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Color Scheme Compensatory Evaluation Method Based on Eye Movement Tracking Technology

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ABSTRACT In the process of product color scheme evaluation, subjective evaluation is liable to mislead evaluation and decision-making. To conduct a more objective quantitative evaluation for color schemes, a compensatory evaluation method for color scheme based on eye movement tracking technology is proposed in this paper. In this method, four types of eye movement experimental data–fixation time, number of fixation points, number of fixation times, and first fixation time–are collected in the area of interest (AOI) from the experimental sample by eye movement tracking technology. SPSS software is employed to test the reliability of the experimental data, and the value assignment method is used to perform compensation processing on the experimental data, so that the final evaluation result can be obtained with the assignment calculation. Taking the evaluation of the disguise color scheme of a camouflage uniform as an example, the operation process of the method is demonstrated, and the effectiveness of the method is verified with the questionnaire. The results show that the color scheme compensatory evaluation method based on eye movement tracking technology can achieve an effective evaluation of color schemes. This method realizes the quantification of and data compensation for color scheme evaluation, making the evaluation results more scientific and accurate and providing a reference basis for color scheme designers in evaluation and decision-making.

INDEX TERMS Eye movement tracking technology, entropy weighting method, compensatory evaluation, color matching evaluation method.

I. INTRODUCTION

The perception of the overall image of a product is usually caused by its form and color; the color has a greater impact than the shape [1]. In the process of product color matching design, it is inevitable to evaluate and make decisions on color schemes. In traditional color scheme evaluation, designers usually evaluate based on subjective experience and many trials and errors, usually lacking data support in the evaluation process. To improve the overall image of the product and reduce the errors in the evaluation of and decision-making for color schemes in product development, and increasing number of design companies and designers have paid attention to the quantitative evaluation of color schemes. The emergence of eye movement tracking technology makes it possible to conduct an objective evaluation of color matching design schemes based on data quantification [2],[3]. With the use and development of eye movement tracking technology, researchers have gradually realized eye tracking and data recording for the evaluation process. Eye movement tracking technology has become an important tool in the evaluation process due to its unique advantages [4].

At present, researchers use various evaluation methods to evaluate color matching design. The design evaluation research includes two different research paradigms: the research paradigm based on the evaluation results and the research paradigm based on the evaluation process [5]. The former focuses on program input and data output in the evaluation and obtains evaluation data through subjective color scheme evaluation through task simulation [6], user interviews [7] and questionnaires [8], which are very mature in research. The latter investigates the relationship between the program input and data output, collects and records data in the evaluation process through physiological recording instruments, and conducts a more objective color scheme evaluation, which is an important research direction in current color matching evaluation research. Hsu *et al.* [9] used eye movement tracking technology to evaluate web design and obtain the best web design plan. Hou *et al.* [10] evaluated the color design of cigarette packages by using data recorded by

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eye movement tracking technology to obtain color schemes that teenagers hate. Liu *et al*. [11] used eye tracking technology to evaluate the appearance design of street lamp products to obtain the most beautiful design scheme. Although the above research introduced advanced eye movement tracking technology in the data collection process, it did not introduce a more complete mathematical model in the subsequent data processing process, which may cause errors.

With the development of evaluation theory, compensatory evaluation was introduced into the evaluation of design schemes. Researchers have quantified and compensated color schemes with various mathematical algorithms to obtain the best color schemes [12]-[14]. Evaluation theories and models can be divided into two categories: compensatory evaluation and noncompensatory evaluation. Compensatory evaluation refers to processing all relevant information in the evaluation process and weighing the weights of all options and their indicators [15]. Hsiao, Tsai, Yeh *et al*. used mathematical methods such as gray theory [16], fuzzy algorithm [17], neural network [18], genetic algorithm [19], and particle swarm algorithm [20] to process the subjectively acquired data to complete a more scientific compensatory color matching evaluation and improve the quality of color matching design. In the field of compensatory evaluation based on the paradigm of the evaluation process, many researchers have also described various results. Li *et al*. [21] obtained product appearance evaluation data through eye movement tracking technology and used fuzzy algorithms for compensatory evaluation to scientifically evaluate the uniqueness of product appearance and provide an objective reference for improving product appearance. Diego-Mas and Garzon-Leal [22] used eye movement tracking technology to obtain user interface layout evaluation data and used genetic algorithms for compensatory evaluation to obtain the best layout of the user interface, which effectively improved user efficiency and satisfaction.

The above research solves the problem of quantitative evaluation for subjective feelings and has achieved fruitful research results. In the compensatory evaluation research based on the evaluation process, the evaluation method using physiological recording instruments and compensatory mathematical algorithms is widely used in the evaluation of advertising programs [23], animation programs [24], product design [25], digital interfaces [26] and many other fields. The compensatory evaluation obtains the expected value of each option through the in-depth calculation and processing of data to obtain more objectively optimal schemes that the decision maker employs to make the decision-making more scientific [12]. However, there are relatively few studies on eye movement tracking technology in the evaluation of color schemes, especially on the evaluation methods based on the combination of eye movement tracking technology and compensatory mathematical algorithms. In the pursuit of a more objective quantitative evaluation of color schemes, more challenges and possibilities are presented to designers.

