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An Automobile Exterior Design Approach Model Linking Form and Color

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In recent years, design has become the most important subjective factor affecting customer vehicle purchases. In this paper, the authors construct the "Automobile Exterior Design Approach Model (AEDAM)", which uses biometric devices along with visualization technology and statistics to establish the relationship between vehicle form and color and customers' subjective responses. Firstly, they analyze lines of sight using an eye camera to understand the perspectives from which customers observe overall automobile design. The subjective data collected during this process is then used to create a numerical model that measures form and color according to an objective scale. Finally, this information is used to construct and assess an evaluation model, and the given results are obtained. The effectiveness of this model is then verified.

Keywords: automobile design, exterior color, statistical science

Introduction

In recent years, design has become the most important subjective factor affecting customer vehicle purchases. In this paper, the authors delve deeper into the idea of automotive profile design (vehicle proportion), which prior research has identified as the primary component in overall automobile design.

They then place importance on the idea of developing form and color in an integrated manner. Using this information, the authors construct the "Automobile Exterior Design Approach Model (AEDAM)", which uses biometric devices along with visualization technology and statistics to establish the relationship between vehicle form and color and customers' subjective responses.

The effectiveness of this model is then verified. Specifically, the authors make use of their research in subjective automobile engineering in the following research process. Firstly, they analyze lines of sight using an eye camera to understand the perspectives from which customers observe overall automobile design. This information is clarified by using actual vehicles and videos.

The subjective data collected during this process is then used to create a numerical model that measures form and color according to an objective scale. The data is used to generate a 3D-CAD (Three-dimensional Computer Aided Design).

Using a device that measures brain waves, the authors then clarify which aspects of form attract the most

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attention in terms of exterior design. At the same time, the relationship between changes in form and color (parameters) and customers' subjective evaluations is visualized by using numerical modeling. Finally, this information is used to construct and assess an evaluation model, and the given results are obtained.

Research Background

One of the most significant challenges facing Japanese industry in the 21st century is producing appealing products. Conversely, the challenge faced by industry in the 20th century was achieving product consistency. It is clearly not enough to focus on price when developing products, especially nowadays when preferences are so varied and customers demand products designed to suit individuals. Similarly, the trial-and-error approach to development being seen during the period of high economic growth is no longer viable.

In the automobile industry, also, it is vital to properly take into account customer preferences and values in the planning and development of new products. This means it is important to verbalize (imagery/conceptualization) customers' feelings (implicit knowledge) and reflect this information on design drawings in the process of "designing" (explicit knowledge) through the application of "Customer Science", which scientifically analyzes customer preferences (Amasaka, Nagaya, & Shibata, 1999; Okabe, Yamaji, & Amasaka, 2006; Amasaka, 2007).

Much research has been conducted on the subject of automobile exterior design (Asami, Ando, Yamaji, & Amasaka, 2010; Takimoto, Ando, Yamaji, & Amasaka, 2010; Satake, Ando, Kuwano, Sato, Hattori, & Kajiwara, 2004). Conventional research focuses on the form of automobiles, and there has been little research on the relationship with color, which has a profound effect on purchasing.

Some research was conducted to associate customers' subjective impressions by changing color while fixing the form (Fujieda, Matsuda, & Nakahara, 2007; Asami, Owada, Murata, Takebuchi, & Amasaka, 2011; Takebuchi, Asami, Nakamura, & Amasaka, 2010). As far as the authors know, however, there has never been any research to associate customers' subjective impressions to vehicle form and color when they are simultaneously changed (i.e., research in which both form and color are treated quantitatively).

This research aims to reveal how the relationship between form and color can affect customers' subjective impressions. Specifically, the authors used an eye camera and an electroencephalogram (EEG, a device that measures brain waves) to clarify which aspects of form attract the most attention of customers. The authors also reveal the relationship between form and color that can affect customers' subjective impressions by reproducing form and color on a CAD design and employing the statistical inference.

Necessity of Numerical Representation of Form Using CAD

In order to visualize the influence rate of profile change on customers' subjective impressions, it is important to quantify them. This research makes use of 3D-CAD (Three-dimensional Computer Aided Design) as a means to quantify profiles.

