

Article

The Design of Automotive Interior for Chinese Young Consumers Based on Kansei Engineering and Eye-Tracking Technology

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Abstract: The reasonable CMF (Color, Material and Finishing) design for automotive interiors could bring positive psychophysical and affective responses of customers, providing an important guideline for automobile enterprises making differentiated products. However, current studies mainly focus on an aspect of CMF design or a single style of the automotive interior, and examined the design mainly through human visual perception. There lack systematic studies on the design and evaluation of automobile interior CMF, and more scientific evaluation of the design through human visual and touching perception was required. Therefore, this study systematically designed the automobile interior CMF based on Kansei engineering and eye-tracking technology. The study consists of five steps: (1) Product positioning: the Chinese young consumers, the new energy vehicles, and bridge and seat are the target users, the automotive model and the key interior components. (2) Kansei physiological measurement: nine groups of Kansei words and thirty-three interior samples were selected, and the interior samples were scored by the Kansei words. (3) Kansei data analysis: three design types were determined, i.e., “hard and stately”, “concise and technological” and “comfortable and safe”. Meanwhile, the CMF design elements of the automotive interiors under the three styles were obtained through mathematical methods. (4) Design practice: four CMF samples under each design style (12 samples) were developed. (5) Kansei evaluation: the design themes were conducted using eye-tracking technology, and the optimal sample that mostly satisfy the user’s Kansei requirements under each style was obtained. The proposed design process of automotive interior CMF may have great implications in the design of automotive interiors.

Keywords: Kansei engineering; eye-tracking technology; automotive interior; CMF



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1. Introduction

With the rapid development of the automobile market and the more diversified consumer demand, consumers are not only concern about the aesthetic appearance and platform performance index of automobiles, but also pay more attention to the driving and riding experience formed by the automotive interior design [1]. The color, material and finishing design (CMF) of the automotive interiors can influence human multiple sensory experience, undergo perceptual communication with people, and thus bring consumers emotional, symbolic and other added value, which is of great importance in influencing user experience [2]. The rational CMF design of the interiors could significantly promote psychophysical and affective responses of customers, and also help automotive enterprises develop differentiated innovative products in today’s competitive environment [1,2]. However, the existing automotive interior design relies greatly on the personal judgment of designers, and lacks consumer participation, which may make the design unable satisfy the demand of the consumers [3]. There is a pressing need to develop a more scientific

CMF design process for automotive interiors with customer engagement to produce more pleasant products.

Kansei engineering provides a way to develop customer-oriented products that fulfill human needs via converting consumers' feeling and preferences to the design elements [4]. This method was extensively investigated in various fields such as in the design of aircraft, automotive, furniture, clothing and other industries [5]. In the area of automotive interiors, Tanoue et al. [4] employed Kansei engineering method to evaluate the users' feeling of spacious and oppression towards the automotive interior space, and developed a comfort diagnostic system. Jindo et al. [6] took the dashboard and steering wheel as research objects, using semantic differential and multivariate analysis to explore the relationship between intention and modeling features, then designed an easy-to-understand speedometer and improved the visual comfort of users. Yanagisawa et al. [7] examined the causal relation between Kansei and design attributes considering human visual attention. Cao et al. [8] studied the perceptual requirement of automotive interior color using Kansei engineering method, and built the relationship between perceptual appeal and the interior color. Sousa et al. [9] explored the visual perception of texturized plastic surfaces of users, both in its psychophysical and affective dimensions. It can be seen that current studies mainly investigated the Kansei design of one aspect of CMF design or a single anterior element of automobile interiors. Besides, they examined the Kansei design of the products only based on human visual perception, and very limited attention has paid to the perception elicited by both touch and observation of an interior. Actually, the surface textures also exert an important role in the perception of consumer products [10]. Thus, more systematic and scientific design of CMF of automotive interiors was needed. Besides, the existing studies usually generate series of design schemes based on the design elements contributing to the enhancement of user experience, but there lacks study on the evaluation of the designs. Considering this, further evaluation should be performed to help automobile enterprise designers select the optimal design.

For evaluating the Kansei design of a product, the commonly employed subjective assessments such as semantic differential method suffer from many systematic biases related to order, scale and halo-effects [11]. Instead, objective methods such as eye-movement tracking and electroencephalography (EEG) technologies could accurately measure humans' original emotions by detecting their physiological signals when viewing a product [2,12,13]. These objective methods have already been widely used to evaluate the Kansei design of various products such as automotive styling, smartphones, clothing and furniture, etc. [12–14]. In addition, few studies demonstrated that using eye-tracking technology is feasible to evaluate Kansei design of automobile interiors or interior-related seats. For instance, Carbon et al. [15] found that the eye-movement tracking technology could effectively evaluate the innovativeness of the automotive interiors. Hsu et al. [16] simultaneously used semantic differential and eye-tracking technology to examine the design of 3D chair forms, and derived the relationship between the eye fixation patterns and Kansei design of the chair forms.

In view of the above, the paper proposed a design process for systematically designing and evaluating the CMF design of automotive interiors based on Kansei engineering and eye-tracking technology. The detailed description of the framework for designing automotive interiors was introduced in the following section. In addition, eye-tracking technology was utilized to evaluate the Kansei design of the automotive interiors.

2. A Design Process for Automotive Interior CMF

The proposed design process for automotive interior CMF was based on the conceptual model of Kansei engineering proposed by Schütte [17], which consists of five steps: (1) Determining the application field of a product (i.e., product positioning); (2) Expanding the semantic space; (3) Expanding the product feature space; (4) Constructing a mapping relationship between users' perceptual images and product features using mathematical methods; and (5) Kansei evaluation. The conceptual model was extensively used in Kansei

design process for various products with some modifications [18–20]. For instance, Huang and Cui [19] developed a smart jewelry CMF design process following the above conceptual model and adding a design practice.

In this study, based on the typical conceptual model of Schütte [17] with the possible modifications to the commercial design flow of automotive interiors [21,22], a five-step design process of automotive interior CMF was developed (Figure 1). It consists of product positioning (S1), Kansei physiological measurement by combining step 2 and 3 above (S2), Kansei data analysis (S3), design practice (S4) and Kansei evaluation (S5).

