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Research Article

An Aesthetic Measurement Approach for Evaluating Product Appearance Design

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After completing the market positioning of products, catering for the functional and emotional needs of consumers is the key to achieve the success of product design. In the present study, the psychological theory is employed to screen the subjects and quantitatively evaluate the alternative design schemes to ensure the optimal design scheme. Then, an evaluation method of product appearance design based on eye tracking and aesthetic perception measurement is obtained. With the design of campus street lamp as an example, this paper evaluates the appearance design of products using emotional measurement and eye tracking technology. IAPS is used to screen out the participants who can represent the emotions and aesthetic experience of the public. Subsequently, the index system of aesthetic evaluation is established according to aesthetic theory, and the transformation relationship between aesthetic evaluation index and physiological eye movement index is determined. Finally, the eye tracking technology is used to evaluate the aesthetic feeling of each alternative, and the best design schemes are obtained. This study aims to explore a simple, practical, and low-cost product design evaluation method. As a hotspot in the research field of product design methodology, emotional design has broad prospects for application. Moreover, this paper also proposes a new direction for the development of emotional design research, which is based on quantitative analysis with the supplement of qualitative analysis.

1. Introduction

A vital purpose of product design is to satisfy the needs of consumers. In the context of economic growth, the enterprise-dominant market has changed into the customer-dominated market. Enterprises can get more market shares only by satisfying customers' diversified and personalized demands. Meanwhile, with the development of science and technology in recent years, a futurist John Naisbitt once said: the more technology we introduce into our lives, the more we seek a high touch balance, namely, a human ballast [1]. Therefore, it is significant for product designers to identify the specific needs of customers, connect it with the product attributes, obtain an accurate product design scheme, and have a valid evaluation method.

The study of perceptual and emotional consumption in the fields of sociology and psychology is earlier than the proposal of the concept of perceptual design in industrial design. Around the 1970s, American cognitive psychologist Donald Norman put forward a well-developed product which can enhance the feeling of our minds and spirits at the same time. Consumers can use it with delight because it took human-computer interaction as a breakthrough point and embodied the design concept of people-centric [2]. Thereafter, the field of perceptual engineering began to develop and become systematized. In the 1990s, researchers represented by Bloch and Peter proposed a series of psychological and behavioural feedback models describing consumer's perceptions of product design [3]. From the perspectives like the color and the product appearance [4], the aesthetic index can be measured through physiological measurement combined with some qualitative analysis methods. The accuracy of physiological measurement was limited by technology years before. However, the development of eye tracking techniques makes the method of measuring the aesthetic indexes of the product by observing visual information, such as eye movements and pupil changes, gradually accepted. For instance, there was a study of weight expansion of 12 aesthetic attributes in car styling by Yadav et al. in 2013 [5]. In addition, the aesthetic measurement method of the web interface was developed in 2008 by Zain to design the interactive product [6]. In the meanwhile, Seckler has analysed how the framework and the color of the website affect people's emotions from the visual aesthetic perception angle in 2015 [7]. In the study of Liu in 2015, the repertory grid method was used in evaluating architectural space design. Students' perceptual points of concerns can be acquired by processing data, which could be the foundation of optimization work [8].

In order to describe the emotional appeal of consumers and connect it with the product parameters accurately, perceptual labels that can fully express the emotional appeal must be extracted. Due to the individual difference of human emotion and the environmental correlation [9], semantics differential method (SD), the multidimensional scale (MDS), and pairwise comparison (PC) were proposed to describe the product based on the thought of the lexicon classification [10, 11]. The SD method created by Osgood in 1942 has been widely applied [12–16]. However, it has a lot of defects like deficiency in standardization of the scale, fuzziness in setting the standard of the differential score on semantics, and its strong subjectivity [17]. In order to get the product image style that is more in consistence with consumers' emotional expectation, statistical means are applied to cope with the initial information. For example, factor analysis, mathematical chemistry class I, multiple regression analysis, and PrEmo method (the Product Emotion Measurement Instrument) are commonly used. Factor analysis can be used to extract statistical results of the SD method, reduce the dimension of the variables, and make full use of the information obtained by the survey to simplify the evaluation scale of the product; thus it is very suitable for the reference and evaluation of the overall design. Mathematical chemistry class I and multiple regression analysis can decompose the product itself and play an important role in the detail and structural design of the product. The PrEmo method is reorganization and innovation of the SD, with ideal cultural adaptability and wide application.

According to emotional dimension theory of Osgood et al., the International Affective Picture System has been worked out by NIMH (the National Institute of Mental Health). From three dimensions of the valence, arousal, and dominance, IAPS can recognize people's mood change precisely when visual stimulation occurs. Combined with the 9-scale scoring form, it plays a great role in the field of emotion research. Because of some inevitable differences between countries, nations, and cultures, certain error would remain in the standard assessment of IAPS in three dimensions; yet universality was NIMH's original intention. This error led to a lack of scientific and comparable results in related studies. For example, the study conducted by Riberro found that when pornographic, adventurous pictures, which have high arousal in the IAPS standard, are used in Brazil subjects, the arousal became much lower [18]. In China, IAPS was tested for local use. Huang et al. conducted a study on the use of IAPS in China and found that it was highly correlated with test results in other countries, but Chinese subjects had significant differences in validity and arousal from standard scores, and some pictures even had completely different emotional performances [19–21]. In response to the above problems, Liu et al. conducted a localization study of the international sentiment picture system for Chinese college students [22]. Today, the use of IAPS system has expanded to various fields. It is found that the aesthetic experience has its own traits in the emotional dimension, covering positive and negative emotions simultaneously [7]. IAPS locates all sorts of emotions precisely using the coordinates of three dimensions like the location in 3D space, which is substantial for the emotion design.