There are three advantages in using 3D-CAD: (1) It is possible to perform numerical conversions of profiles (parameterization) using CAD software that allows numeric definitions of form; (2) Because exterior design can be viewed from different angles (front, side, rear, etc.), it is possible to compare different views with customers' subjective impressions; and (3) 3D-CAD is also the primary modeling tool in the actual design process.

Automobile Exterior Design Approach Model Linking Form and Color

The authors think it is important to visualize customer preferences and make use of this information in product development, and thus create the "Automobile Exterior Design Approach Model (AEDAM)" shown in Figure 1 that plays an important role in the development. The following Steps 1 to 3 show an outline of this model.

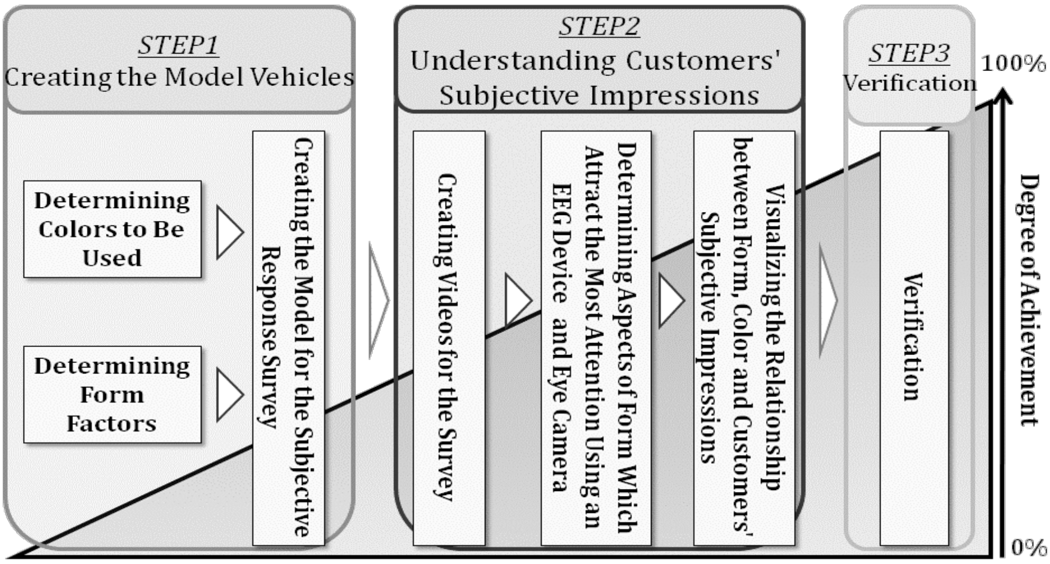

Figure 1. Automobile exterior design approach model, AEDAM.

Creating the Model Vehicles (Step 1)

In Step 1, the authors created model vehicles for a subjective response evaluation by using 3D-CAD that included some intentional parameters as a means to associate customers' subjective impressions with vehicle form. This research attempted to clarify the relationship between customers' preference and automobile design by performing the subjective response evaluation using videos of vehicle models.

First of all, the authors determined the colors of the vehicle model for the subjective response survey. The authors conducted surveys in Ginza, Roppongi, and Harajuku areas to check which body colors are popular, and took pictures of over 600 cars. As a result, the authors found that there were many white, black, and silver vehicles. However, there are many variations in each color, and each vehicle has a considerably different shade of white or silver. The authors therefore realized that colors to be used when determining color factors must be treated quantitatively.

This research used a colorimeter to measure RGB values of the body colors of 30 sample vehicles that were actually on sale. Then, the authors categorized the RGB data with cluster analysis (group average method, with standardization), and investigated the data to see what color clusters they were divided into. As a result, the authors found five color clusters (white, red, blue, black, and silver) as shown in Figure 2. Because the colors obtained in this process correspond to the recent major vehicle colors (Harada & Ozawa, 2009), this research will use these five colors to create the models for the subjective response survey.

Because sedan-type bodies were targeted in this research, the authors used the color data for sedan-type vehicles and used these five colors as color factors. The RGB values of the measured color data (see Table 1) were used in the models for the subjective response survey.