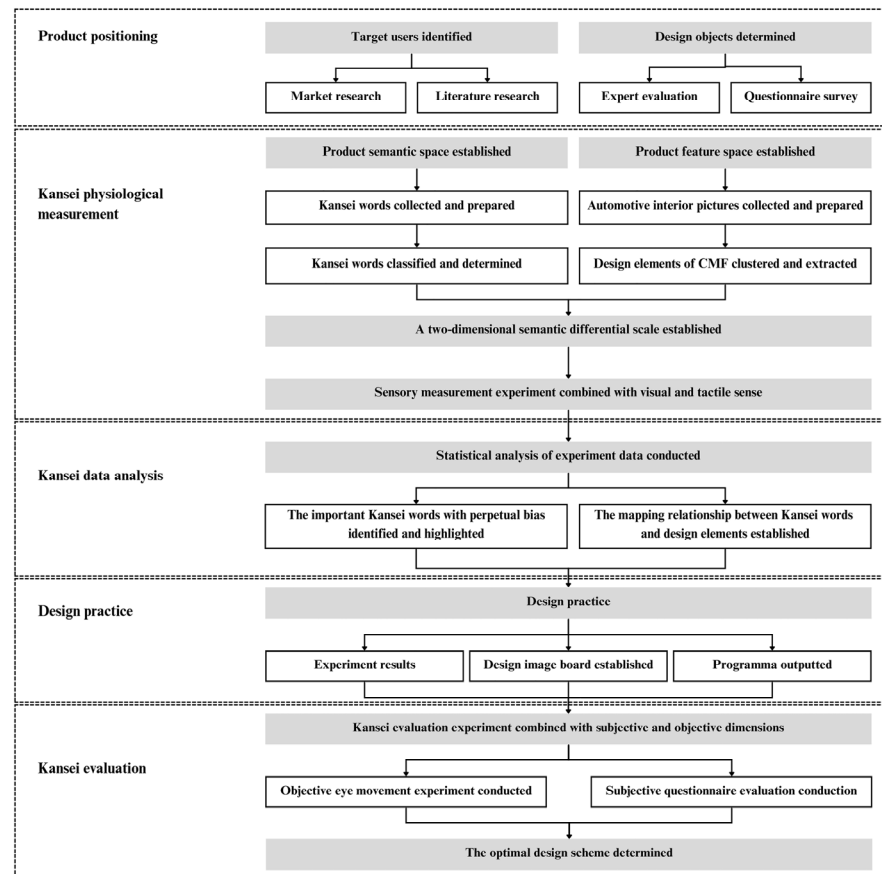


Figure 1. Flow diagram of the design procedure.

In the product positioning step (S1), the target users and automotive model as well as the key interior components were determined. The target users and automotive could be selected through market survey and wide literature review [8,21]. The key interior components could be detected based on questionnaire survey [8,21].

In the Kansei physiological measurement step (S2), the aim is to establish the Kansei image space of the products, including three small steps, i.e., establishment of product semantic space, product feature space and Kansei measurement experiment [8,18]. In the establishment of product semantic space, a great many product Kansei words from multiple channels are collected, screened and refined using reasonable evaluation methods such as focus group discussion composed of experts, and the representative Kansei words were finally selected. To establish product feature space, the images of automotive interiors are collected extensively from multiple channels, which were reclassified and selected to obtain the more representative samples, and the automotive design elements were determined. In the experiment for Kansei measurement, the semantic differential method is adopted to build a 7-point Likert scale by combining the representative Kansei words with experimental samples to construct Kansei image space. It is noted that Kansei measurement

was conducted by combining both visual and tactile sensations to evaluate the product comprehensively, as reported by previous studies that the unique texture characteristics of interior materials influence human tactile sensation, and thus affects human psychological and emotional responses [23,24].

In the perceptual image analysis step (S3), the prominent Kansei words that best represent users' emotional needs were chosen (i.e., the Kansei styles), and a mapping relationship between the CMF design elements and the chosen Kansei words was established. In this process, mathematical statistics such as factor analysis, multiple linear regression and quantification theory type I, are generally adopted to quantitatively analyze the data collected by perceptual measurement experiment and do the establishment [25].

In the design practice step (S4), the design schemes of automotive interiors with a certain Kansei style were determined based on the results of data analysis in step S3.

In the Kansei evaluation step (S5), the design schemes were evaluated using eye-tracking technology, and the optimal scheme with a certain Kansei style was determined.

3. Detailed Design of Automotive Interior CMF

3.1. Product Positioning

It is reported that by the end of 2020, the number of people aged from 18 to 24 years who hold driver's licenses has reached 40 million, but 75% of young people have not owned cars yet [26]. The main force of car purchase is developing towards youth. Different from other age groups, they tend to be futuristic, personalized, modern and environmentally sustainable. They are willing to experience new things, pursue trends and fashion, and are curious about technological intelligence. In terms of vehicle preference, they showed strong interest and willingness to buy new energy, intelligence and customization, pay more attention to comfort, security and convenience in daily driving, and have higher requirements for diverse entertainment systems in leisure and recreation. If automotive enterprises could understand the new generation of young consumers, they will have the opportunity to take the lead in the market competition in the next few years. Therefore, the target users of this study are the Chinese young consumers.

Recent years, the new energy vehicle is more energy saving, economical and maintenance friendly, and gained wide affinity of young consumers [27,28]. Thus, it was the chosen as the representative automobile model.

The key interior components were determined using questionnaire survey based on the feedbacks of the user group and expert group. In the survey, 200 potential car purchasers (102 males and 98 females) aged from 18 to 25 years participated in this study, mainly involving 165 college students and 35 social members. They all have obtained the driving license, and have the experience of driving. Besides, they mainly live in first-tier and second-tier cities, have a bachelor's degree or above and majored in design discipline. For social members, they just started working for a few years, have an annual income level slightly above the average value of the city they lived, and have the potential to buy a car in the next few years. In addition, a total of 25 professionals engaged in automotive interior design were also invited to help determine the key components, including the interior designers from automotive companies and university teachers in researching automotive interiors. To obtain the key components, eight interior components were firstly identified based on the literature review and opinions of professionals, i.e., steering wheel, seat, dashboard, console, roof trim, door panel, carpet and A-pillar panel. Then, the subjects were asked to fill the questionnaire survey online to score the importance of the eight interior components using the 7-point Likert scale with "−3" represents extremely unimportant, "0" represents neutral and "3" represents extremely important.

Results found that for the user group, a total of 182 valid questionnaires were obtained, including 90 and 84 from males and females, respectively. For the professional group, a total of 25 valid questionnaires were collected, including 14 and 11 from males and females, respectively. It is noted that the valid questionnaires were obtained by deleting the invalid questionnaires such as those with short filling time and identical scores. Reliability

analysis showed the reliability coefficient could reach to 0.84 and 0.92 for the user group and professional group, respectively, indicating that the questionnaire results are effective. Figure 2 displayed the overall score of the user group and professional group on the interior components, respectively. It indicated that the overall score of the seat, steering wheel, main dashboard and console were higher than other interior parts for both groups. Here, the steering wheel, dashboard and console are located in the front part of the main and deputy seats, and were collectively referred to as the bridge. Therefore, we will mainly examine the CMF design of the bridge and the seat components. Specifically, the color and material design of the two components were considered in this paper, considering the effect of surface finishing presents in materials [29].