This paper explored an aesthetic measurement approach for assessing product appearance design. First, an index system of aesthetic appraisal was established based on aesthetic theory. Then, based on IASP system, several representative participants were selected to evaluate a few schemes of the street lamp appearance design by employing emotional measurement and eye tracking technology. Afterwards, the conversion relationship between the aesthetic evaluation index and the physiological index was determined. Finally, the eye tracking technology was utilized to evaluate the aesthetic perception of the alternatives, and the final design scheme was attained.

2. The Framework

2.1. Selection of Customer Representatives Based on IAPS. In the perceptual design process, especially on the product's appearance, initial evaluation for design schemes must be made from consumers' will instead of designers' will. However, investigation on this large scale can cause huge costs. Furthermore, taste of niche consumers may affect the result of evaluation. In this chapter, IAPS, the relatively authoritative method in emotion measurement, is used to decide if participants can represent the public on the emotional response level by analysing the difference of standard value of the emotion index between participants and the public. Then, qualified participants are tested for the later aesthetic measurement survey. These participants are representative on the emotional dimension; therefore, they are also qualified in other mental experiments like semantics differential method.

2.2. The Aesthetic Measurement Evaluation System Based on the Eye Tracking Technique. It has been an obstacle for designers to pick out design themes that genuinely meet consumers' need since those designs have apparent personal style. In this research, an effective aesthetic measurement evaluation is established using relevance theory of emotions and aesthetics to solve the obstacle. First, subjects are selected by using the method mentioned in Section 2.1 (IAPS emotion measurement). Next, the eye tracking technique is used to measure the physiological index of the eyeball, which occupies an important position in the visual aesthetic process. With the fruits of psychology studies, both a conversion formula of the physiological index into the aesthetic evaluation index and an aesthetic computational formula are put forward. In the end, the whole evaluation system is confirmed and revised through specific experiments.

2.2.1. Aesthetic Measurement. To establish a quantitative measurement for aesthetics, whose elements are the influential factors of aesthetics, is the first thing to determine. Aesthetic elements can be clearly defined from the basic principle of human vision. For example, when there is a blank canvas, every time visual elements appear and the contrast between the elements and the background appears and could be recognized by human. When the elements' number increases, an index, pureness, is needed to define the degree of beauty. Another index, proportion, is used to weigh comparability between elements. These two indexes can accurately measure the beauty relatively. In addition, the primary task of product design is to achieve its function. We define the index of appropriateness as cognitive differences of design elements in order to realize the prescribed function. Briefly, appropriateness can explain what kind of design elements is suitable for most people. Besides, products become stale after being used for a period of time, which requires new design for novelty. It is generally accepted that appropriateness and novelty are the main attractive features of the product. Combining the beauty and attraction, the designed elements are connected with aesthetics. Therefore, aesthetics can be measured by designed elements and the best aesthetic level of designed elements' types would be located.

(1) Beauty. Beauty is represented by contrast and composed of pureness and contrast. It has an influence on eye recognition to visual elements.

(1) Contrast: contrast differences are generated by individual visual differences for recognizing design elements. Contrast is split into two categories: the number of different elements and the degree of difference between elements, which are measured by pureness and proportion, respectively.

(2) Pureness: pureness, which defines the degree from sobriety to complexity and is related to the number of elements, is the quantitative index of contrast.

(3) Proportion: the proportion defines visual inertia's proportion of total vision, showing the degree of similarity between elements, including the shape, size, and the location (as shown in Figure 1).

(4) Relationships: the pureness and proportion are variables that describe contrast. Contrast diminishes with the pureness and proportion increasing, as shown in Figure 2. Therefore, contrast is a function that rests on 1/pureness and 1/proportion.

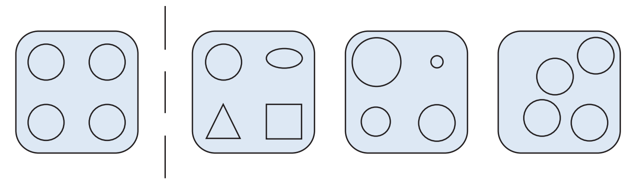

Figure 1: An illustration of a gradual decrease in the proportion due to the shape, size, and the location.

Beauty is a specific relationship between contrast, pureness, and proportion [23]. When the contrast reaches a certain value, the best aesthetic effect can be acquired.

As Figure 2 shows, from left to right, Example 2 has lower pureness than Example 1, for there are more elements in Example 2, and so its contrast is higher; Example 3 has a lower proportion than Example 1 because of the greater element differences in Example 3, and thus its contrast is higher; Example 4 has lower pureness and the lower proportion than Example 1 because the contrast of Example 4 is significantly larger.

(2) Attraction. Attraction changes with time and different individuals, including the index of appropriateness and novelty.

(1) Appropriateness: it shows consumers' tendencies of seeing some typical design elements for some functions, which is normally a visual characteristic of a product.

(2) Novelty: it incorporates unforeseen and unprecedented design elements needed to actualize some functions.

(3) Aesthetics. As the final index to evaluate aesthetics, aesthetics is calculated by beauty, appropriateness, and novelty.

According to the research conducted by Khalighy, if contrast is half of the total observation time, the aesthetic value is the best. When $C/T < 0.5$ and $C/T > 0.5$, contrast and aesthetic values are related in the quadratic function. The relationship between every aesthetic evaluation index is shown in Figure 3.