In order to determine which aspects of form have the largest impact on customers' subjective impressions, the authors analyzed lines of sight using an eye camera as shown in Figure 3 to reveal which aspects of form attracted the most attention from customers and in which order customers observe vehicles. To determine aspects of form that influence customers' subjective impressions, the authors asked eight subjects to observe vehicles freely, and they analyzed which part of the vehicle they paid attention to. The authors were able to reveal that the subjects focused on belt lines as well as bonnet edges.

The authors created a model for the subjective response survey to check how the impression given to customers changed when the authors intentionally alter the aspects of the form to which customers were paying attention. In this step, the authors determined four aspects (bonnet edge depth, beltline angle, front pillar angle and rear pillar angle) as the main form factors based on the information obtained in the previous research, and set degrees of form variation (three levels), when creating the model vehicle for the subjective response survey.

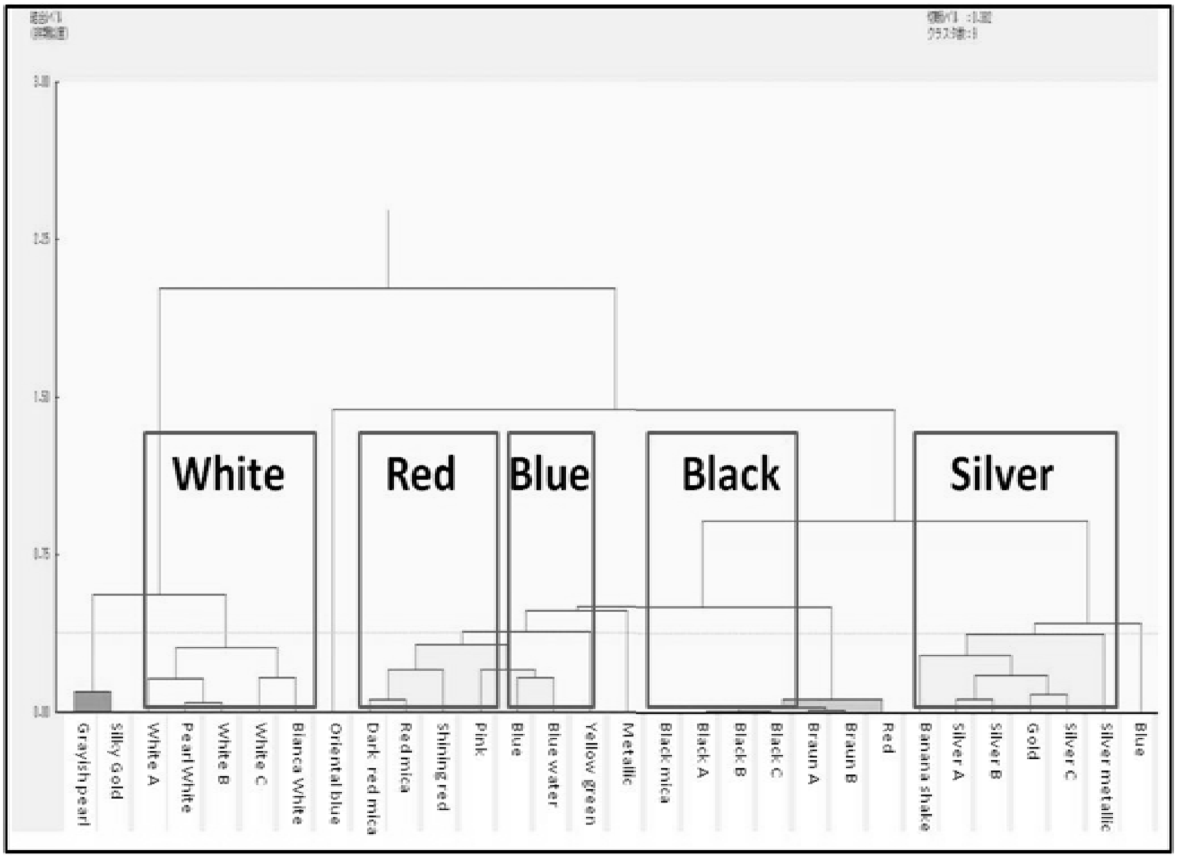

Figure 2. Categorized the RGB data with cluster analysis.

Table 1

The RGB Values of the Measured Color Data

Color	Red	Green	Blue
White	1005	992	965
Red	134	186	73
Blue	33	139	86
Black	15	15	15
Silver	429	435	436

Figure 3. Analyzed using an eye camera.