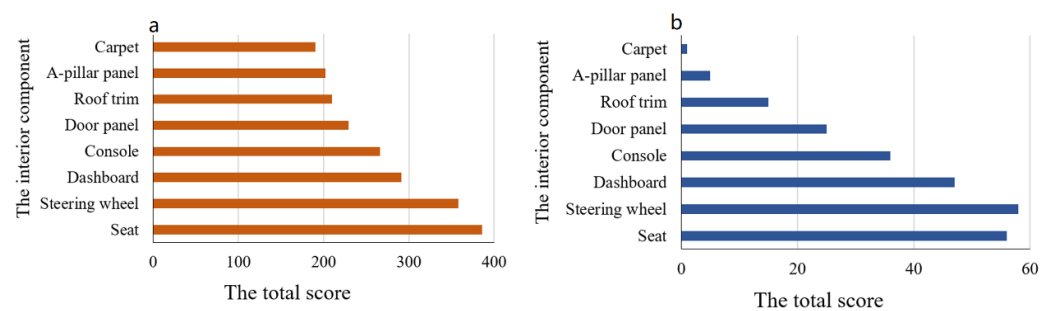


Figure 2. The average score of automotive interior components: (a) User group; (b) Professional group.

Based on the above analysis, a total of four experimental groups were identified, which are named as the seat color group, seat material group, bridge color group and bridge material group, respectively.

3.2. Kansei Physiological Measurement

3.2.1. Establishing the Product Semantic Space

To establish product semantic space, extensive search was conducted to detect the Kansei words describing automotive interior design from the Internet, advertising magazines, and literature, and also through group interview of target users, interview of professional designers. A total of 163 Kansei words were gleaned. To avoid the possible fatigue of the subjects due to the rating of the excessive words in the subsequent experiment, Kansei words that are of similar meaning or less important are deleted. After that, 15 experts from automobile manufacturing companies and specialized in automotive interior CMF design (8 males and 7 females) were invited to further screen the Kansei words, and 30 typical Kansei words were selected (Table 1).

Table 1. The 30 Kansei words after preliminary screening.

No.	Kansei Words	No.	Kansei Words	No.	Kansei Words
01	Concise	11	Graceful	21	Technological
02	Steady	12	Upscale	22	Delicate
03	Hard	13	Prospective	23	Plump
04	Warm	14	Fashionable	24	Environmentally friendly
05	Stylish	15	Harmonious	25	Soft
06	Luxurious	16	Pure	26	Exquisite
07	Modern	17	Characteristic	27	Comfortable
08	Splendid	18	Flamboyant	28	Durable
09	Stately	19	Safe	29	Sportive
10	Commercial	20	Energetic	30	Intelligent

Based on previous studies, the Kansei words could be classified into three groups based on users' perceptions towards the products, i.e., "visual perception", "functional

experience” and “psychological perception” [30]. “Visual perception” refers to the semantic interpretation of morphological structure, which means the feedback of users through the five senses when they get contact with the product at the first time [30]. “Function experience” focuses on the user’s sense of operation, which means the physical feeling of the users in the process of using the product (Buley, 2013; Nagasawa, 2008). “Psychological feeling” focuses on the user’s psychological experience, which has certain social and cultural attributes [30]. To determine the attribution of the 30 Kansei words, the 15 experts above were asked to group the words. Besides, the 3 mostly representative words were selected under each group. A total of 9 representative Kansei words were selected, matched with opposite words, forming the product semantic space (Table 2). It is reported by similar studies that 5~9 Kansei words could fully express the Kansei features of products and also are proper for Kansei measurements [31].

Table 2. The representative 9 groups of Kansei words.

No.	The “Visual Perception” Group	No.	The “Function Experiencing” Group	No.	The “Psychological Perception” Group
01	Complex vs. concise	04	Traditional vs. technological	07	Impassive vs. cozy
02	Soft vs. hard	05	Fragile vs. durable	08	Contaminated vs. environmentally friendly
03	Rough vs. graceful	06	Afflictive vs. comfortable	09	Dangerous vs. safe

3.2.2. Establishing the Product Feature Space

To establish the product feature space, wide search was performed to find the various automotive interiors through official websites of automotive brands, vehicle selling websites, magazines, books, etc. A total number of 110 automotive interior images of 32 mainstream brands were collected, covering most of the interior CMF collocation of the new energy vehicles. Then, the images that are of similar interiors and old fashioned are deleted, producing a total number of 92 automotive interior samples (Figure 3).



Figure 3. The 92 interior samples collected from the market.

To finally select the experimental samples, 10 out of the above 15 experts were invited for a group discussion. During the process, similarity comparison, classification and selection of automotive interior samples were performed through cards classification.

Specifically, by combining the interior samples with the same CMF design elements and extracting the design elements with more occurrences, four groups were clustered, i.e., the seat color group, the seat material group, the bridge color group and the bridge material group. Seven colors were obtained for the seats, i.e., black (A1), gray (A2), coffee (A3), off-white (A4), black with khaki (A5), black with off-white (A6) and black with red (A7). Six types of materials of seats were obtained, i.e., leather (B1), geometrically textured leather (B2), leather with suede (B3), leather with woven cloth (B4), woven cloth (B5) and geometrically textured woven cloth (B6). Seven colors were attained for the bridge, i.e., black with silver (C1), black with coffee (C2), dark gray with silver (C3), black and off-white with silver (C4), black and red with silver (C5), off-white and khaki with black (C6), black and off-white with coffee (C7). Eight types of materials for the bridge were obtained including plastic with brushed metal (D1), plastic with anodized metal (D2), plastic and chrome plated metal with wood grain (D3), plastic and chrome plated metal with suede (D4), leather and plastic with chrome plated metal (D5), leather and plastic with anodized metal (D6), leather, plastic and wood grain with anodized metal (D7), plastic with carbon fiber (D8).

It is noted that to make the design scheme more popular with consumers, multiple design elements were also obtained from various channels through market research to further expand the product feature space. Wide survey was performed through the investigation of the annual CMF design trend report issued by the authority, the visit to the 2022 International Auto Show and the excellent design cases from various industries (Figure 4) [32]. It is found that blue and blue with white color displayed both the future sense of personability and a high-level sense of atmosphere. The elegant anodized champagne metal balances tradition and modernity. In terms of materials, fabric and wood grain were used by new energy brands in the interiors to highlight the home feeling, the concept of natural environmental protection and also make the car interior more artistic. The aluminum material is still the mainstream of decorative parts. Additionally, a large number of three-dimensional, parametric and geometric texture patterns are used to bring human a fresh and organized feeling. In terms of surface treatment technology, the transparent effect of the coating technology can echo the atmosphere lamp, which increases the sense of design hierarchy. In view of the above analysis, off-white with blue (A8) was added to the seat color group, and parametric texture textile cloth (B7) was added to the seat material group. Black and off-white with champagne (C8), and blue and off-white with silver (C9) were added to the bridge color group. Plastic and chromium plated metal with wood grain (D9) was added to the bridge material group. Figure 5 displayed automotive CMF design elements of the four groups for experiment. It is noted that automotive interior models were constructed using Rhino ver.6 software, and rendered by the Keyshot ver. 10 software. A total of 33 interior images were included. To make the following Kansei measurements more accurate, the images were kept of the same size, background, resolution and rendering angle.