3. The Experiment

3.1. The Screening Experiment for Customer Representatives

3.1.1. The Experimental Purpose of the Screening Experiment. To select customer representatives who can represent the aesthetics of the public from all participants, this experiment is going to examine the emotional level discrepancy between the particular level of participants when they are influenced by external visual stimuli and the average emotional level of the general public. These customer representatives are the participants in the next chapter's aesthetic measurement and subsequent emotional design-related experiments.

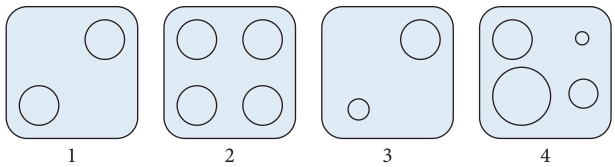

Figure 2: Four examples of indices.

3.1.2. The Experimental Process of the Screening Experiment. A total of 50 participants participated in this experiment, composed by 20 females and 30 males around 22 years old, all of whom were undergraduate students with a certain industrial design basis, with some wearing glasses.

The test used nine subscales to allow participants to evaluate the three emotional dimensions of each image. The three dimensions are as follows:

Valence. A change in the range of emotions from pleasure to tranquility after stimulation.

Arousal. A change in the range of emotions from excitement to calmness after stimulation.

Dominance. The range of emotions perceived to be dominated by the stimulus after being stimulated.

Not all participants have psychological backgrounds, which limited their understanding of the meaning of the three emotional dimensions. This could cause the problem of unclear standards when they are watching the picture and lead to a wrong point. Thus, to ensure the experiment consequence, rate training is needed before conducting the experiment.

Pictures with the highest score (9), the middle score (5), and the lowest score (1) in each of the three dimensions were selected. After we attach language explanation to every picture, the training material was formed and learned by participants.

In order to let the participants comprehend the relationship between ratings and emotions more vividly, 3–6 pictures with scores of 8, 5, and 2 in each of the three dimensions were selected and listed with SAM scale and nine subscales at the same time.

The formal test using IAPS was conducted alone after the training. There are more than 800 stimulating pictures in the IAPS system, and the content covers all aspects. To ensure the scientific and reasonable experiment, it is necessary to screen pictures in line with the content of the picture and the three-dimensional standard values of each picture. First, considering the purpose of the experiment and participants' mental endurance capacity, pictures with contents of the corpse, sex, violence, diseases, and so forth have been removed. Besides, pictures that may affect the results due to cultural differences, such as 3K party activities, have also been removed. According to the attributes of the remaining pictures, 16 positive, neutral, and negative pictures were selected, and totally 48 pictures were used as stimulus materials. The participants evaluated the pictures of the IAPS system independently without any interference with the situation of emotional calm. All the evaluations were the first choice of the individual. After the test was completed, the results were taken back and the participants were not allowed to do any second modification.

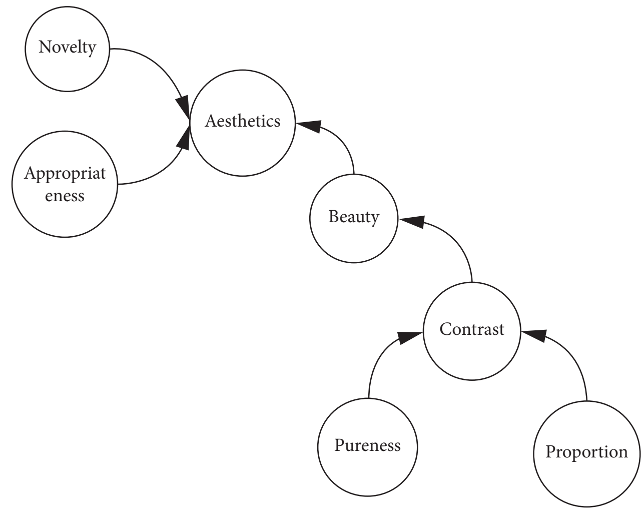

Figure 3: Aesthetic evaluation indices.

3.2. The Eye Movement Experiment

3.2.1. The Experimental Purpose of the Eye Movement Experiment. Individual aesthetic activity is a process of the visual perception. Therefore, in this experiment, we chose "eye tracking" technology that can track and record eye movement. In this experiment, we use "eye tracking" technology to measure the human eye movements when evaluating the product design and then establish a relationship with the above-mentioned aesthetic indices and obtain the aesthetic values of each design in the light of the evaluation system. According to the experimental result, better schemes were selected.

Participants in this experiment must represent the public's aesthetic level. Based on the method described in Chapter 2, we selected 20 participants from Experiment 1 to participate in this experiment.

3.2.2. The Laboratory Equipment of the Eye Movement Experiment. The eye tracking technology is realized by an eye tracker, which can measure the attention area of the participants in the image and the duration of attention of each area. The duration of attention refers to the time between two eye movements (sweeping). Additionally, it also measures the size and duration of pupil dilation and blinking. For the experiment, the T60XL eye tracker (Figure 4) produced by Tobii Company of Sweden is used. As the only wide-screen eye tracker with the edges of simple operation and high tracking quality, it also allows the participants to move their heads during the experiment.