The authors investigated the aspects of form that attract the most attention with an eye camera, revealing that customers identified the bonnet edge and beltline as a set and the front pillar and rear pillar as a set. Based on this result, the authors created a CAD model for the subjective response survey with the directions of changes in these parameters treated as a set.

The authors created five types (Types A-E) of model vehicles. Considering the overall design balance when independently changing each aspect of form, the authors linked (1) the bonnet edge depth and beltline angle (flow of lines), and also linked (2) the direction of level change in the front and rear pillars (flow of pillars). Table 2 shows form parameters of the four aspects for the five types of model vehicles. Values in the table are set within a specific range so that the sedan form can be maintained without dramatically changing the exterior dimensions of vehicles.

Figure 4 shows a comparison between Type C and Type E of silver color. In this example, the angles of the front and rear pillars on each of these two vehicle types are changed. The authors applied the five color options (white, red, blue, black, and silver) to the five types of model vehicles, creating 25 different types of model vehicles in total for the survey.

Table 2

Form Parameters of the Four Aspects for the Five Types of Model Vehicles (Degree)

Type	Bonnet edge	Beltline	Front pillar	Rear pillar
Type A	40°	2°	40°	40°
Type B	25°	0°	30°	20°
Type C	45°	5°	30°	20°
Type D	25°	0°	60°	60°
Type E	45°	5°	60°	60°

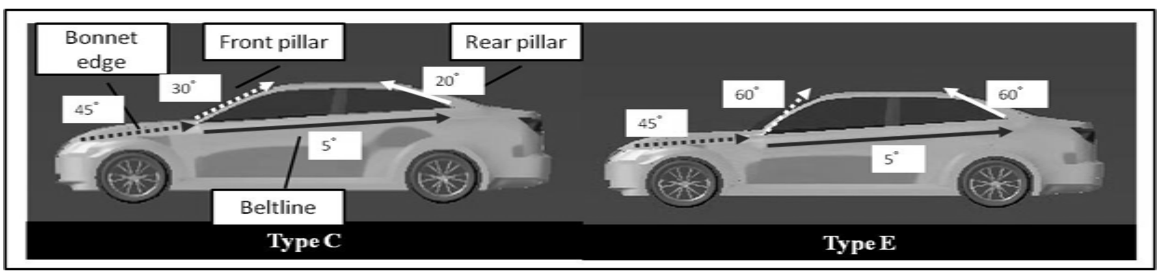

Figure 4. Model Vehicles (Type C, E).

Understanding Customers' Subjective Impressions (Step2)

To understand the relationship between automobile exterior design and customers' subjective impressions, this research used the model for the subjective response evaluation created previously to measure customers' subjective impressions, with the aid of visualization technology and statistical science through biometric devices. Line-of-sight analysis revealed that customers observed vehicles from multiple directions (Yamaji, Hifumi, Sakalsiz, & Amasaka, 2010). In other words, customers determine the impression of vehicles by observing the connections between flat surfaces rather than just by observing from one direction.

One of the advantages of CAD modeling is that the connections with all surfaces can be seen. For this reason, this research used videos rather than still images in the subjective response evaluation to more closely represent the way in which customers actually perceived vehicles. As for the content of the videos, vehicles were shown in order from the front, side and rear, and each view was zoomed in. The length of the videos was set to 20 seconds, and the authors created the videos by emulating the actual perception process performed by customers using an electroencephalogram (EEG) device, the authors clarified aspects of form which attract the most attention. This research captured lines of sight with an eye camera. However, looking at a specific portion for a longer period of time does not necessarily mean that portion attracts more attention. This research therefore used both an EEG and eye camera to quantify the degree of attention paid by customers to automobile exterior design.

Much research has been conducted on the relationship between brain waves and subjective responses (Gyoba, 2009; Kawano, Konjiki, & Ago, 2004; Kato, Shikoda, Mochizuki, Ishikawa, K. Kobayashi, & T. Kobayashi, 2008), and they show that it is useful to capture brain waves when customers' feelings change dynamically. To collect data on customers' preference, the authors revealed which aspects of form customers were paying attention to using an EEG device and an eye camera. To do so, the authors played back five videos of model vehicles from the ones created for the subjective response survey, in which the color was fixed to silver and only the form was changed. Then the authors analyzed the brainwaves and information on lines of sight of the subjects during video playback.