Therefore, a color scheme compensation evaluation method based on eye movement tracking technology is introduced to solve the objective quantitative evaluation problem of color matching design in color evaluation. This method provides designers with new measures and means to solve the problem of color matching design scheme evaluation and has become an important extension and innovation of the existing color scheme evaluation theory and application. This method combines eye movement tracking technology and entropy weighting method to perform compensatory evaluation of color schemes to obtain the best color scheme. In this study, four eye movement experimental data– the fixation time, number of fixation points, number of fixation times, and first fixation time–were collected in the area of interest (AOI) using eye movement tracking technology. SPSS software was used to test the reliability of the experimental data, the entropy weighting method was used to perform compensatory processing on the data to obtain the scoring weights of different indicators, and the final evaluation result was obtained through assignment and calculation. The experiment took the evaluation of the disguise color scheme of the Chinese 07-style military jungle camouflage clothing as an example to demonstrate the operation process of this method, combined with a questionnaire to verify its effectiveness. The results show that the color scheme compensation evaluation method based on eye movement tracking technology can achieve effective evaluation of color schemes. This method realizes the quantification and compensation of the color scheme evaluation, improves the scientific basis and accuracy of the color scheme evaluation, and provides a reference for the evaluation and decision-making of the color scheme designer. The method is beneficial to reduce R& D errors caused by product color matching evaluation during product development, which can enhance the overall image of the product.

The structure of this article is as follows: The introduction describes the latest technology in the field of color scheme evaluation. In the second section, the concepts and methods of eye movement tracking technology and entropy weighting method are introduced. The third section focuses on the results of the color design scheme evaluation experiments, as well as the experiments and analysis. Section 4 describes the subjective verification process of this method. The last section comprises the conclusions of this research and thoughts on the future.

II. METHODS AND PROCESSES

A. EYE MOVEMENT TRACKING TECHNOLOGY

Eye movement tracking technology is based on infrared equipment and image acquisition equipment, which can track subtle changes in eye features in real time by actively projecting infrared beams to the iris. Eye movement tracking technology has less interference in the collection and evaluation process of participants, and it can record a variety of data during eye movements. To ensure the accuracy of the evaluation, the eye movement tracking device can achieve a more objective description of the design scheme [27].

1) EYE MOVEMENT TRACKING DATA VISUALIZATION METHOD

There are four common methods for visualizing eye movement tracking data: the scanning path method, the heat zone map method, the three-dimensional space method and the AOI method. The scanning path method can intuitively represent the participants' dynamic distribution of fixation and search process, but it is difficult to understand when there are more scanning paths. The hot zone map method is more intuitive to show the spatial distribution of fixation points, but it cannot express the order of fixation points. The three-dimensional space method can also intuitively show eye movements in three-dimensional space, but its visualization accuracy is low. Compared with the above three methods, the AOI method can extract accurate data for various indicators in the experimental process and conduct a comprehensive analysis of the visual search and information processing process [28]. Therefore, the AOI method is the most commonly used data visualization extraction method in eye movement tracking experiments.

2) EYE MOVEMENT TRACKING INDICATORS AND THEIR MEANINGS

Many eye movement indicators are collected using the AOI method, such as the fixation time, number of fixation points, and number of fixation times. Different eye movement indexes represent different meanings. Common eye movement tracking indicators and their meanings are as follows.

1) Fixation time: statistics of the duration of each visit interest area.
2) Number of fixation points: the number of fixation points for participants in the area of interest.
3) Number of fixation times: visits from one area of interest to the next, recording the number of visits in an area of interest.
4) First fixation time: the duration of the first fixation point in the interest area.
5) First entry time: how long did it take for the participant to look at this area of interest for the first time.
6) Total fixation time: the calculated sum of all visit times in the area of interest.
7) Sum of fixation points time: the calculated sum of the duration of all fixation points in the area of interest.
8) Visit time percentage: the calculated total fixation time as a percentage of the total time.

3) EYE MOVEMENT TRACKING INDEXES AND DESIGN EVALUATION

The eye movement tracking indicators need to be reasonably selected based on the actual design evaluation content [29]. The eye movement tracking evaluation experiments are divided into two types: autonomous decision-making tasks and rule-forced selection tasks. Autonomous decision-making tasks focus on an information search for attributes, while eye movement tracking data focuses on the number of saccades between options. Participants in the rule-forced selection task focus on regular information search, and the eye movement tracking data for target searches usually focuses on the fixation duration and number of fixation times [30].

A large number of studies have shown that there is an objective close connection between eye movement data and design evaluation schemes [31]. Wang *et al*. [32] used five eye movement indicators including the fixation time, number of fixation points, number of fixation times, total saccade length, and average pupil diameter to quantitatively evaluate the interface usability, comfort and aesthetics. Wang *et al*. [33] used four eye movement indicators: fixation time, number of fixation points, first fixation time, and average pupil diameter to quantitatively evaluate the degree of concealment of bicycle battery boxes. Michalski [26] used three eye movement indicators: total fixation time, number of fixation points, and number of fixation times to quantitatively evaluate the aesthetic quality in product design.

4) SELECTION OF EYE MOVEMENT TRACKING INDEXES

Based on previous research results and experimental tasks, this study selects four highly correlated indicators for analysis and calculation– fixation time, number of fixation points, number of fixation times, and first fixation time. These four indexes can generally reflect users' visual preferences.

1) The indicator of fixation time collects the time the participant's fixation stays in a certain area in seconds. The longer the attention is, the greater the user's interest in the color matching of the area.
2) The indicator of number of points collects the number of fixation points of the participants in a certain area. The more fixation points indicate the higher the satisfaction of color matching.
3) The indicator of number of fixation times collects the number of times the participant has relooked in a certain area. The more relooks indicate the more attractive the color matching of the area.
4) The indicator of first fixation time collects the duration of the participant's first fixation in a certain area in seconds. The longer the first fixation time is, the more important the color collocation of the area.