3.2.3. The Experimental Process of the Eye Movement Experiment. As the street lamps is an industrial product (not art) and has universal recognition, it also has obvious differences in terms of popular aesthetics and artistic

Figure 4: Tobii T60XL eye tracker.

aesthetics, so this paper chose a set of street lamp schemes as the experimental stimulus material, including 20 ordinary schemes and 1 excellent scheme. Firstly, image processing is carried out. The three-dimensional street lamp design schemes were projected into two-dimensional images. In order to avoid the influence of the color and materials on the experimental results, the gray-level image is dealt with uniformly and changed into the bitmap image with resolution of $567 * 567$ (as shown in Figure 5), and the image is input into Tobii Studio, supporting software of the Eye Tracker. In the second step, the participants were experimented with the eye tracker. Before the start of the experiment, we need to determine the observation time of each picture. If the time is too short, the participants will fail to observe the detail design completely. If the time is too long, the difference of the observation data of each picture will be too small. Therefore, a preliminary experiment is a requisite. Participants with ID of 9, 5, 30, and 34 selected from Chapter 3.1 were invited to observe similar pictures. Finally, the observation time of each picture was determined to be 7 seconds. Next, a formal experiment is conducted. The pictures are imported into Tobii Studio, with each picture taking 7 seconds to observe and play in a certain order. Firstly, the position of the participants was adjusted, and the distance between the eyes and the screen was kept at about 64 cm. Then, the eye movement habit of the current participant was recorded by 9-point calibration. Then, the participants were asked to view all the pictures on the screen. The process record is shown in Figure 4. The output data were saved as the tab-separated text format file or the xlsx file, including experimental ID, experimental time, scanning times, the gaze position, pupil size, and blinking times. The third step is to preprocess the data. Owing to the limited functions of Tobii Studio, the data derived are too intricate and huge. In order to facilitate designers to easily complete the program evaluation step, a MATLAB program used for calculation below and for aesthetic evaluation is specially compiled. The steps of data analysis are as follows: import the required data from Tobii Studio into Import Data function of MATLAB, run coordinate.m, get the output result, and then run aesthetics.m to obtain the final result.

Figure 5: The sample of gray-level processing for the design scheme.

3.2.4. The Measurement Index and Calculating Formula in the Eye Movement Experiment. The relationship between the output data and aesthetic perception indices needs to be established. The output data include the number, the position, and duration of gaze points in each experiment. We calculate the accurate value of the aesthetic index through several formulas.

(1) Pureness Measurement. As mentioned in 2.2.2, purity denotes the number of elements. The fewer the elements are, the higher the pureness is. The number of gaze points in eye tracking data reflects that of elements. Because participants have a high probability of seeing each element, when the elements are more, the number of gaze points increases. Therefore, if the number of gaze points is indicated, one has

$$\text{Pureness} = \frac{1}{N_F}. \tag{1}$$

(2) Proportion Measurement. According to the definition, because of the similarity of visual inertia in unit time, the eyes will be attracted by the elements of the optimum proportion. Hence, the greater the variance of the duration of each gaze point is, the lower its proportion is. If the variance of the duration of each gaze point is indicated, one has

$$\text{Proportion} = \frac{1}{\sigma_F}. \tag{2}$$

(3) Contrast Measurement. In accordance with Section 2.2, contrast is inversely proportional to pureness and proportion. When both increase, it will have a significant impact on the contrast. For example, the contrast of five low proportion elements is higher than that of two low proportion elements. As a result, the contrast can be calculated by

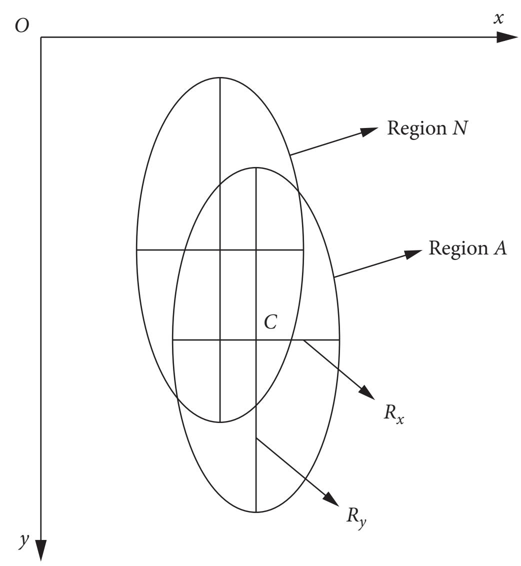

FIGURE 6: The gaze point area.

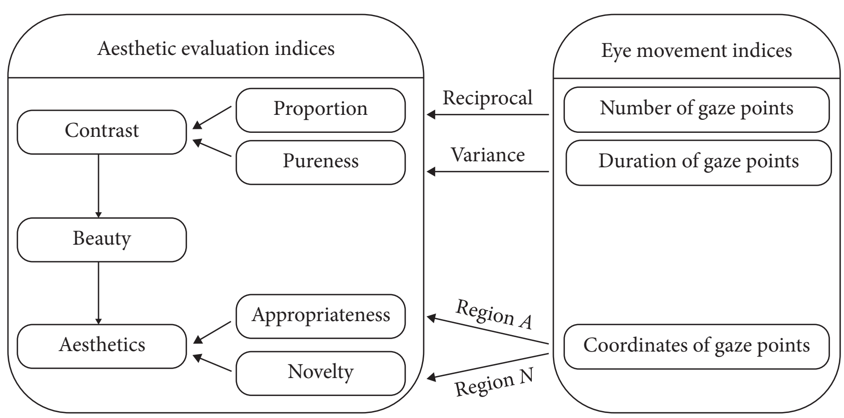

FIGURE 7: The relation table between eye movement indices and aesthetic evaluation indices.

$$\text{Contrast} = N_F \times \sigma_F. \tag{3}$$

A similar formula was proposed by Eli Peli in 1990.