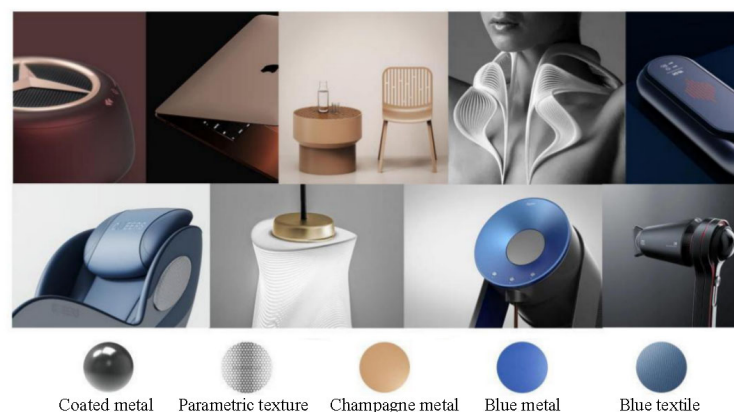


Figure 4. The supplementary CMF designs from various industries.



Figure 5. The interior CMF samples for examination: (A) the seat color group, (B) the seat material group, (C) the bridge color group and (D) the bridge material group.

3.2.3. Kansei Measurement

To establish the relationship between the Kansei words and the experimental samples, the 33 samples were scored using the 9 groups of Kansei words. It is noted that each pair of Kansei words corresponded to a 7-point scale. Taking the phrase of “concise-complex” as an example, it is was scaled from “very complex” (−3), “complex” (−2), “relatively complex” (−1), “neutral” (0), “relatively concise” (1), “concise” (2) and “very concise” (3). The data collection is performed using questionnaires online.

A total of 160 graduate students aged from 18 to 25 years and majored in industrial design participated in this study, including 80 males and 80 females. To improve the accuracy of the study, human tests were performed offline, and only one subject was invited to score the interior samples each time. Besides, the interior materials were prepared to make the measurement more accurately, which were made into the size of 15 cm × 15 cm (length × width). Before the tests, the participants were introduced of the experimental process in detail. During the tests, the subjects observed and touched the samples, and scored them (Figure 6).

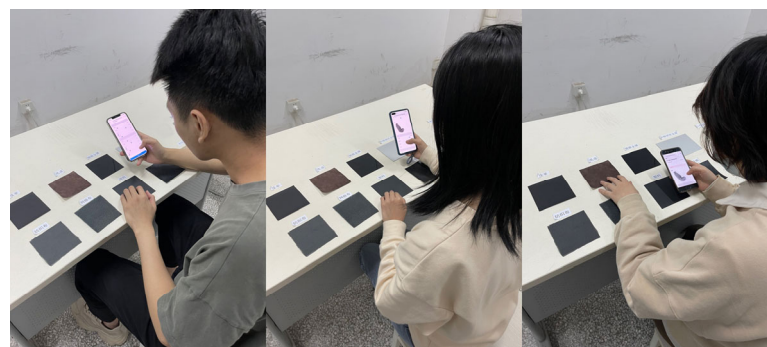


Figure 6. The supplementary CMF designs from various samples.

3.3. Kansei Data Analysis

3.3.1. The Determination of the Prominent Kansei Words

In the above experiment, a total of 152 valid questionnaires from 76 males and 76 females were obtained after eliminating abnormal data such as those with short filling time and the same score. The alpha reliability coefficient of the questionnaire is 0.95, indicating the high dependability of the survey results.

To obtain the prominent Kansei words that could highlight the CMF samples, principal component analysis (PCA) was performed using SPSS ver.26.0 to reduce the dimension of the data collected from the Kansei measurement experiment. The test of the questionnaire data showed that Kaiser-Meyer-Olkin (KMO) is 0.763 and the p value of the Bartlett sphericity test is less than 0.05, satisfying the prerequisite requirements of factor analysis.

Figure 7 displayed the scree plot, showing that nearly the first three components can be attracted, indicated by the value of characteristic near or larger than 1. Furthermore, the cumulative contribution rate reached 64% when the above three components were extracted listed in Table 3, indicating that the remaining factors after extraction were ideal.

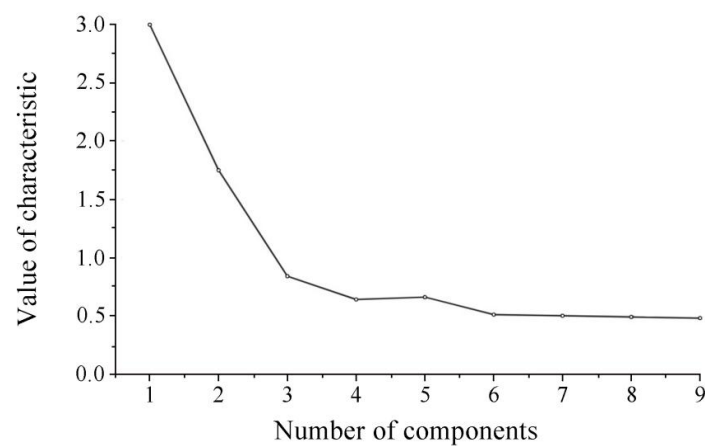


Figure 7. Diagram of scree plot.

Table 3. Total variance of explanation.

Component	Value of Characteristic			Extraction Sum of Squares Loading			Rotation Sum of Squares Loading		
	Total	Variance Proportion	Cumulative%	Total	Variance Proportion	Cumulative%	Total	Variance Proportion	Cumulative%
1	2.99	33.20	33.20	2.99	33.20	33.20	2.37	26.31	26.31
2	1.81	20.06	53.26	1.81	20.06	53.26	1.69	18.86	45.17
3	0.91	10.12	63.38	0.91	10.12	63.38	1.64	18.20	63.38
4	0.74	8.23	71.61						
5	0.72	8.03	79.64						
6	0.56	6.18	85.81						
7	0.48	5.35	91.16						
8	0.41	4.59	95.75						
9	0.38	4.25	100.00						

Table 4 lists the relationship between the Kansei words and the three principal component factors. The larger value in the table indicates the stronger the correlation between the perceptual word and the corresponding principal component. Principal component 1 is mainly associated with “afflictive vs. comfortable”, “cold vs. warm”, “pollutional vs. environmentally friendly” and “dangerous vs. safe”, which describes the functional experience of the interior CMF design. Principal component factor 2 is mainly associated with “complex vs. concise”, “rough vs. graceful” and “traditional vs. technological”, which describes the users’ visual perception towards the automotive interiors. Principal component factor 3 is closely related to “hard vs. soft” and “fragile vs. durable”, and is intended

to describe the psychological perception of the users towards the automobile interior. After comparing the scores in Table 3, 5 groups of Kansei words are more important in describing automotive interiors are chosen, i.e., “complex vs. concise”, “soft vs. hard”, “traditional vs. technological”, “afflictive vs. comfortable” and “dangerous vs. safe”.

Table 4. Component score matrix.