B. ENTROPY WEIGHTING METHOD

The entropy weighting method can obtain the optimal plan for the decision makers more objectively and improve the scientific for evaluation of the color design scheme [34]. The entropy weighting method is usually used to solve the multiattribute decision-making problem. The weighting of the four eye movement indicators is essentially a multiattribute decision-making problem whereas the four eye movement tracking indicators extracted in this study have different credibility and are given different weights. Therefore, it is necessary to perform weighting calculations on the eye movement tracking data to ensure the professional and scientific basis of the color scheme evaluation [35]. Fuzzy comprehensive evaluation, analytic hierarchy process, gray relational analysis and other commonly used methods to determine weights are difficult to establish mathematical models or obtain evaluation results with greater randomness. Minor changes in the eye movement index data in this study may lead to very different results of the design evaluation [36]. In contrast, the entropy weighting method obtains the objective index weight expected by each eye movement index through the deep calculation and processing of the eye movement tracking data, which has high reproducibility and reliability. Therefore, the entropy value is used to allow for the color scheme evaluation based on eye movement tracking technology to be more scientific, realistic, and effective.

The entropy weighting method is widely used in the field of evaluation. Yang and Wang [37] used the entropy weighting method for compensatory evaluation to provide a theoretical basis for the selection of clinical prescriptions. Zuo and Li [38] used the entropy weighting method to conduct a compensatory evaluation, and objectively evaluated the advantages and disadvantages of community opening to traffic. Wang *et al*. [34] used the entropy weighting method for compensatory evaluation, which provided a richer reference for the evaluation of the optimal design of the human-machine interface of special vehicles.

1) BASIC PROPERTIES OF THE ENTROPY WEIGHTING METHOD

The entropy weighting method is a commonly used method to determine the index weight. Its main basis is the amount of information that each indicator transmits to decision makers. It is generally believed that the greater the dispersion of the scores of each group of programs under a certain index, the greater the amount of information that the data can provide. In contrast, if the scores of all programs under a certain index are the same, then the index is meaningless for program evaluation. Entropy is an important indicator in measuring the stability of evaluation data. The physical meaning of entropy is the degree of chaos in the system. In information theory, the entropy value is inversely proportional to the degree of information dispersion, that is, it is inversely proportional to the weight value of the evaluation index [39].

The entropy weighting method has the following basic properties: (1) When the value of the evaluated object on a certain index is exactly the same, the entropy value reaches the maximum and the entropy weight is zero, indicating that the index does not provide any useful information to the evaluator and can be considered for omission. In contrast, when the value of the evaluated object on a certain index differs greatly, the entropy value is relatively small and the entropy weight is relatively large, which indicates that the index provides useful information to the evaluator and should be focused on. (2) The larger the entropy value of the evaluated index, the smaller the entropy weight and the less important the index is. The sum of the entropy weights is 1. (3) The entropy weight does not indicate the actual importance coefficient of a certain index in the evaluation problem but is the relative intensity of the actual competition among the indexes [40].

2) SPECIFIC STEPS OF THE ENTROPY WEIGHTING METHOD

The entropy weighting method is a mature objective weighting method. According to the characteristics of the entropy weighting, the entropy value can be calculated to determine the degree of dispersion of an indicator in the evaluation of color schemes [41]. This study uses the entropy method for weighting because it only relies on the discreteness of the data itself. The specific steps of the entropy weighting method are as follows:

(1) Data standardization processing: When the calculation dimensions of each index are different, the data must be dedimensionalized. Data processing is generally divided into positive index processing and negative index processing. Positive indexes are processed by Eq. (1) and negative indexes by Eq. (2).

$$X`_{ij} = \frac{X_{ij} - \min\{X_j\}}{\max\{X_j\} - \min\{X_j\}} \tag{1}$$

$$X`_{ij} = \frac{\max\{X_j\} - X_{ij}}{\max\{X_j\} - \min\{X_j\}} \tag{2}$$

In the equation, X_{ij} is the value of the i-th scheme for the *j-th* evaluation index, $\max\{X_j\}$ is the maximum value under the *j-th* evaluation index, and $\min\{X_j\}$ is the minimum value under the *j-th* evaluation index.

(2) Calculate the proportion of each evaluation index:

$$Y_{ij} = \frac{X`_{ij}}{\sum_{i=1}^{m} X`_{ij}} \tag{3}$$

In the equation, m is the number of schemes to be evaluated.

(3) Calculate the information entropy of each evaluation index:

$$e_j = -k \sum_{i=1}^{m} (Y_{ij} \times \ln Y_{ij}) \tag{4}$$

In the equation, $k = \frac{1}{\ln m}$, m is the number of schemes to be evaluated.

(4) Calculate the information entropy redundancy:

$$d_j = 1 - e_j \tag{5}$$

(5) Calculate the weight of each evaluation index:

$$W_i = d_j / \sum_{j=1}^{n} d_j \tag{6}$$

In the equation, n is the number of evaluation indicators.

(6) Calculate the evaluation score of each evaluation index taking into account the weight:

$$S_{ij} = W_i \times X`_{ij} \tag{7}$$

(7) Calculate the final total score for each scheme:

$$G_i = \sum_{j=1}^{n} S_{ij} \tag{8}$$

In the equation, n is the number of evaluation indicators.