(4) Appropriateness and Novelty Measurement. As mentioned above, appropriateness and novelty are related to time and the function. Therefore, for products of different times, measuring these qualities requires an up-to-date benchmark. The appropriateness template can be obtained from a well-known and excellent product in a certain kind of product. Through the appropriateness template, the focus area of attention distribution in the best product can be revealed. The novelty area should suggest the nonoverlapping elements of the known products, and the novelty area should be the most focused area in the product design scheme. These areas can be fitted as an elliptical area with the center being the average of coordinates of all gaze points and the radius being the standard deviation of X and Y coordinates. According to these elliptic areas, the distribution of gaze points can be gained. The gaze points are concentrated in the regions with large visual stimuli. As shown in Figure 6, A region represents appropriateness region (coordinates of existing design schemes) and T region denotes typicality region (coordinates of all schemes). Let $C = (\overline{x}, \overline{y})$, $R_x = \sigma_x$, $R_y = \sigma_y$, and A = appropriateness, and then $A = (x, y) \in A$; let N = novelty, and then $N = (x, y) \in T$ or $N = (x, y) \notin T$.

T' represents the area outside the T region. Suppose that N_T is the total number of gaze points; N_A is the number of gaze points in area A; and N_N is the number of gaze points in area N. Then, the appropriateness and novelty can be derived from the following two formulas:

$$A = \frac{N_A}{N_T}, \tag{4}$$

$$N = \frac{N_N}{N_T}. \tag{5}$$

Equation mentioned above is the conversion formula between the eye movement measurement index and the aesthetic evaluation index. So far, the evaluation system based on aesthetic measurement has been established, and the conversion relationship between each index is shown in Figure 7.

4. Data Analysis

4.1. Data Analysis of the Screening Experiment

4.1.1. Analysis of Experimental Data. A total of 50 participants were tested in this experiment, and 47 subjects completed the experiment. The recovery rate of the test results was 94%. Among them, no irregular test results with ratings exceeding 1–9 and the same ratings in large areas were found. The effective rate was 100%.

The gap between the participants' emotional level and the general emotional level was assessed. The evaluation results of the third dimension of the test results i can be deemed as a matrix A_i, and the standard values of the three dimensions representing the level of public emotion can be perceived as matrix B. We simply need to calculate the similarity of matrix A_i and matrix B in turn and then compare their sizes. Then, the gap between the emotional level of each subject and the level of public emotion can be obtained. There are multiple methods to calculate matrix similarity. In order to enhance the generality, we use the vector space model, which is the most widely used basic similarity calculation model.

In vector space model, each object is mapped to an eigenvector:

$$V\left(\text{object}\right) = \left(\text{feature}_1, w_1; \text{feature}_2, w_2; \ldots; \text{feature}_n, w_n\right). \tag{6}$$

Next, we calculate the Euclidean distance of the two vectors:

$$\text{distance}\left(d_i, d_j\right) = \sqrt{\sum_{k=1}^{k=n}\left(w_k\left(d_i\right) - w_k\left(d_j\right)\right)^2}. \tag{7}$$

The smaller the Euclidean distance is, the higher the similarity of the two vectors is, and vice versa.

In this experiment, we first transform matrix B into a 152-dimensional vector $\overrightarrow{B}$. The specific method is to connect each row of matrix B to the end of the previous row sequentially and then use the identical method to turn the matrix A_i into a vector $\overrightarrow{A_{\text{i}}}$ sequentially. Next, the Euclidean distance G_i between $\overrightarrow{A_{\text{i}}}$ and $\overrightarrow{B}$ was calculated as the proximity of participant i's emotional level to the average emotional level of the general public.

The results show the proximity G_i of 47 participants to the average level of the public (Table 1). The smaller G_i is, the closer the emotional level is to the average level of the public.

According to the degree of proximity, 20 participants with lower scores were selected: numbers 9, 5, 30, 34, 3, 15, 39, 42, 2, 6, 16, 24, 37, 13, 4, 14, 20, 38, 31, and 21. These 20 participants' lower scores illustrate that their emotional levels are close to the average level of public moods and can represent consumers' aesthetic purposes in a certain extent. So, they would be the participants in the next experiment.

Table 1: 47 Effective participants' approximation of the emotional level.

Participants' number	G_i
1	15.31501
2	12.29727
3	12.00178
4	13.62214
5	10.79982
6	12.70759
7	15.16474
8	22.09652
9	10.38891
10	16.31899
11	16.30346
12	17.33444
13	13.50417
14	13.76406
15	12.04392
16	13.32427
17	16.70816
18	16.10329
19	17.60822
20	13.83411
21	14.23948
22	17.99118
23	16.62637
24	13.37495
25	16.21119
26	17.66417
27	15.05909
28	18.0295
29	18.86998
30	10.85431
31	14.14105
32	16.395
33	18.17368
34	11.01073
35	19.84984
36	17.83095
37	13.43563
38	14.036
39	12.2413
40	23.71644
41	19.0834
42	12.27746
43	19.75844
44	16.71195
45	14.66274
46	16.63038
47	16.11467

4.1.2. The Reliability Test. Considering that the individual's emotional level will fluctuate with time or be stimulated by external events, which will generate errors in the measurement results, the second experiment method is used to retest the reliability of the above experimental results in order to evaluate the reliability of the experimental conclusion.

