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Research on the Influence of Wheel Type on the Visual Image of Urban Bicycle

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As green vehicles, urban bicycles play an important role in releasing urban traffic pressure and promoting energy conservation and emission reduction. The research is designed to evaluate the visual image of wheel types in the urban bicycles. Due to the variety of wheels, 10 models with high market share are taken as research samples. First, the 2D images of 10 types of wheels are drawn by the drawing software Photoshop. Six sets of visual image adjectives obtained by factor analysis are used to conduct a questionnaire survey to collect consumer visual evaluation of ten types of wheels. Then, the obtained data is further calculated by the triangular fuzzy number of the fuzzy theory, and the evaluation scores of the ten types of visual images are obtained. The research results show that the visual image evaluation of different types of wheels distinguish in "trimmed and stable", "superior and presentable" and "holistic and balanced", while little differ in "novel and individualized" and "rhythmic and metrical". In addition, the four visual groups of the overall visual image evaluation are compared from the sample by the qualitative classification. The results of the visual evaluation can effectively reflect the potential preference of urban residents for type of wheel of urban bicycles, which can be used by relevant operators and help to improve the design efficiency of the product development stage.

Keywords: urban bicycle; wheel type; visual evaluation; fuzzy logic; Factor analysis

1 Introduction

In recent years, with people's concept changing, saving energy and protecting the environment is deeply rooted in the hearts of the people's mind around the world. As important means of transportation in the city, bicycles are green and health products that are energy-saving and environmentally friendly. It can save the significant social resources since the usage of bicycles does not require asphalt paved roads. Besides, urban bicycles can't cause traffic congestion and serious traffic accidents due to their small size and slow speed. At present, many crowd funding companies have participated in the promotion of urban bicycles and have produced various types of urban bicycles. However, urban bicycles users are a large number of non-professional consumers who do not have a strong demand for the functionality of bicycles. Instead, they are more concerned with the user experience and appearance of urban bicycles. Therefore, designers should try their best to meet the potential psychological needs of consumers and shift the focus of design to the appearance

design of urban bicycles. Among the components of the bicycle, the wheel, the handle, the frame, the seat cushion and crank affect the consumer's preference for the bicycle(Hsiao & Ko,2013), wherein the wheel set can be regarded as one of important components in the bicycle appearance due to its large area.

More and more urban residents tend to use urban bicycles in the world. Scholars such as Murphy and Usher (2015) conducted a questionnaire survey on the use of urban bicycles by Irish citizens. In 360 valid questionnaires, urban bicycles were accepted by middle and high income people. Shaheen, Zhang, Martin, and Guzman (2011) surveyed 806 citizens in Hangzhou, and 30% of them said that they would include cycling shared bicycles in their transportation mode. According to a survey by Chinese scholar Zhu (2018), the official website statistics of Mobike show that as of June 2017, Mobike shared more than 100 million registered bicycle users, with a market volume of more than 5 million vehicles and covering more than 100 cities. What's more, according to public data, the number of bicycles in Beijing has reached 200,000, and the total number of shared bicycles in Shanghai has exceeded 360,000. The shared bicycles in Guangzhou and Shenzhen are not to be underestimated, with nearly 200,000 and 320,000 respectively. The penetration rates reached 1.5%, 0.9%, 1.4%, and 2.8%, respectively (Li,2017).

Urban bicycles have many brands, of which only a dozen shared in the Chinese market, which are differences between the wheel types of each brand. Different types of wheels for the design of urban bicycles will bring different psychological feelings for customers, which in turn will affect their preferences in subjective shape of urban bicycles. In the development and design stage of new products, designers usually rely on their own accumulation of aesthetic perception and experiences. Although the designer can interpret the shape, color or material in the design expression, consumers still have different feelings in their mind, and the feelings would affects the consumer's judgment on product preferences. Therefore, if we can conduct an investigation and analysis of the different visual psychological feelings of different types of wheels and people by objective research methods, and explore the user's visual image evaluation of various wheels. On the one hand, it will help to narrow the gap in the perception of wheel types for designers and users. On the other hand, it can also improve the design benefits of urban bicycles, and provide the help for related businesses, designers and consumers.