C. THE OVERALL OPERATION PROCESSES

The operation processes of the compensation evaluation method of color matching schemes based on eye movement tracking technology is divided into three steps: (1) the eye movement tracking experimental design; (2) data credibility analysis; and (3) entropy weighting method calculation. The method primarily uses eye movement tracking technology to track the four eye movement data of the fixation time, number of fixation points, number of fixation times and the first fixation time in the color scheme evaluation process. SPSS software is used to test the reliability of the experimental data, the entropy weighting method is used to perform compensatory processing on the experimental data, and the final evaluation result is obtained from the value calculation. The overall framework of the research is shown in Fig. 1.

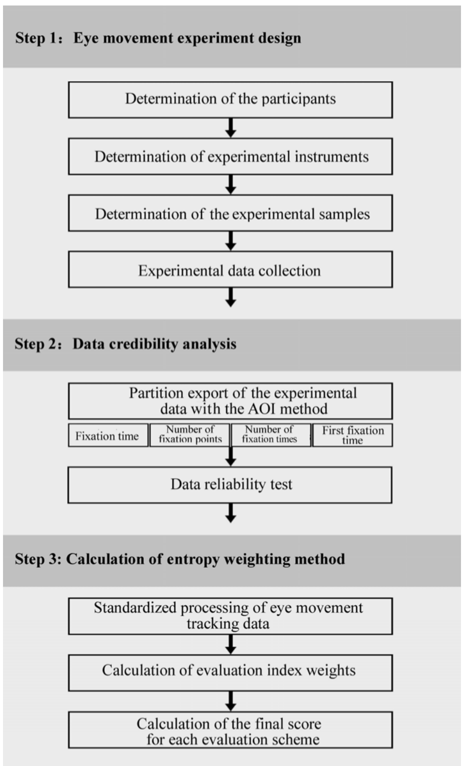

FIGURE 1. Schematic diagram of the operation flow of the compensation evaluation method for a color scheme based on eye movement tracking technology.

III. IMPLEMENTATION AND RESULTS

The implementation of this study used the evaluation of different color schemes of Chinese 07-style military jungle camouflage as a research case to demonstrate the operation process of the method. The purpose of the experiment is to obtain the most disguised color scheme in the sample. Jungle camouflage occupies an important position in camouflage equipment, which has higher requirements for the scientific basis of color camouflage. The higher the degree of fusion between the jungle camouflage and background, the better the effect of disguise [42]. Although the reflected light wave of the 07-style military jungle camouflage is roughly the same as that of the surrounding scenery, it can be seen from many public exercise photos that the disguise effect in the jungle terrain is not very good [43]. Disguise can conceal combat intentions and reduce damage to personnel, fortifications, and weapons, thereby improving the survivability of the troops and aiding the initiative on the battlefield [44]. Therefore, the evaluation of the 07-style jungle camouflage color scheme as a research case is worthy of discussion.

Camouflage disguise is a common method against military reconnaissance and weapon attack systems [45]. Traditional camouflage evaluation methods often use field observations. This method is subjectively affected by the observers, its evaluation results are unscientific, and it requires much manpower, material resources and time [46]. How to objectively determine the optimal disguise scheme has become a difficult problem in the evaluation of camouflage disguise effects [47].

A. EYE MOVEMENT EXPERIMENTAL DESIGN

1) DETERMINATION OF THE PARTICIPANTS

Twenty graduate students from our school participated in this experiment, including 12 men and 8 women. All participants had normal naked vision, no color blindness or color weakness, and wearing glasses did not affect the eye movement tracking data collection. The order in which all participants conducted the experiment was randomly assigned. After the experiment was completed, participants could receive certain material rewards.

2) DETERMINATION OF EXPERIMENTAL INSTRUMENTS

The experiment used the Tobii Pro X2 desktop eye movement tracker produced by Tobii in Sweden to collect the experimental data. This tracker has a sampling frequency of 60 Hz and a gaze positioning accuracy of 0.5°. The tracker was installed directly at the bottom of the computer screen to obtain eye movement tracking data. The experiment was carried out in the science laboratory of the Innovation Building of Shandong University. The experiment was carried out in an environment where the light was moderate and no other factors interfered.

3) DETERMINATION OF THE EXPERIMENTAL SAMPLES

The experimental sample was a picture of 20 people wearing jungle camouflage uniforms with different colors. The shape of the plane texture was taken from the actual clothing shape of China 07-style military jungle camouflage, whose main colors are yellow, green, brown and black. Twenty colors from each color system were randomly extracted

FIGURE 2. Jungle camouflage plane map color scheme (schemes are numbered from left to right, top to bottom, 1, 2, 3…20 in sequence).

FIGURE 3. Characters in jungle camouflage.

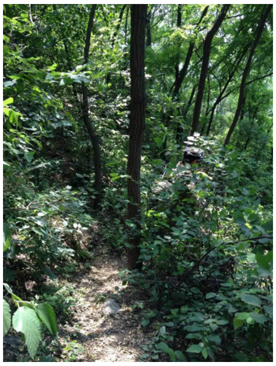

FIGURE 4. Background image of experimental sample.

to form a jungle camouflage plane texture color scheme, as shown in Fig. 2. The colors used in each scheme are shown in Table 1. Each color scheme was mapped and rendered, and the effects are shown in Fig. 3. The rendered character renderings were made the same size and placed in the same position in the background. Last (Fig. 4), 20 jungle camouflage character pictures with a background were evenly distributed in the final experimental sample, as shown in Fig. 5.

4) EXPERIMENTAL DATA COLLECTION

The experiment was conducted with the participants one by one. When the participants entered the laboratory, they sat in front of the eye movement tracking instrument, keeping a fixed distance from the monitor. The observation position of the participant's eyes was calibrated. After the calibration was completed, the experiment started and data were collected. If the eye movement tracking device could not accurately locate the participant's eyes, the participant could not participate in this experiment [48]. The specific experimental verification processes were as follows.