According to the results of the first experiment, the five participants with the lowest score and the five participants with the highest score were chosen as the experimental samples. Firstly, the first experimental results of the 10 subjects were listed, as shown in Table 2.

Table 2: The statistical table of the first experimental results of 10 participants.

Participants' number	9	5	30	34	3	41	43	35	8	40
Proximity	10.38891	10.79982	10.85431	11.01073	12.00178	19.0834	19.75844	19.84984	22.09652	23.71644

Table 3: The statistical table of the second experimental results of 10 participants.

Participants' number	9	5	30	34	3	41	43	35	8	40
Proximity	10.71	11.01	10.10	12.33	12.40	18.01	21.88	21.36	24.20	24.08

Table 4: Pearson product-moment correlation coefficients for two experiments.

	First experiment	Second experiment
First experiment	1	0.985**
Second experiment	0.985**	1

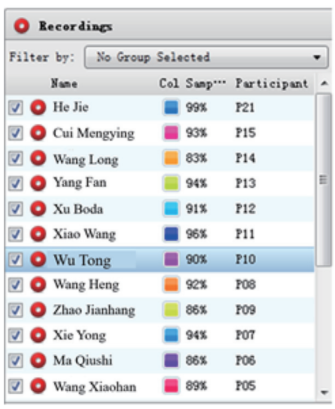

Figure 8: Partial recording of the eye movement index acquisition rate.

A week later, these 10 participants were tested twice with the stimulus material of the first experiment. The calculated results are shown in Table 3.

Pearson product-moment correlation coefficients were used to analyse the correlation between the two experimental results of the 10 participants (8). The results are shown in Table 4.

$$r_{xy} = \frac{\sum (X - \overline{X})(Y - \overline{Y})}{\left(\sqrt{\sum (X - \overline{X})^2}\right)\left(\sqrt{\sum (Y - \overline{Y})^2}\right)}. \tag{8}$$

Among them, X and Y are the score in the first and second experiment, respectively, and $\overline{X}$ and $\overline{Y}$ are the average scores in the first and second experiment, respectively.

Pearson product-moment correlation coefficient ranges from −1 to 1, where 1 indicates that the variables are utterly positively correlated. Besides, 0 is irrelevant, and −1 is totally negatively correlated. The closer the value is to 1, the stronger the positive correlation between the two variables is; the closer the value is to −1, the stronger the negative correlation between the two variables is. In line with the calculation results, the Pearson product-moment correlation coefficient of the two experimental scores is 0.985, which shows that the two experimental scores have a significant positive correlation, and so we can conclude that the experiment has high reliability.

4.2. Data Analysis of the Eye Movement Experiment. The experimental records of each participant were evaluated. If the collection rate of eye movement was less than 80%, they were retested. The acquisition rate of some records is shown in Figure 8. The number of gaze points, the variance of the duration of each gaze point, the total gaze time, and the coordinates of all gaze points in each record are derived. For convenience of processing, all the above data are processed in a worksheet.

4.2.1. Beauty Value Calculation. The pureness and the proportion are calculated in the light of the number of gaze points and the variance of the duration of gaze points. The pureness is calculated by (6). In terms of the number of gaze points here, we take the average value of all participants' gaze points in the current picture and convert it into the percentage. It should be noted that there is only one main element in the current picture. If there are two or more main elements, it should be divided by the number of corresponding elements. The number of gaze points is shown in Figure 9 as an example.

Equation (7) is used to calculate the proportion. Since the unit of the duration of the gaze is milliseconds (ms), the unit of the gaze should be converted to seconds (s) before calculation. Finally, according to (8), the ratio of contrast to total time is computed. Table 5 calculates scheme 1 and scheme 2 as examples.

The results reflect that when the contrast is half of the average total gaze time, the beauty reaches the highest; that is, $C/T = 0.5$. When $C/T < 0.5$ or $C/T > 0.5$, the relationship between beauty and C/T decreases quadratically. Table 6 shows the pureness, the proportion, contrast, and C/T values of all 21 pictures (20 designs and one excellent one).

According to the empirical formula of beauty,

$$\text{Beauty} = \begin{cases} \dfrac{100}{19} \times \left(\dfrac{C}{T}\right)^2 - 9 \times \dfrac{C}{T} + 4.18, & \dfrac{C}{T} \geq 0.5, \\[2ex] 35 \times \dfrac{C}{T} - \dfrac{100}{3} \times \left(\dfrac{C}{T}\right)^2 - 8.37, & \dfrac{C}{T} < 0.5. \end{cases} \tag{9}$$

(a) (b)

Figure 9: The number of gaze points in schemes 1 and 8.

Table 5: Examples of calculating aesthetic value.

Scheme number	1	2
Number of gaze points	364	341
Variance of duration of gaze point	0.23	0.24
Average duration of gaze point (s)	6.49	6.53
Pureness (%)	$1/(364/20/1) \times 100\% = 5.49\%$	$1/(341/20/1) \times 100\% = 5.87\%$
Proportion (s)	$1/0.23 = 4.35$	$1/0.24 = 4.17$
Contrast (s)	$364 \times 0.23/20 = 3.64$	$341 \times 0.24/20 = 3.56$
C/T	$3.64/6.49 = 0.56$	$3.56/6.53 = 0.54$

Table 6: The pureness, the proportion, contrast, and C/T values of all pictures.