Brainwaves are categorized into Delta (4 Hz or below), Theta (4 Hz-8 Hz), Alpha (8 Hz-13 Hz) and Beta (13 Hz or above) according to frequency ranges. In this research, the authors monitored the change in feelings, focusing attention on Beta waves (13 Hz or above) that appeared in conjunction with a conscious thought.

Brainwaves measured while watching the subjective response survey videos showed that stronger Beta waves were emitted for approximately seven to ten seconds for all five vehicle types compared to Beta waves that appeared under normal circumstances. Figure 5 shows changes in the average Beta wave values of the eight subjects. When correlated with the subjective response survey videos, it was found that the time of peak Beta wave emission (circled in Figure 5) was the time at which the focus was moved from the front view to the side view of the 3D-CAD model. This research tried to identify which parts attracted the most attention from the line-of-sight data recorded with the eye camera, and found that the subjects particularly paid attention to the line flowing from the front pillar to the rear pillar and the line flowing from the bonnet edge to the beltline. These results indicate that the four form factors defined in this research are likely to attract the most attention of customers.

The authors conducted a questionnaire survey and analyzed the obtained data to reveal how changes in vehicle form and color affect customers' subjective impressions. As shown in Table 3, the authors asked the eight subjects to watch the videos of 25 types of vehicles that were created for the subjective response survey, and evaluate them using 12 subjective words on a scale of 1 to 7 (7 indicating a very strong impression, and 1 indicating a very weak impression).

First, the authors performed factor analysis to investigate the relationships between the subjective words (maximum-likelihood method). Table 4 shows influence rates for each subjective word in factor loadings after varimax rotation. As for Factor 1, the words “Advanced” and “Original” are strongly influential in the positive direction and words “Traditional” and “Simple” are strongly influential in the negative direction. As for Factor 2, “Intelligent” and “Elegant” have a strong influence as indicated. According to the characteristics of subjective words that affect each factor, the authors defined Factor 1 as “Innovative” and Factor 2 as “Matured”.

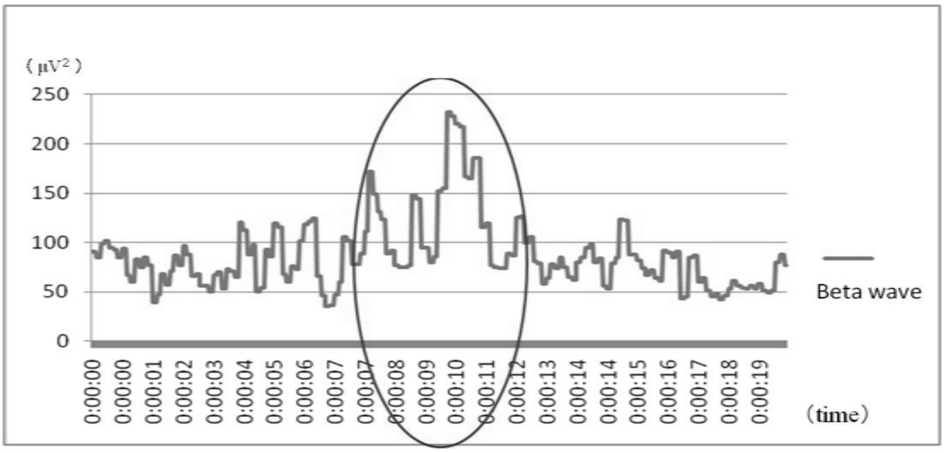

Figure 5. Changes in the average Beta wave.

Table 3

Eight Subjects Words

Sophisticated	Intelligent	Elegant
Traditional	Advanced	High class
Original	Simple	Composed
Cute	Powerful	Sporty

Table 4

Factor Loadings

Subjective Words	Factor 1	Factor 2
Sophisticated	0.529	0.590
Intelligent	-0.036	0.839
Elegant	-0.005	0.748
Traditional	-0.894	-0.095
Advanced	0.815	0.225
High class	0.447	0.516
Original	0.861	0.045
Simple	-0.882	-0.063
Composed	-0.689	0.072
Cute	-0.656	-0.089
Powerful	0.724	0.260
Sporty	0.696	0.332

Then, the authors evaluated the weightings to the form and color for each factor. To do so, the authors performed quantification theory type I analysis to reveal the degree of influence on the form and color factors, and created the model shown in Figure 6. The right side of this figure shows the result of the factor analysis, and the left side shows the result of the quantification theory type I analysis. This model made it possible to predict the degree of influence on the factors when the form and color were arbitrarily selected.