1) The samples and rules needed for the experiment were input and the display parameters were set. The experiment asked participants to look for 5 obvious schemes.
2) The eye movement tracking position was calibrated such that the participant was correlated with the device and accurately located it.
3) Participants watched and understood the experimental instructions and were informed of the test procedures, time and rules.

TABLE 1. Summary of colors used in the color schemes of the jungle camouflage plane map.

Number	Color	R[a]	G[a]	B[a]	Number	Color	R[a]	G[a]	B[a]
1		232	222	151	11		195	172	96
		118	163	124			109	125	63
		133	104	70			125	82	29
		20	19	14			23	19	16
2		193	203	143	12		189	137	1
		62	96	72			51	110	28
		73	63	54			169	136	103
		0	0	0			0	0	0
3		198	191	85	13		192	191	145
		31	112	56			62	96	72
		77	73	36			98	65	46
		0	0	0			18	17	12
4		217	209	137	14		217	209	137
		42	148	0			31	112	56
		96	87	48			133	104	70
		39	30	35			0	0	0
5		192	191	145	15		155	146	91
		80	96	57			32	67	34
		64	48	32			80	58	37
		36	39	30			13	15	28
6		155	145	24	16		197	197	111
		66	112	40			80	117	74
		80	70	56			83	78	49
		30	34	45			39	30	35
7		217	209	137	17		238	243	203
		75	91	65			83	159	87
		96	87	48			133	104	70
		36	39	30			13	15	28
8		223	221	136	18		213	208	140
		83	115	74			23	108	27
		132	97	59			169	136	103
		39	30	35			29	43	43
9		232	222	151	19		151	150	85
		66	112	40			75	101	27
		149	128	97			95	86	47
		36	39	30			13	15	28
10		211	196	19	20		194	192	107
		80	117	74			79	98	76
		80	58	37			116	103	87
		4	10	0			10	12	9

[a]RGB color mode is the color standard in the industry; R = Red, G = Green, B = Blue.

4) At the beginning of the formal test, the participants were asked to watch the test sample for 100 seconds, select the 3 color schemes that they considered the most beautiful within the specified time, and complete the final questionnaire.
5) At the end of the test, the eye movement tracker stopped recording.
6) Participants participated in the questionnaire survey and subjectively ranked each scheme. The higher the rank, the higher the satisfaction.

B. DATA ANALYSIS

1) PARTITION EXPORT OF THE EXPERIMENTAL DATA WITH THE AOI METHOD

ErgoLAB man-machine environment synchronization and platform system software equipped in the Tobii Pro X2 desktop eye movement tracker was used to calculate AOI data statistics. First, the AOI method was used to partition the experimental samples. Each color represents a partition, and each partition has the same size and area, as shown in Fig. 6. The visualization data was partitioned by AOI and selected

FIGURE 5. Schematic diagram of the final eye movement experiment samples of the color schemes based on eye movement tracking technology (schemes are numbered from left to right, top to bottom, 1, 2, 3…20 in sequence).

to be exported, and the eye movement tracking data needed in each partition was extracted. The data credibility analysis results are shown in Table 2.

2) DATA RELIABILITY TEST

The multifactor variance analysis model in SPSS software was used to test the credibility of the 4 kinds eye movement data. The multifactor variance analysis model finds the T value and P value. The T value represents the test value of a single variable and the P value represents the data significance. Generally, a T value greater than 3 or a P value less than 0.05 represents a high significant reliability of the data. In contrast, if the T value is less than 3 or the P value is greater than 0.05, it represents low data significance and low reliability [49].

The test results showed that the T values of the 4 kinds eye movement data in the 20 schemes were all higher than 3, and their P values were all lower than 0.05. This shows that these 4 kinds eye movement data are related to the saliency score of the camouflage color scheme and can be used for mathematical modeling and calculation. With 20 groups of 4 kinds eye movement data, the summary table is shown in Table 3.

C. CALCULATION OF THE ENTROPY WEIGHTING METHOD

1) STANDARDIZED PROCESSING OF EYE MOVEMENT EXPERIMENT DATA

The four evaluation indicators with different dimensions in the article are all positive indicators. Therefore, the data in Table 3 was normalized according to Eq. (1), and the standardized indicator values obtained are shown in Table 4.

2) CALCULATION OF EVALUATION INDEX WEIGHTS

According to Eqs. (3) and (4), the information entropy of the four evaluation indicators is:

$$e_j = [0.9009 \quad 0.9131 \quad 0.9154 \quad 0.8931] \tag{9}$$

In the equation, $j = 1, 2, 3, 4$ are the number of the evaluation index.

In the calculation results, the entropy value of index 4 is the smallest, its data dispersion is the largest, and it has the strongest impact on the evaluation results of the program.

According to Eqs. (5) and (6), the weights of the four indicators are:

$$w_j = [0.2625 \quad 0.2301 \quad 0.2240 \quad 0.2834] \tag{10}$$

In the equation, j =1, 2, 3, 4 are index numbers.