Scheme number	Average duration of gaze point T (s)	Pureness (%)	Proportion (s)	Contrast (s)	C/T
1	6.49	5.49	4.35	3.64	0.56
2	6.53	5.87	4.17	3.56	0.54
3	6.40	5.59	4.55	3.42	0.54
4	6.52	6.06	3.13	4.59	0.70
5	6.65	6.37	3.13	4.37	0.66
6	6.43	6.33	3.03	4.53	0.71
7	6.51	5.73	4.17	3.64	0.56
8	6.70	6.04	3.45	4.17	0.62
9	6.85	5.67	3.57	4.30	0.63
10	6.78	5.46	4.00	3.98	0.59
11	6.95	7.07	1.79	6.89	0.99
12	7.00	5.49	2.44	6.49	0.93
13	6.96	5.25	2.70	6.13	0.88
14	6.92	5.57	3.03	5.15	0.74
15	6.31	5.75	3.85	3.93	0.62
16	6.49	6.21	2.44	5.74	0.88
17	6.88	6.19	2.94	4.77	0.69
18	6.55	6.27	2.86	4.85	0.74
19	6.62	6.15	2.56	5.51	0.83
20	6.72	6.37	2.13	6.42	0.95
Excellent	6.51	5.13	5.00	3.39	0.52

The beauty value of 20 design schemes and excellent schemes can be obtained (Table 7).

4.2.2. Attraction Value Calculation. The existing excellent schemes are utilized as templates to find their C points, R_X and R_Y, and then to draw the elliptic region A. Next, the C points, R_X and R_Y, and the elliptic regions of the schemes can be obtained, as shown in Figure 10.

The coordinate origin is located at the top left of the picture and the x-axis is located at the top of the picture. The y-axis is located at the bottom of the picture, as shown in Table 8.

Tobii Studio is employed to calculate the number of gaze points in each scheme area A and the region in turn. According to (8) and (9), the appropriateness and novelty of each scheme can be calculated. The results are shown in Table 9.

Table 7: Calculation results of every scheme.

Scheme 1	Scheme 2	Scheme 3	Scheme 4	Scheme 5	Scheme 6	Scheme 7	Scheme 8	Scheme 9	Scheme 10	Scheme 11	Scheme 12	Scheme 13	Scheme 14	Scheme 15	Scheme 16	Scheme 17	Scheme 18	Scheme 19	Scheme 20	Excellent
0.788	0.839	0.871	0.452	0.539	0.451	0.792	0.616	0.605	0.711	0.430	0.360	0.336	0.397	0.615	0.337	0.469	0.401	0.335	0.385	0.920

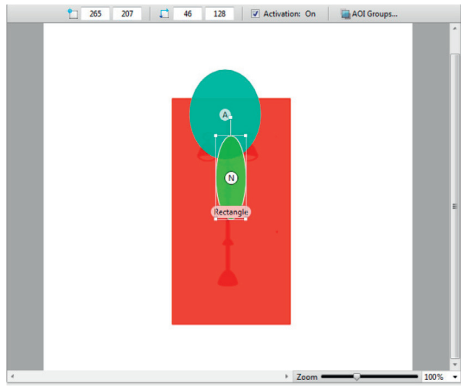

FIGURE 10: Regionalization of scheme 2.

4.2.3. Aesthetic Value Calculation. Aesthetic value of each scheme is calculated in line with three indicators. Let N be novelty, A be appropriateness, B be beauty, and Aes be aesthetics, and then one has the following.

The values of all variables in this formula are between 0 and 1, and the aesthetic values calculated are shown in Table 10.

4.3. Evaluation Results. Through eye movement experiments and analysis of the results, we get the aesthetic value of 20 design schemes. After comparison, we find that the aesthetic value of scheme 2, scheme 1, scheme 5, and scheme 4 (as shown in Figure 11) is higher. In other words, it is more in consistence with the public's aesthetics.

5. Discussion

The first experiment of this paper solved two key problems of aesthetic perception measurement: first, aesthetic experience was individual. If it relied entirely on individual language narration and was limited by the level of individual expression, the results were often erroneous. After demonstrating the relationship between aesthetic perception and emotion, we can reflect individual aesthetic perception by measuring physiological indicators of emotional response. Second, in the process of aesthetic measurement, the selection of participants was rather crucial. Whether they represent the aesthetic level of the public determined the accuracy of the measurement results. Therefore, the selection method described in this paper can be applied to both aesthetic measurement experiments and emotional design experiments of other products.

The second experiment was the key part of this study. The aesthetic measurement technology introduced in this section breaks the limitation of psychological measurement through semantic evaluation in the past. In the meanwhile, it differed from the existing physiological index measurement primarily based on qualitative analysis. Through a systematic evaluation index system, it can better quantify the individual aesthetic experience, so that the aesthetic evaluation of various design schemes can be done. By comparison, designers can choose a more scientific and accurate approach after completing the preliminary design scheme.

However, after acquiring consumers' needs, the design criteria were merely qualitatively described, and there was no quantitative method to correlate consumers' needs with product attributes. Although this can make designers play better, it may also give rise to deviations in understanding of consumers' needs, thus affecting the quality of products. In the part of aesthetic perception measurement, the conversion of the evaluation index and the eye physiological index was still slightly rough, especially the index novelty and appropriateness. The precise division of regions still needed to be discussed. We hope that we can measure the novelty and appropriateness of the design scheme more precisely through more subtle transformation, to make the results of aesthetic measurement closer to the real experience of consumers.