Perceptual Words	Components		
	1	2	3
Complex vs. concise	0.199	0.636	0.195
Hard vs. soft	−0.109	0.149	0.824
Rough vs. graceful	0.443	0.637	−0.290
Traditional vs. technological	0.041	0.814	0.171
Fragile vs. durable	0.538	0.090	0.639
Afflictive vs. comfortable	0.725	0.299	−0.263
Cold vs. warm	0.617	−0.082	−0.562
Pollutional vs. environmentally friendly	0.565	0.292	0.041
Dangerous vs. safe	0.777	0.109	0.112

3.3.2. Establishing the Mapping Relationship between the CMF Design Elements and Kansei Words

To determine the influence of the CMF design elements on the prominent Kansei words, Quantification Theory I was adopted. The theory can be used to perform quantitative research on problems that are difficult to quantify, and thus could examine the relationship between things more comprehensively [33,34]. The theory could establish the relationship between a set of independent and dependent variables. After quantifying the qualitative variables into quantitative data of 0 and 1, multiple linear regression is then used to establish the mathematical relationship between the two variables, which is to achieve the goal of predicting the dependent variables.

In the Quantification Theory I, the design factors were set as category, and the design elements under each design factor were set as subcategory. Assuming the first category X_1 has a number of r_1 subcategories, i.e., $X_{11}, X_{12}, \dots, X_{1r_1}$, the second category X_2 owns a number of r_2 subcategories, i.e., $X_{21}, X_{22}, \dots, X_{2r_2}$, and the category X_m owns a number of r_m subcategories, i.e., $X_{m1}, X_{m2}, \dots, X_{mr_m}$, a total number of $\sum_{j=1}^m r_j = p$ subcategories were involved.

The symbol $\delta_{ik}(j, k)$ ($i = 1, \dots, n; j = 1, 2, \dots, m; k = 1, 2, \dots, r_j$) represents the response values of the k th subcategory from the j th category in the i th sample, and the values were taken as Equation (1).

$$\delta_{ik}(j, k) = \begin{cases} 1, & \text{When the qualitative data of the } j\text{th category in the } i\text{th sample is the } k\text{th subcategory} \\ 0, & \text{Others} \end{cases} \quad (1)$$

An order matrix of $n \times p$ was constituted from all $\delta_{ik}(j, k)$, forming the response matrix, listed in Equation (2)

$$\delta_{ik}(j, k) = \begin{bmatrix} \delta_1(1, 1) & \dots & \delta_1(1, r_1) & \delta_1(2, 1) & \dots & \delta_1(2, r_2) & \delta_1(m, 1) & \dots & \delta_1(m, r_m) \\ \delta_2(1, 1) & \dots & \delta_2(1, r_1) & \delta_2(2, 1) & \dots & \delta_2(2, r_2) & \delta_2(m, 1) & \dots & \delta_2(m, r_m) \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \delta_n(1, 1) & \dots & \delta_n(1, r_1) & \delta_n(2, 1) & \dots & \delta_n(2, r_2) & \delta_n(m, 1) & \dots & \delta_n(m, r_m) \end{bmatrix} \quad (2)$$

The relationship between the values of the perceptual words (y) and the design elements could be established, showing in Equation (3).

$$y = \sum_{j=1}^m \sum_{k=1}^{r_j} \delta_{jk}(j, k) b_{j,k} + \varepsilon_i \quad (i = 1, 2, \dots, n) \quad (3)$$

where $b_{j,k}$ only depends on the undetermined coefficient of the k th design element in the j th design factor, and ε_i is the random error of the i th sampling.

Based on Figure 5 and Equation (2), the response matrix of the 33 samples was obtained. The matrix of the design elements was regarded as the independent variables, and the five perceptual words discussed above was set as the dependent variables. Multiple linear regression analysis was performed using SPSS ver.26.0 software. During calculation, the forced entry method was adopted and all variables were included in the regression model for comprehensive analysis. It was detected that the determination coefficients were all greater than 0.8, indicating the high reliability of the regression. Besides, all variance inflation factor values were lower than 2.1, indicating that there was no collinearity.

Tables 5 and 6 lists the results of multiple linear regression analysis, and the results of the four groups were presented. It is noted that each design element in the tables corresponds to a score, which means the correlation coefficient between the element and a Kansei word. The negative score value means the words on the left of the phrase could describe the design element well, and vice versa. For instance, the seat color of black or off-white shows the users' a sense of simplicity. The value of the partial correlation coefficient (PCC) in the tables represents the contribution of each experimental group to the overall prediction. A large partial correlation coefficient means the experimental group has a great impact on Kansei words. For instance, seat color has the greatest influence on the phrase of "complex vs. concise". The possible explanation is that the seat occupies a large visual space in the automotive interior, which may be much easier to affect the perceptions of users.

Table 5. Results of multiple linear regression analysis (Seat group).

Testing Group	Design Element	Hard vs. Soft		Complex vs. Concise		Traditional vs. Technological		Dangerous vs. Safe		Afflictive vs. Comfortable	
		Score	PCC	Score	PCC	Score	PCC	Score	PCC	Score	PCC
Group A Seat Color	A1	−1.60		−2.19		−0.11		−0.33		−0.37	
	A2	−0.10		−1.97		−0.30		−0.12		−0.32	
	A3	0.42		−0.63		0.99		−0.37		−0.83	
	A4	1.66	0.55	−2.67	0.58	−1.20	0.51	−0.23	−0.42	−0.82	−0.50
	A5	−0.70		0.91		0.83		0.11		0.53	
	A6	−0.60		−0.45		−1.26		0.09		0.38	
	A7	−0.77		0.99		−0.33		0.75		0.45	
	A8	1.26		−1.11		−1.24		−0.18		−0.67	
Group B Seat Material	B1	−0.37		−1.71		0.78		−0.79		−1.12	
	B2	0.48		0.94		0.69		−0.32		−0.34	
	B3	1.53		0.57		1.24		−0.32		−0.95	
	B4	0.99	0.47	−0.11	−0.38	1.43	0.54	0.2	−0.45	0.28	0.48
	B5	1.34		−1.06		1.61		0.28		0.28	
	B6	0.84		0.97		−0.36		0.17		0.03	
	B7	1.01		1.23		0.74		−0.06		−0.41	

Table 6. Results of multiple linear regression analysis (Bridge group).