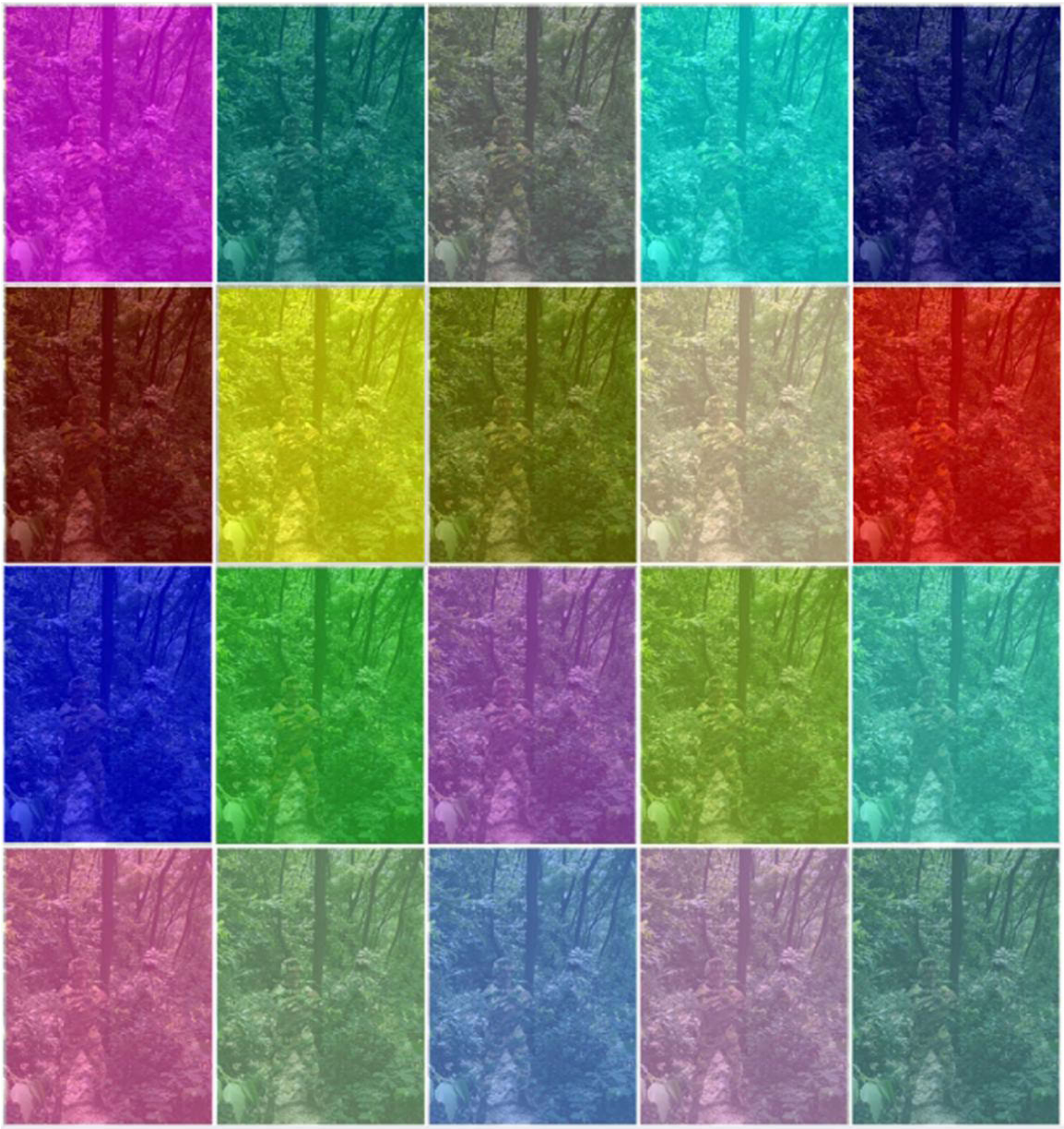

FIGURE 6. Schematic diagram of the visualized data AOI partition based on eye movement tracking technology (schemes are numbered from left to right, top to bottom, AOI1, AOI2, AOI3…AOI20 in sequence).

3) CALCULATION OF THE FINAL SCORE FOR EACH EVALUATION SCHEME

According to Eqs. (7) and (8), the total score of each scheme taking the weight into account can be obtained, and the scores are sorted from high to low, as shown in Table 5. It should be noted that the higher the score of the scheme in Table 5 is, the worse the concealment effect.

In Table 5, Scheme 9 and Scheme 12 scored higher, indicating that their jungle camouflage color schemes are more obvious in the background and their camouflage effect is poor. Scheme 5 and Scheme 20 scored lower, indicating that their jungle camouflage color schemes in the background are easy to be ignored and their camouflage effect is better.

4) COMPARISON WITH SUBJECTIVE WEIGHTING

In this part, the results obtained by the subjective weighting method and the entropy weighting method are compared. The evaluation results obtained by the designer's subjective weighting and calculation were compared with the results obtained by objective weighting, which is usually not considered in many other color design-related experiments [50-51]. Since subjectivity is a key aspect in the field of color design evaluation, this paper incorporates the subjective weighting model of color into comparative research to provide more insights.

An on-site questionnaire survey was conducted with 20 graduate students familiar with eye movement experiments in our school, 8 males and 12 females. The on-site

TABLE 2. Summary of the data credibility analysis results.