6. Conclusion

In the first experiment of this study, the participants representing the aesthetic level of the public are selected through the emotional measurement test, providing the foundation for the next aesthetic measurement experiment and other related experiments of product emotional design. After training, all the participants expressed that they had mastered the scoring standard of IAPS emotional measurement system and then used it to quantify the level of emotional response. Totally 50 participants observed 48 emotional stimulus pictures in turn and scored each picture from three emotional dimensions using nine subscales. Forty-seven participants completed the experiment. Finally, the experimental results were compared with the average scores of the public provided by the IAPS system, and 20 subjects with the closest degree were selected as participants of aesthetic measurement and other product emotional experiments.

In the second experiment of the study, according to the analysis of customer demand, the designer devised 20 alternative design schemes that meet the needs of consumers. This study evaluated these schemes through the aesthetic experiment based on eye tracking technology, so as to assist designers in making decisions from the perspective of appearance design. According to the principle of aesthetics, four layers with seven aesthetic indices are defined in this

Table 8: The division of a region of excellent and N region of each design scheme.

Scheme	Excellent	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
x	278.7	274.6	265.7	291.7	281.4	276.4	281.6	283.5	287.9	290.9	244.5	265.9	298.0	262.9	289.8	285.7	262.0	254.3	270.8	289.6	280.3
y	174.5	235.4	220.2	234.2	212.5	209.9	261.8	251.8	271.3	190.0	204.9	274.7	263.3	265.0	268.3	148.6	182.8	221.2	201.6	204.6	244.4
Short axis	54.1	27.0	17.9	32.9	29.0	25.0	34.9	22.4	23.1	29.6	26.3	25.1	64.8	47.9	61.3	33.4	20.9	18.4	15.0	11.5	20.3
Long axis	68.0	113.2	138.4	144.0	105.5	100.3	55.2	76.3	64.0	77.3	86.0	52.6	34.4	61.2	36.7	86.6	151.6	116.1	157.7	103.3	121.9
Region	Appropriateness	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty	Novelty

Table 9: Calculation results of appropriateness and novelty of design schemes.

Scheme	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Gaze point in region A	242	238	144	211	211	189	202	131	210	176	103	65	83	32	132	123	138	122	161	169
Gaze point in region N	150	190	106	148	128	187	196	170	183	168	129	144	83	122	176	228	143	178	149	146
Total gaze point	364	341	358	330	314	316	349	331	353	366	283	364	381	359	348	322	323	319	325	314
Appropriateness (%)	66.48	69.79	40.22	63.94	67.20	59.81	57.88	39.58	59.49	48.09	36.40	17.86	21.78	8.91	37.93	38.20	42.72	38.24	49.54	53.82
Novelty (%)	41.21	55.72	29.61	44.85	40.76	59.18	56.16	51.36	51.84	45.90	45.58	39.56	21.78	33.98	50.57	70.81	44.27	55.80	45.85	46.50

Table 10: Aesthetic value calculation results of design schemes.

Scheme	Beauty	Appropriateness (%)	Novelty (%)	Aesthetics
1	0.788	66.5	41.2	0.679
2	0.839	69.8	55.7	0.728
3	0.871	40.2	29.6	0.411
4	0.452	63.9	44.8	0.645
5	0.539	67.2	40.8	0.678
6	0.451	59.8	59.2	0.608
7	0.792	57.9	56.2	0.609
8	0.616	39.6	51.4	0.410
9	0.605	59.5	51.8	0.609
10	0.711	48.1	45.9	0.497
11	0.430	36.4	45.6	0.369
12	0.360	17.9	39.6	0.180
13	0.336	21.8	21.8	0.218
14	0.397	8.9	34.0	0.090
15	0.615	37.9	50.6	0.392
16	0.337	38.2	70.8	0.390
17	0.469	42.7	44.3	0.433
18	0.401	38.2	55.8	0.389
19	0.335	49.5	45.8	0.499
20	0.385	53.8	46.5	0.543

(a) (b) (c) (d)

Figure 11: Selected excellent design schemes. (a) Scheme 1. (b) Scheme 2. (c) Scheme 4. (d) Scheme 5.

paper. The first layer is the proportion and pureness; the second layer is contrast; the third layer is beauty, appropriateness, and novelty; the fourth layer is aesthetic value. After that, the three main eye movement indicators in visual observation, that is, the total number of gaze points, the number of regional gaze points, and the duration of gaze points, are linked with aesthetic perception indices, and then a quantitative measurement method of aesthetic perception based on visual tracking technology is obtained. Subsequently, 20 participants selected from Experiment 1 were invited to carry out the experiment. Twenty design schemes designed by the designer were processed by projecting grayscale pixels, and experiments were designed on Tobii Studio. Participants were asked to observe in front of the eye tracker. Based on the aesthetic measurement index system established before, each index was calculated. At last, in line with the aesthetic value obtained, the evaluation and the ranking of each scheme show that scheme 2, scheme 1, scheme 4, and scheme 5 have higher scores that can be considered as excellent schemes.

The aesthetic measurement technology introduced in this research breaks the limitations of previous psychological measurement through semantic evaluation. At the same time, it is also different from the current physiological index measurement based on qualitative analysis. It quantifies the individual's aesthetic experience through a systematic evaluation index system, so that the aesthetic evaluation of each design scheme can be compared. It allows designers to have a scientific and accurate way to choose after completing the preliminary design scheme. It can also make the entire product design not only conform to the concept of "everything starts from consumers" but also do not restrict designers' artistic innovation activities due to the fixed aesthetic model of the public. It can thoroughly enable designers to release their imagination and design capabilities. While satisfying consumers' basic functions and emotional needs, it also promotes the continuous development of the entire industry.

Data Availability

The data supporting the findings of this study are available within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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