The authors then performed quantification theory type I analysis. First, the authors performed the analysis by setting external criteria (Factor 1 "Innovative", Factor 2 "Matured") as factors and items as form types (Types A to E) and colors (white, red, blue, black, and silver). The model created at this point is shown on the left side of Figure 6. As for Factor 1 "Innovative", the result of the analysis revealed that the Type C (silver) vehicle was given the impression as the most innovative.

However, the freedom-degree-adjusted contribution rate (R2*) is 0.419, so the authors cannot say that the result of the analysis is very reliable. This means that this analysis result has not sufficiently revealed the relationship between the change in form and color and customers' subjective impressions.

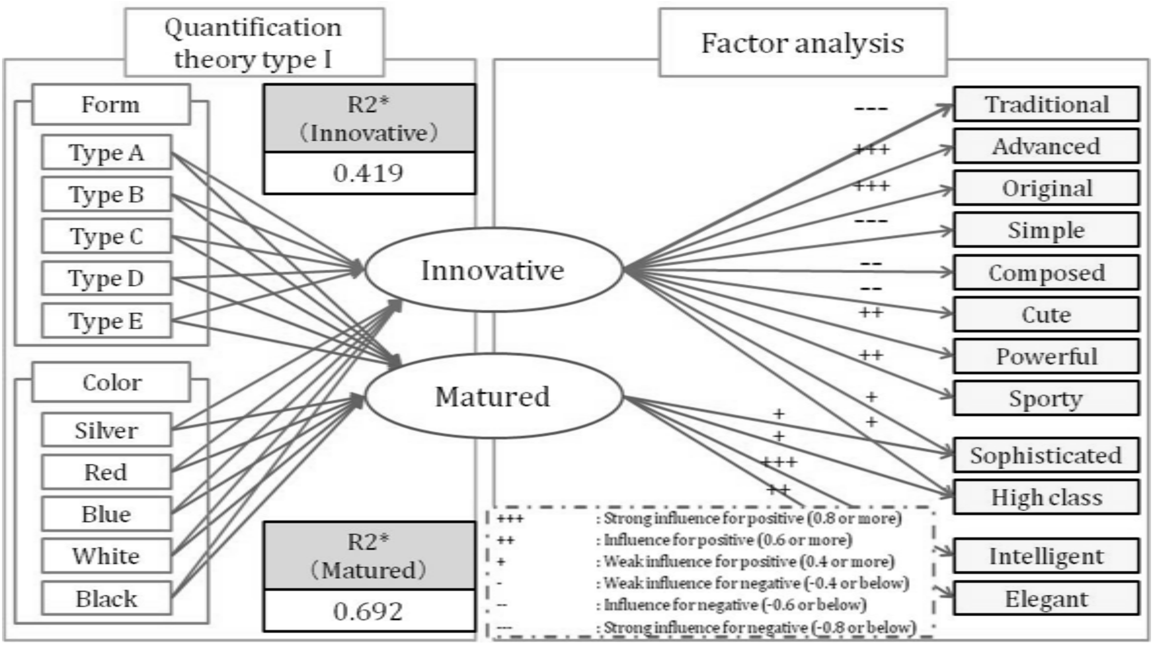

Figure 6. Factor analysis and quantification theory type I analysis (first).

The authors further investigated this analysis result. In this analysis, quantification theory type I analysis was performed using two items (form types and colors) as shown in Figure 6. However, when the authors assumed that there was a combinatorial effect between form and color in this method of analysis, it was not necessarily possible to identify the combinatorial effect. The authors therefore changed items used in quantification theory type I analysis. Specifically, as shown in Figure 7, the authors performed quantification theory type I analysis again by using 25 model vehicle types as form type items and color items. In this way, the authors can confirm whether or not there is a combinatorial effect by comparing the analysis results.