Partition	Fixation time		Number of fixation points		Number of fixation times		First fixation time	
	T value	P value	T value	P value	T value	P value	T value	P value
AOI1	3.535	0.002	3.697	0.002	3.671	0.002	3.56	0.002
AOI2	6.236	0	6.55	0	6.716	0	5.083	0
AOI3	7.05	0	5.297	0	5.696	0	6.801	0
AOI4	4.101	0.001	4.097	0.001	4.206	0	4.215	0
AOI5	3.129	0.006	3.812	0.001	4.06	0.001	3.394	0.003
AOI6	4.844	0	5.788	0	5.925	0	4.391	0
AOI7	5.929	0	9.66	0	10.274	0	5.896	0
AOI8	7.411	0	6.508	0	7.37	0	7.908	0
AOI9	5.329	0	7.16	0	7.916	0	5.618	0
AOI10	5.618	0	6.057	0	6.146	0	5.615	0
AOI11	7.389	0	9.359	0	9.765	0	7.907	0
AOI12	7.217	0	9.259	0	9.549	0	7.808	0
AOI13	7.817	0	8.335	0	8.567	0	8.053	0
AOI14	4.974	0	7.046	0	7.495	0	5.272	0
AOI15	3.98	0.001	4.498	0	4.498	0	4.037	0.001
AOI16	3.635	0.002	3.508	0.002	3.336	0.003	3.58	0.002
AOI17	5.459	0	4.349	0	4.534	0	5.24	0
AOI18	5.16	0	6.85	0	4.534	0	5.362	0
AOI19	5.155	0	6.474	0	6.161	0	5.318	0
AOI20	3.043	0.007	4.722	0	5.48	0	3.049	0.007

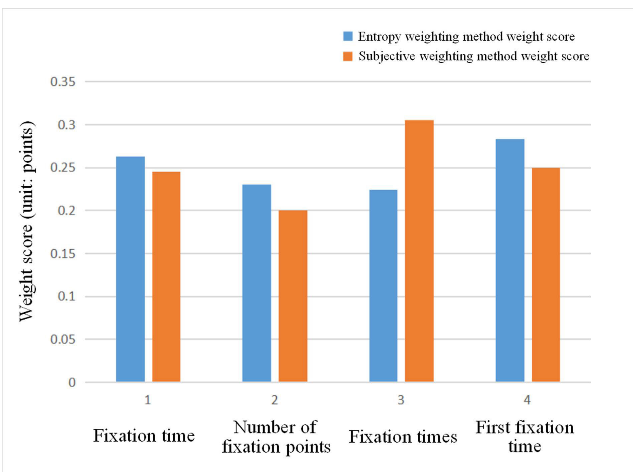

FIGURE 7. Comparison of weight scores between entropy weighting and subjective weighting.

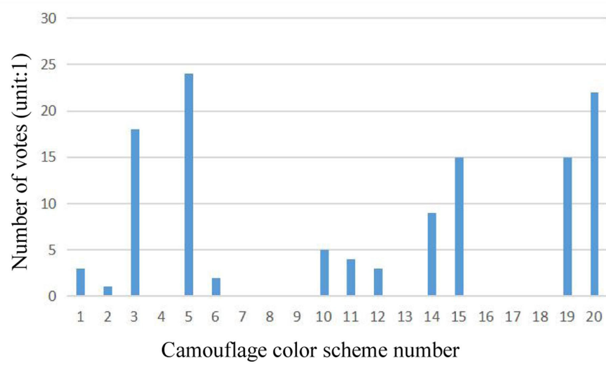

FIGURE 8. Summary table of the subjective survey questionnaire.

questionnaire obtained their subjective scores on the weight of each eye movement index in the evaluation of the color scheme. The subjective weighting scoring table is shown in Table 6. The average calculation of the subjective weighting table obtains the weights of fixation time, number of fixation points, number of fixation times, and first fixation time of 0.245, 0.200, 0.305, and 0.250, respectively. The weight results obtained by subjective weighting was compared with the results obtained by the entropy weighting method, as shown in Fig. 7. As expected, the subjective scoring in Table 6 is easily affected by the designer's own perception of eye movement indicators. The data of the other

TABLE 3. Summary of four kinds of eye movement tracking data.

Partition	Fixation time	Number of fixation points	Number of fixation times	First fixation time
AOI1	36.19	43	38	31.34
AOI3	156.42	115	99	143
AOI4	139.01	97	87	125.58
AOI5	24.08	26	24	20.48
AOI6	96.12	79	74	61.9
AOI7	158.42	109	100	135.41
AOI8	211.23	164	145	186.73
AOI9	229.65	183	161	207.57
AOI10	92.13	129	123	73.02
AOI11	117.88	126	115	100
AOI12	213.74	184	167	180.77
AOI13	165.24	127	114	146.44
AOI14	146.95	90	81	134.32
AOI15	30.13	38	38	24.84
AOI16	54.92	52	47	45.97
AOI17	89.14	82	71	75.56
AOI18	72.89	66	63	64.44
AOI19	84.65	68	65	76.46
AOI20	25.2	31	28	20.25

TABLE 4. Standardized scores.

Partition	Fixation time	Number of fixation points	Number of fixation times	First fixation time
AOI1	0.0589	0.1076	0.0979	0.0592
AOI2	0.3369	0.2911	0.3007	0.2615
AOI3	0.6438	0.5633	0.5245	0.6553
AOI4	0.5591	0.4494	0.4406	0.5623
AOI5	0.0000	0.0000	0.0000	0.0012
AOI6	0.3504	0.3354	0.3497	0.2223
AOI7	0.6535	0.5253	0.5315	0.6148
AOI8	0.9104	0.8734	0.8462	0.8887
AOI9	1.0000	0.9937	0.9580	1.0000
AOI10	0.3310	0.6519	0.6923	0.2817
AOI11	0.4563	0.6329	0.6364	0.4257
AOI12	0.9226	1.0000	1.0000	0.8569
AOI13	0.6867	0.6392	0.6294	0.6737
AOI14	0.5977	0.4051	0.3986	0.6090
AOI15	0.0294	0.0759	0.0979	0.0245
AOI16	0.1500	0.1646	0.1608	0.1373
AOI17	0.3165	0.3544	0.3287	0.2953
AOI18	0.2374	0.2532	0.2727	0.2359
AOI19	0.2946	0.2658	0.2867	0.3001
AOI20	0.0054	0.0316	0.0280	0.0000

three eye movement indicators fluctuate greatly except for the number of fixations. The difference in the number of fixation points in the eye movement index was the largest, with 6 people giving 0.1 points and 4 people giving 0.3 points. Fig. 7 shows that the subjective weight of the number of fixations index is greater than the entropy weighting weight, and the subjective weights of other eye movement indicators are less than the entropy weighting weight. Finally, the weights obtained by the subjective weighting method were calculated, and the ranking of the calculation results was consistent with the ranking of the schemes in Table 5.