As for the study of vision and imagery, Arnheim (1969), a well-known American aesthetic intuition psychologist, the late representative of Gestalt psychology clearly pointed out: "Vision is a very active form of feeling", "A positive choice is a basic feature of vision, just as it is the basic feature of other sensible things." Zhang (1986), a professor of Chinese psychology, in his book "Feeling Psychology" edited in the 1940s, pointed out: "Vision is the most powerful in all human feelings, followed by hearing." The scope of the world is limitless, and the world culture and progress depend more on vision." Regarding the interpretation of imagery, Peng (2000) believes that imagery is a symbol or representation, representing a certain object or event, and the information that is transmitted has distinct perceptual characteristics. Del Bimbo, Pala, and Santini(1994) pointed out that the image is obtained through the similarity between the imagination of the shape of the object and the sketch drawn by the user. Therefore, the complexity of the shape of the object that the user feels is in fact impossible to define it accurately by numbers.

Regarding the related research on bicycle shape design, Pan and Lei (2017) takes the Mobike as an example, and clearly defines the bicycle design oriented by "shape and

innovation", which will be well received by the market. Hsiao and Ko (2013) proposed an evaluation model for product shape. Through this evaluation model, consumers' preference for bicycle components can be obtained. The questionnaire survey results of 89 subjects show the importance of five evaluation items, namely: "handlebar", "saddle", "frame", "wheel set" and "chainwheel set and crank", Although the wheelset is of the least importance in this study, its area is the largest among all components, which deserves further study. This research is aimed at the Chinese market. In comparison, the type of the research sample is richer and modern with more design. Therefore, it is necessary to further study the influence of the wheel set on the appearance of the bicycle. Lin, Ho, and Xia (2018) focuses on the frame image of shared bicycles in Hangzhou, and evaluates and classifies various frame types through semantic difference method and factor analysis to ensure reasonable allocation and use of shared bicycles in Hangzhou. Hsiao, Chen, and Leng (2015) proposed a method for measuring the comfort of riding, and applied it to the design of bicycles, which can help consumers of different heights to choose the suitable bicycles. Due to the differences in the wheel types of different brands of urban bicycles, this research mainly focuses on the wheel types of urban bicycles, trying to explore the influence of different types of wheels on the visual image of bicycles. The research not only help consumers to purchase bicycles with their aesthetic needs, but also help designers to choose the wheel type that suits different styles in the development phase of new bicycles.

In summary, the average consumer has different sensory values for different wheel types. Therefore, the research aims to investigate and analyze different wheel types and different visual psychological feelings of consumers through objective research methods. The influence of the pattern on the visual image of urban bicycles is analyzed by appropriate image adjectives to compare the visual images of different wheel types. Next, the fuzzy number calculation method in fuzzy theory is used to analyze the visual image evaluation of various wheels. Finally, the research results are supposed to be reference for relevant operators, designers and consumers.

2 Materials and methods

2.1 Research framework

This research takes the shape of urban bicycle wheels as the research object. The main research process is shown in Figure 1. First, collect adjectives related to the visual imagery of the wheel type. Urban bicycles are still a hot topic in Chinese society today. The research on various components of bicycles has accumulated many achievements. Some scholars have studied the visual image of bicycle frames. Therefore, this study refers to relevant paper research and product design related information (for example Shared bicycle official website) and related news networks (such as Tencent News and Today's headlines) as the main source of the collection of words. Finally, the adjectives suitable for expressing the image of bicycle wheel type are selected, and 110 adjectives are summarized and used as the consumer survey questionnaire of this study.

At the meanwhile, different types of wheels were collected as research samples. Through market research, we found that there are many types of bicycles in the city. In order to ensure the rigor and objectivity of the research, we chose urban bicycles with high market share at home as research samples, and comprehensively considered the relevant data of their users' registration and service. After sorting out the statistics, it was decided to take the top 10 types of wheels of the market share as the research samples and randomly number

them, as shown in Table 1.

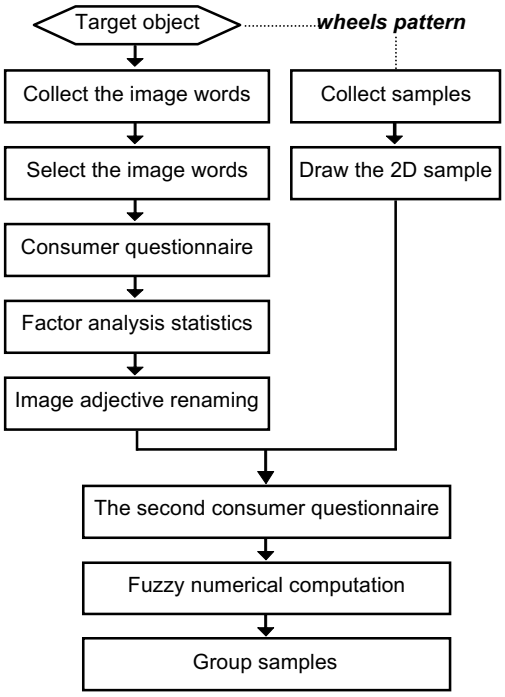


Figure 1. Research flowchart.