Figure 7 shows the result of the re-analysis conducted by setting Factor 1 "Innovative" and Factor 2 "Matured" as external criteria and form types (from Type A silver to Type E black) as items. As Figure 7 indicates, the freedom-degree-adjusted contribution rate of Factor 1 "Innovative" rises by 0.137 and becomes

0.556. The reliability of the analysis is improved because of the re-analysis. Further, the freedom-degree-adjusted contribution rate of Factor 2 “Matured” is 0.711 which is sufficiently persuasive.

From these results, the authors think that, when conducting quantification theory type I analysis with two items (form and color) as shown in Figure 6, form and color are separated, and consequently no combinatorial effect is taken into account in the created model resulting in low freedom-degree-adjusted contribution rates. To counter this problem, the authors increased the freedom-degree-adjusted contribution rates by performing analysis in consideration of combinatorial effects, as shown in Figure 7. As for Factor 2, the freedom-degree-adjusted contribution rate was not dramatically improved. The authors assume that this is because the impression is mainly determined by either form or color.

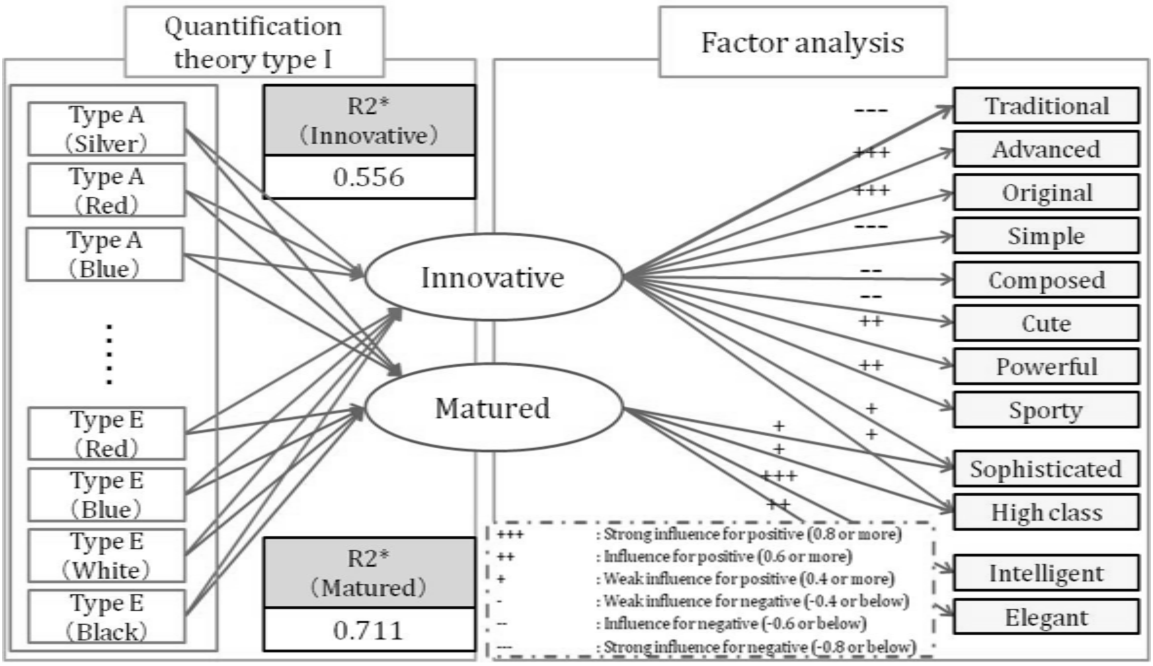

Figure 7. Factor analysis and quantification theory type I analysis (second).

Moreover, Figure 8 shows the partial correlation coefficient value of the quantification theory type I analysis result for Factor 1 “Innovative”. Looking at each partial regression coefficient in this way makes it possible to understand the degree of influence on Factor 1 “Innovative” of the model vehicle. As a result, the author can interpret that the partial regression coefficient of Category 20 (Type C, black) becomes the greatest (1.864) and it gives the most innovative impression among the 25 types of vehicles.

As for Factor 2 “Matured”, the authors can interpret that the partial regression coefficient of Category 17 (Type E, red) became the greatest (2.645) and it gives the most matured impression among the 25 types of vehicles. By creating a model using quantification theory type I analysis and factor analysis in combination, the authors clarified the degrees of influence on the subjective words in each category by using partial regression coefficients.