IV. SUBJECTIVE VERIFICATION

The results of the subjective selection were obtained by means of an online questionnaire survey, and the results are shown in Fig. 8. For the camouflage of the 07-style military camouflage color scheme, 40 people were asked to choose the 3 schemes with the strongest concealment among 20 different camouflage color schemes, and the subjective data

obtained were counted. Table 5 shows that, in the subjective data, 24 people and 22 people thought that the concealment of schemes 5 and 20, respectively, were relatively strong and that other camouflage color schemes were relatively weak. This indicates the effectiveness of the compensation method of color schemes based on eye movement tracking technology.

V. DISCUSSION

This research focuses on the evaluation of compensatory color schemes based on the evaluation process research paradigm and proposes a compensatory evaluation method for color schemes based on eye movement tracking technology. This method combines eye movement tracking technology with compensatory mathematical algorithms, uses eye movement tracking technology to collect the eye movement data of participants in the evaluation process, analyzes the validity of the data, uses the entropy weighting method to perform compensatory evaluation of data and calculates the final evaluation results. The questionnaire survey verified that the participants' subjective feelings were basically consistent with the calculation results, which indicates that it is feasible to adopt the compensation method of color schemes based on eye movement tracking technology.

The main work of this research was divided into the following aspects:

1) Design and conduct the eye movement experiment and select four kinds of eye movement indicators to derive eye movement tracking data– total fixation time, total fixation points number, total number of fixation times, and first fixation time.
2) Analyze data reliability using SPSS software to perform reliability analysis on eye movement experimental data.

TABLE 5. Total scores with weights.

Number	Scheme	Score
1	AOI9	0.9891
2	AOI12	0.9391
3	AOI8	0.8814
4	AOI13	0.6592
5	AOI3	0.6018
6	AOI7	0.5857
7	AOI11	0.5286
8	AOI14	0.512
9	AOI4	0.5082
10	AOI10	0.4718
11	AOI17	0.3219
12	AOI6	0.3105
13	AOI2	0.2969
14	AOI19	0.2878
15	AOI18	0.2485
16	AOI16	0.1522
17	AOI1	0.0789
18	AOI15	0.0541
19	AOI20	0.015
20	AOI5	0.0003

TABLE 6. Subjective weighting scoring table.

Personnel No.	Fixation time	Number of fixation points	Number of fixation times	First fixation time
AOI1	0.3	0.1	0.4	0.2
AOI2	0.2	0.25	0.2	0.35
AOI3	0.3	0.1	0.4	0.2
AOI4	0.2	0.1	0.4	0.3
AOI5	0.2	0.2	0.3	0.3
AOI6	0.2	0.3	0.2	0.3
AOI7	0.3	0.3	0.2	0.2
AOI8	0.1	0.2	0.4	0.3
AOI9	0.2	0.3	0.2	0.3
AOI10	0.1	0.3	0.3	0.3
AOI11	0.3	0.1	0.3	0.3
AOI12	0.1	0.1	0.4	0.4
AOI13	0.3	0.2	0.3	0.2
AOI14	0.2	0.1	0.35	0.35
AOI15	0.3	0.2	0.4	0.1
AOI16	0.3	0.3	0.2	0.2
AOI17	0.4	0.15	0.15	0.3
AOI18	0.4	0.2	0.3	0.1
AOI19	0.2	0.3	0.4	0.1
AOI20	0.3	0.2	0.3	0.2

3) Obtain compensatory calculation results and use the entropy weighting method to calculate the weights of the four eye movement tracking indicators and obtain the evaluation results.
4) Take the camouflage color scheme of Chinese 07-style military camouflage clothing as an example to demonstrate the operation process of this method and compare with previous eye movement data using a subjective questionnaire to show that this method can realize the evaluation of color matching design scheme.

The color scheme compensation evaluation method based on eye movement tracking technology can effectively solve the problem of color scheme evaluation. The eye movement tracking experiment has realized the analysis of the design evaluation process and the quantification of design evaluation indicators, and the compensatory entropy weighting method can obtain the expected value of each indicator objectively through data processing to determine the optimal product color matching design scheme. When faced with many schemes with small differences, the advantages of this method are more obvious. This method makes the evaluation results more scientific and accurate, provides a reference basis for color matching designers, describes new ideas for avoiding decision-making errors and risks caused by early design evaluation, enriches color matching design evaluation theory and may guide decisions to enhance the overall image of a product.

Future work will focus on the exploration of more indicators or combine brain oxygen physiological equipment for more physiological data collection and verification to provide a more comprehensive design reference for color scheme evaluation.

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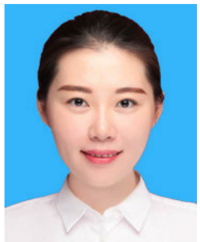

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