meaning of products and inherit traditional culture.

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