Testing Group	Design Element	Hard vs. Soft		Complex vs. Concise		Traditional vs. Traditional		Dangerous vs. Safe		Afflictive vs. Comfortable	
		Score	PCC	Score	PCC	Score	PCC	Score	PCC	Score	PCC
Group C Bridge Color	C1	−1.81		−1.51		−1.24		−0.25		0.43	
	C2	−0.12		−0.04		0.68		−0.50		−0.59	
	C3	−0.38		−1.18		−0.76		0.22		0.56	
	C4	−0.34		0.75		−1.15		0.13		0.62	
	C5	−0.21	−0.45	2.07	0.54	0.40	−0.47	0.50	0.74	1.29	0.69
	C6	−0.63		2.26		−0.05		1.44		1.56	
	C7	0.64		−0.11		−1.11		−0.14		0.07	
	C8	1.13		0.82		0.44		−0.17		−0.29	
	C9	−0.32		1.10		−0.02		−0.20		0.00	
Group D Bridge Material	D1	−1.59		−0.86		−0.52		0.14		0.62	
	D2	−1.33		−1.25		−0.80		0.16		0.28	
	D3	−1.18		0.09		−1.17		0.37		0.46	
	D4	0.35		1.39		1.03		0.10		−0.19	
	D5	1.21	0.56	1.62	−0.51	0.95	0.53	0.04	0.29	−0.32	−0.31
	D6	−0.36		0.20		0.08		−0.25		−0.24	
	D7	−0.34		0.29		−0.35		−0.31		−0.15	
	D8	0.56		2.24		0.89		0.07		0.23	
	D9	−1.14		−1.34		−1.22		−0.28		−0.21	

Table 7 showed the representative design elements under each Kansei word derived from Tables 4 and 5. In the table, “hard” represents the rational aesthetics and pragmatic design style, which were pursued by modern young users. For example, the interior space formed by all black highlights the sense of superlatives and cold, whose coldness and hardness can be diluted with some wine red added, creating a sense of warm feeling. This is consistent with the finding of Zhou et al. [34] who also found that automotive interiors with black and red can bring young consumers enthusiasm, excitement and driving impulse. In terms of materials, brushed metal gives human a rigorous and delicate psychological perception [35]. The smooth texture of the metal surface and the delicate leather surface set off each other, might providing human a sense of hardness and softness. “Concise” design is to create a simple atmosphere, which could be realized by using color with low brightness and low saturation. The transparent and refreshing off-white color, the light and breathable textile fabric, and the soft sanding effect of anodized metal could all give human a sense of simple feeling. “Technological” design often adopts new materials, technologies and novel design style. The blue embellishments on the basis of black, white and gray, the bright surfaces of coated metal and chrome metal which reflect the surrounding environment luster, and the linear geometric texture of carbon fibers could all provide human a sense of science and technology. Shen et al. [36] also discovered that using blue color decorated with white color could present human a sense of technology and fashion. Besides, many research studies detected that lightweight carbon fibers with extremely high strength as well as the rough crazy weaves formed by them could bring a sense of movement and high technology feeling [31,37].

“Safe” design is not only reflected in the automotive operating system, but also through the CMF design of interiors. For example, black and brown colors convey a visual sense of safety and stability. Soft materials such as suede and geometric texture decorative leather bring human better comfort and security. “Comfortable” design provides human natural and friendly visual perception as well as soft and warm tactile experience. Nowadays, the car has gradually become the third space outside the home and office, and consumers pursue the comfortable home-like environment when driving the car. Wood, woven textile cloth and the mesh cloth all provide human with a sense of relaxed, natural and comfort perceptions.

Table 7. Suggestions on the design corresponding to each perceptual image words.

Kansei Words	Seat Colors	Seat Materials	Bridge Colors	Bridge Materials
Hard	Black; Black and Red	Leather	Black and Silvery; Black, Red and Silvery	Plastic and brushed metal; Plastic, coated metal and chrome plated metal; Plastic and carbon fiber
Concise	Off-white; Black	Leather; Fabric	Black and Silvery; Dark grey and Silvery	Plastic and anodized metal; Plastic and carbon fiber
Technological	Black and off- white; Blue and off-white; Off-white	Woven fabric with parametric texture	Black and Silvery; Black and Silvery; Black, off-white and silvery; Blue, off-white & silvery	Plastic, coated metal and chrome plated metal; Plastic and carbon fiber
Safe	Brown; Black	Leather; Suede and Leather; Leather with geometric texture	Black and brown; Black, off-white & brown	Leather, anodized metal and plastic; Plastic and carbon fiber; Leather, chrome plated metal and plastic suede, chrome plated metal and plastic; Leather, chrome plated metal and plastic; Plastic, wood and chrome plated metal
Comfortable	Brown; Off-white	Leather; Suede and Leather; Woven fabric and mesh fabric	Off-white, khaki and black; Black and brown	

Based on the interpretation of Kansei words and the data analysis results obtained from the Kansei measurement experiment, the design style themes are determined to be “hard and stately”, “simple and technological” and “comfortable and safe”.

3.4. Design Practice

The interior of Tesla model 3 was used as the shape carrier of CMF design, considering that it has been the world’s best-selling new energy vehicle for four consecutive years since the year of 2018, with “hard and stately”, “concise and technological” and “comfortable and safe” as the main design style. Taking the mapping relationship between colors and materials in Table 7 as reference, the CMF designs of the automotive interiors were obtained, shown in Figure 8. Four automotive interior samples were designed under each design theme. A total of 12 sample images were obtained, numbered as Y1–Y4, K1–K2 and S1–S2 respectively, which were evaluated in Section 3.5.

3.5. Kansei Evaluation

3.5.1. Subjects Selection

A total of 30 college students majoring in design methodology were recruited to participate in the experiment, including 15 males and 15 females. Assuming an effect size $f = 0.4$, $\alpha = 0.05$, and power $(1 - \beta)$ error probability of 0.95, 12 participants would provide enough power to detect a significant difference (G*Power, version 3.1.9.2), indicating that the number of participants employed here is enough. Their average age, height and weight (mean $\pm$ standard deviation) were 21.55 ± 1.44 years, 165.85 ± 7.63 cm and 56.5 ± 8.56 kg, respectively. In addition, all the participators have no problems such as short-sightedness, color blindness or color weakness and also no history of taking drugs or alcohol. The study is approved by the Ethics Committee of Guangdong University of Technology.

Group A: Hard and stately



Group B: Simple and technology



Group C: Comfortable and safe



Figure 8. The automotive interior samples were obtained under the three design themes (groups): (A) “Hard and stately”, (B) “Simple and technology”, (C) “Comfortable and safe”.

3.5.2. Eye-Movement Tracking Equipment and the Stimuli

Eyelink 1000 Plus (SR research, Ottawa, ON, Canada) with a sampling rate of 1000 Hz was used for eye-movement tracking. The experimental samples were edited by E-Prime Professional 3.0 and presented on a 21-inch LCD screen with a resolution of 1920×1080 pixel. To display more abundant information, the automotive interiors were presented in the view angle of 45 degree, showing the bridge, seats, steering wheel and doors. The sample images were preliminary rendered using Keyshot 10 software and the post-processed using Photoshop V.22.0, and the images of the 12 design themes in 45 °C view angle were obtained (Figure 8). It is noted that the images are of the same size, white background, and resolution (i.e., $1920 \text{ dpi} \times 1080 \text{ dpi}$). Meanwhile, to improve the reliability of the experiment, 4 samples of each design theme were displayed on the screen simultaneously, served as a set of stimuli, so that the subjects could directly compare the differences among the samples. Additionally, the Latin square design was arranged to eliminate the influence of the display layout of the samples. The areas of interest (AOI) and the eye movement data were captured and analyzed using the eye movement software (SR research, Ottawa, ON, Canada).