Verification (Step3)

The authors performed verification through analysis to make sure that the degrees of influence on customers’ subjective impressions of the change in vehicle form and color are practical. As for the verification procedure, the authors created a model vehicle that represented a Factor 1 "Innovative" impression and performed a verification questionnaire survey with the same content as the previous questionnaire but with different subjects. That way, the authors determined whether or not the target subjective word is properly represented to verify the validity of the analysis results.

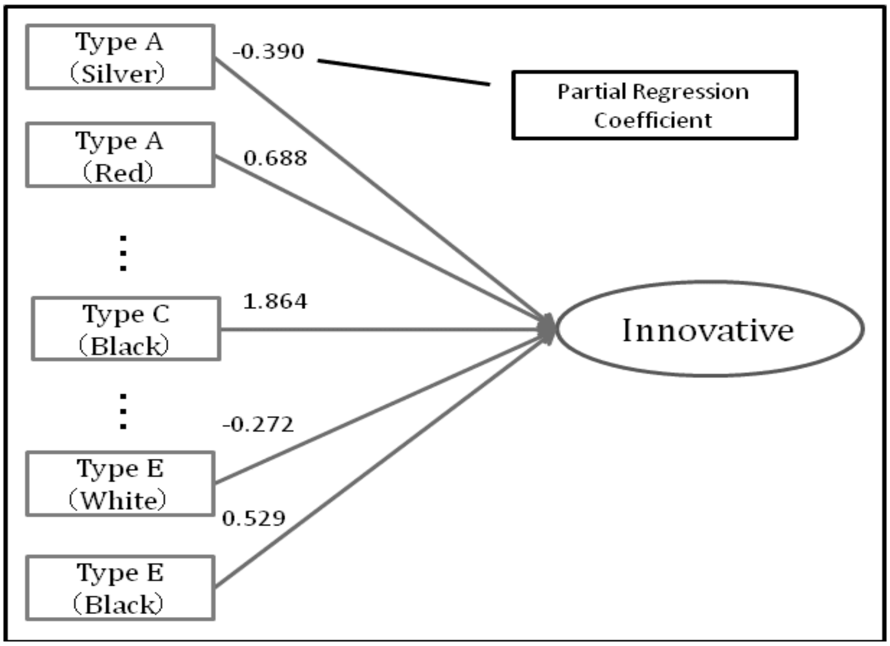

Figure 8. Partial correlation coefficient value for Factor 1.

Specifically, the authors used the factor loadings in the data obtained from the above-mentioned questionnaire (Table 4) to calculate the average factor score of Factor 1 "Innovative" for the data obtained from the verification questionnaire. Moreover, the authors compared Category 20 (Type C, black), which was considered to present the most innovative impression as a result of the re-analysis, against Category 11 (Type C, silver), which was considered as the most innovative in the first analysis performed without considering combinatorial effects.

Table 5 shows scores expected from the two quantification theory type I analysis and scores obtained from the verification questionnaire. The values obtained from the questionnaire are close to the predicted values obtained from the analysis of 25 combinations of forms and colors. The authors can, therefore, say that there is a combinatory effect between form and color, and the analyses prove the combinatorial effect. Further, Category 20 gives a more innovative impression than Category 11 because it becomes possible to give the intended impression as a result of the re-analysis. Therefore, the authors think that the adequacy of the analysis results has been properly verified.

Table 5

Scores Expected from the Two Analyses and the Verification Questionnaire

Method	Type C, Silver	Type C, Black
Scores expected from the first quantification theory type I analysis	1.221	0.970
Scores expected from the second quantification theory type I analysis	0.812	1.458
Scores obtained from the verification questionnaire	1.158	1.757

Conclusions

In this research, the authors focused attention on automotive exterior design. The authors analyzed ambiguous concepts such as form and color quantitatively with the aim of measuring their degrees of influence on customers' subjective impressions. By combining line-of-sight analysis, biometric devices such as an electroencephalogram (EEG), factor analysis, and quantification theory type I analysis, the authors constructed an "Automobile Exterior Design Approach Model" that illustrated the relationship between vehicle form and color. The authors were able to verify that the design created by applying this model can convey the intended impression to customers, and thereby demonstrated the effectiveness of this model.

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