3.5.3. Experimental Procedure

Upon arrival the testing room, the subjects sat on a seat and put their chin on a handle fixed on a desk. Next, the height of the handle was adjusted to ensure that the subjects face the center of the screen in a comfortable posture. Before each formal test, calibration was performed, and the eyes of the subjects followed a “+” sign that appeared at 5 specific locations on the screen in sequence, and the “+” sign lasts for 10 s in each location. During

tests, the subjects looked at each set of stimuli for 5 s, and they were required to keep staring at the sample that they thought best matched the design style of the group until the disappearance of the stimuli. After that, the subjects rated their preference for the samples using a 5-point scale, ranging from -3 (“dislike very much”) to 3 (“like very much”). The above procedure was repeated until all the images were examined. It was noted that the three groups of images were randomly displayed on the screen to minimize the influence of physiological factors such as visual fatigue. In addition, to help the participants fully understand the experimental process, a pre-test using a set of stimuli image like the selected ones was conducted following the above procedure before each formal experiment, which is not included in the final data analysis.

The eye movement data in terms of the average fixation duration (AFD), relative fixation proportions of each AOI to the total AOIs (RFP), the average number of fixation points (ANFP) and the average fixation frequency (AFF), were used for the assessment. These eye-movement indexes were widely used to assess the attractiveness of particular AOIs [38] and the level of concern or preference for particular AOIs [39]. It is noted that all tests were performed in a quiet, well-lit room with air temperature of 26°C and relative humidity of 50% RH.

3.5.4. Data Analysis

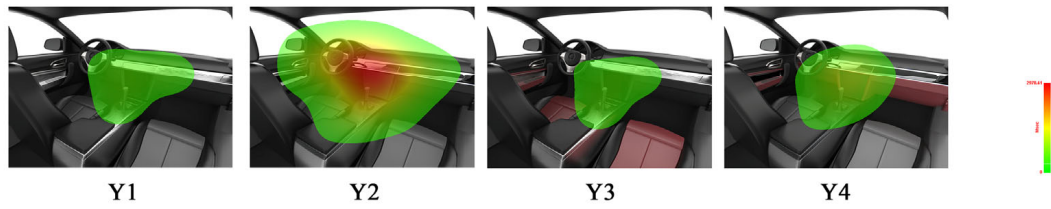
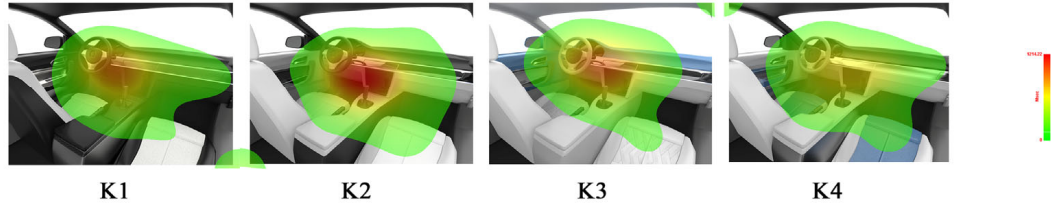
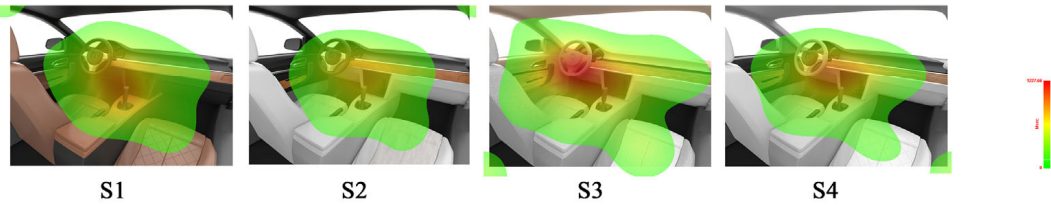
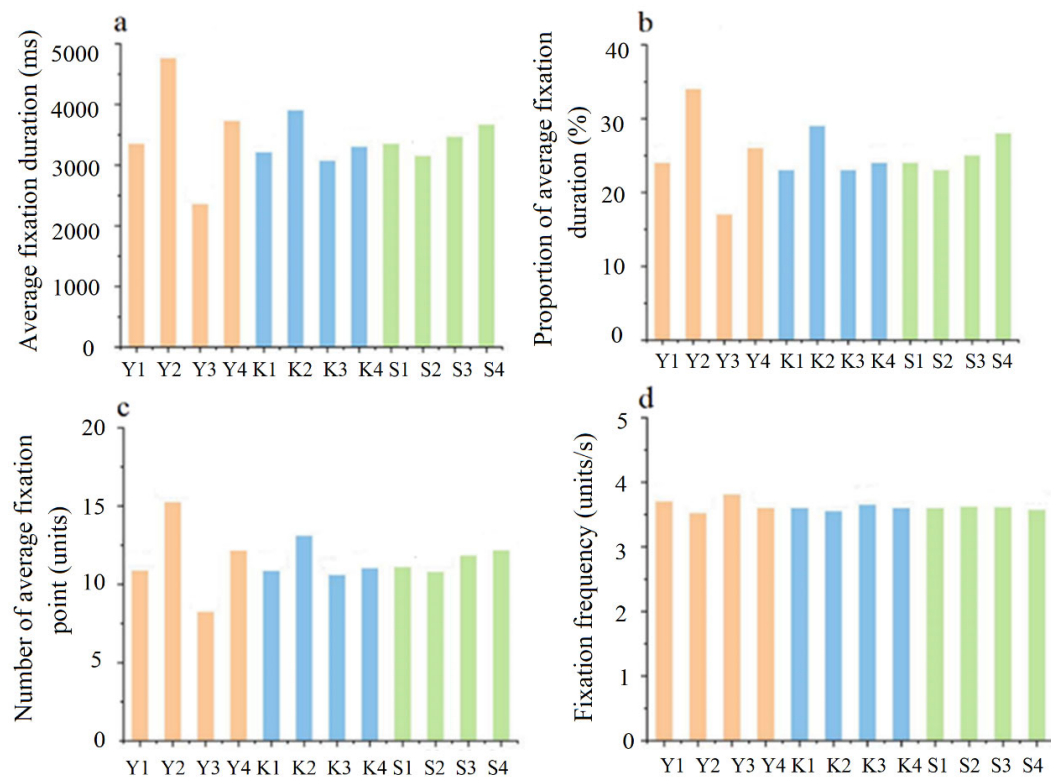
The one-way analysis of variance (ANOVA) is widely applied to examine whether there are any statistically significant differences between the means of three or more independent variables [30,34]. It was used here to analyze the differences in eye movement data and subjective data among the themes under each design style and also among the 12 themes. The results were corrected by Bonferroni multiple comparison, a widely used conservative approach for detecting the difference [40]. All the data were analyzed using SPSS ver. 22 (IBM, New York, NY, USA). The differences were expressed as p values, and the differences with statistical significance were set as $p < 0.05$.

3.5.5. Results and Discussion

Figure 9 showed that the AOI heat maps of the 3 groups of automotive interior design. It is found that Y2, K2 and S4 correspond more well with the design themes, i.e., “hard and stately”, “concise and technological” and “comfortable and safe”, respectively.

Figure 10 displayed the mean histogram of the eye movement data in AOI region of 12 samples. It is found that Y2 showed significantly higher AFD, RFP and ANFP than Y1, Y3 and Y4 ($p < 0.05$), while Y2 demonstrated significantly lower AFF than the rest three samples ($p > 0.05$). This indicates that Y2 has received more attention from the subjects, which more fits the Kansei word of “hard and stately”. Similarly, the AFD, RFP and ANFP of K2 are significantly higher than those of the other 3 samples (K1, K3 and K4) ($p < 0.05$), while no significant difference in AFF was discovered among the four samples ($p > 0.05$). Additionally, AFD and RFP of S4 are significantly higher than other 3 designs (S1, S2 and S3) ($p < 0.05$), but no significant difference in ANFP and AFF was found among the samples ($p > 0.05$). The results indicate that Y2, K2 and S4 are superior to the other 3 designs in the same group.

Figure 11 showed that the preference of the subjects to the experimental samples. It is discovered that Y2, K2 and S4 were more preferred by subjects than other samples in the same group ($p < 0.05$). In addition, Y2 was the most preferred sample and K2 ranked second, followed by S4.

Group A: Hard and stately**Group B: Simple and technological****Group C: Comfortable and safe****Figure 9.** Heat maps of the automotive interior.**Figure 10.** Mean values of eye movement data of the 12 samples. (a) Average fixation duration, (b) Proportion of average fixation duration, (c) Average fixation points and (d) Average fixation frequency.

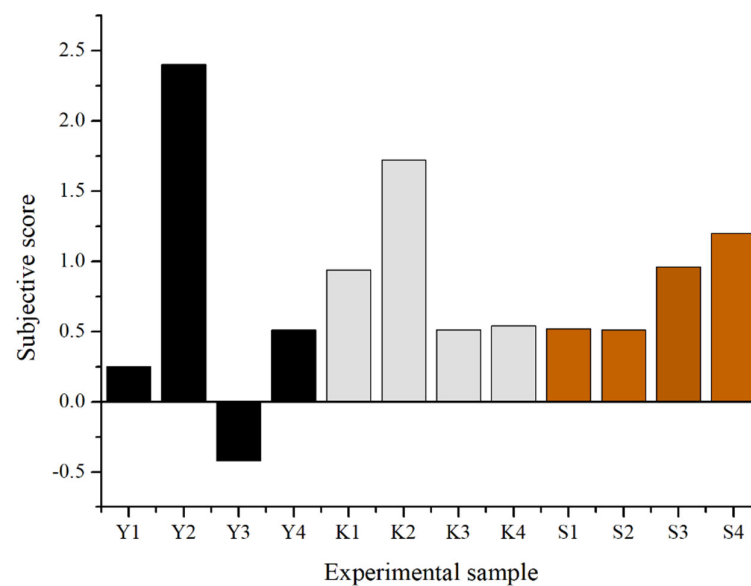


Figure 11. The preference of the subjects to the experimental samples.

It is noted that Y2 in the “hard & stately” group adopts all black monochrome color style, whose seats, bridge and door panels are mainly covered with leather material. In addition, the bridge was decorated with coated metal and chrome metal strip to improve the overall quality of the interior, the above and below of which were plastic of moderate softness. The overall collocation of concise and pure materials provides the users with the impression of calm, introverted and pragmatic, consistent with the perceptual word of “hard and stately”. K2 provides the users with the perception of “concise & technological”, which displays the neutral color with low brightness and saturation, and a combination of black at the top and white at the bottom conforming to the principle of balance and stability of interior design. The seat is completely made of off-white leather, and the middle of the bridge is made of coated metal and chrome plated metal decorative strip, which shows a sense of technology well under the clear and bright collocation. Besides, the design gets rid of the sense of industrial machinery of the bridge. S4 in the “comfortable & safe” group conforms to the two-color matching principle, i.e., adopting off-white and khaki to create the main color environment with black color ornamented in local areas. The seat is made of skin-friendly textile cloth with fine texture, the seat is covered with mesh cloth with good breathability, and the bridge and door panel are made of leather at the top, natural walnut grain in the middle and soft plastic at the bottom, which was decorated with the bright chrome-plated metal strip locally. The overall interior environment of S4 is similar to the indoor atmosphere, which could convey the home-like natural and friendly visual sensory experience as well as the soft and warm tactile sensory experience. The color and material with natural texture are well matched represented by the theme of “comfortable and safe”. Interestingly, Y2 with “hard & stately” style was mostly preferred by subjects, providing the direction for the automotive interior design.

4. Limitations, and the Future Studies

We must acknowledge there are several limitations in this study. Firstly, the CMF design of other important interior components such as doors and top decoration were not examined due to the complexity of the experimental design, and future studies should include these components. Secondly, only four design themes were provided under each style in the design practice step, and future studies should produce more design themes to help select the best design. Thirdly, only a small number of young University student majoring in design methodology were employed in the Kansei evaluation step, and future studies should employ a larger sample of subjects from various disciplines and also include different age ranges. Fourthly, this study only examined human visual attention and

preference for to select the optimum design, and future studies will be performed from the perspective of marketing behaviors (such as decision making), and the relationship among the CMF designs, human visual attention, and their marketing behaviors to improve the design of automotive interiors.

5. Conclusions and Practical Applications

In this study, we proposed a custom-oriented process for systematically designing the automotive interior CMF based on Kansei engineering and eye-tracking technology, and five steps were identified. In the product positioning step, the target users, the automotive model and the key interior components were determined, which are Chinese young consumers, the new energy vehicles, and bridge and seat, respectively. This provides automotive enterprises with important design directions. In the Kansei physiological measurement step, nine groups of Kansei words and thirty-three interior samples were selected using clustering method by the experts, and the interior samples were scored by the Kansei words. In the Kansei data analysis step, three principal components highlighting the Kansei image were selected by using the principal component analysis method, and three design types were determined, i.e., “hard & stately”, “concise & technological” and “comfortable & safe”. Meanwhile, the CMF design elements of the automotive interiors under the three styles were obtained through mathematical methods. This indicates that the above three styles are the main design direction for young consumers, and combining the CMF design elements could achieve a certain design style. Design practice was also performed and four CMF samples under each design style (12 samples) were developed. Finally, Kansei evaluation was conducted using eye-tracking technology based on both human visual and touching perception, and the optimal sample that mostly satisfy the user’s Kansei requirements under each style was obtained. The proposed design and evaluation steps could help automotive enterprises select the optimal design. Compared with existing studies that only examined the Kansei design of a certain automotive interior component and lack quantitative evaluation for the design, this study proposed a more systematic and scientific design process for automotive interior CMF. The proposed design process has great implications in the design of automotive interiors to satisfy the demand of Chinese customers.

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