The research selects the image word by expert questionnaires, and invites 10 designers and college teachers related to product design as the subjects. Subjects are asked to subjectively screen out 40 to 50 adjectives that best fit the wheel image in the 110 image vocabulary provided by the questionnaire, and then sort out the top 40 adjectives with the highest number of scores in a number-average manner. Used as a follow-up study.

In order to further reduce the number of adjectives, the 40 adjectives obtained from the expert questionnaire were used to conduct a questionnaire survey on the semantic differences of urban bicycle consumers through the Likert Five-Point Scale Questionnaire. Factor analysis was conducted on the questionnaire survey data using SPSS, and then renaming each group of adjectives. The five grades in the scale included “very unsuitable”, “unsuitable”, “ordinary”, “suitable” and “very suitable”, and a total of 104 valid questionnaire samples (47 males, 57 females) were obtained.

According to Table 1, 10 types of urban bicycle wheel images were collected, and 2D images were drawn by Photoshop plane drawing software. As shown in Figure 2, the second consumer questionnaire was conducted with the renamed wheel type visual image adjectives survey. The frame, handlebar, saddle and crank image samples used in the questionnaire were selected according to the principle of simplicity. During the questionnaire survey, the subject used the finger to slide the screen left and right to replace the different types of wheels, as shown in Figure 3. Then the questionnaire results are numerically calculated by fuzzy theory, and then the graphs are drawn with various values for further comparative analysis.

Table 1 The numbers of the 10 species of bicycle wheel type.

No.	Name of Urban bicycle	Code	No.	Name of Urban bicycle	Code
1	Xiaoming	XM	1	Other 1	OT_1
2	Mobike	MB	2	Hellobike 2	HB_2
3	Hellobike 1	HB_1	3	Other 2	OT_2
4	Ofo	OF	4	Bluegogo	BG
5	Youon	YH	5	Other 3	OT_3

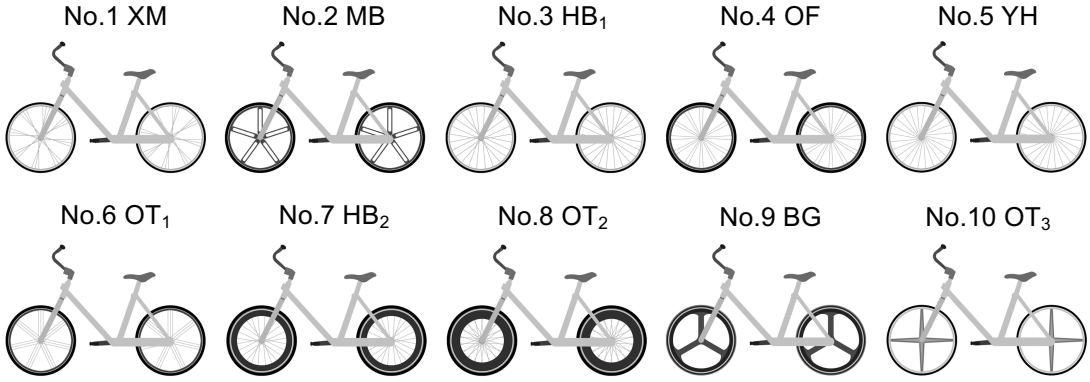


Figure 2. The 2D pictures of the 10 species of bicycle wheel type.

Figure 3. The survey of examinees on the virtual images of Mobike (MB).

2.2 Factor analysis

Factor analysis is generally used to simplify complex data (Kline,2014), a method to quantitatively determine the direction and extent of influence of various factors on analytical indicators (Brown, Cash, & Mikulka,1990). Brown defines factor analysis as "a statistical method for determining how many factors are needed to explain the association between a set of variances. One factor is the combination of multiple associated variables, so the same characteristics can be measured "(Brown,1983). In other words, factor analysis can use less dimension to represent the original data structure and retain most of the information that the original data can provide. Hu and Liao (2010) integrated factor analysis and two-step cluster analysis to explore the user's evaluation of product style, confirming that factor analysis is an objective and effective research method. Therefore, this method is still used in this study.

2.3 Fuzzy logic

Fuzzy theory is a scientific method used to study and deal with fuzzy phenomena. Fuzzy theory has published for more than 50 years since it was first proposed. L.A. Zadeh, a professor at the University of California, Berkeley, proposed in 1965. It was often used to deal with inaccurate (inexact) fuzzy data, in the fuzzy environment through the rigorous mathematical calculations to solve the problem of decision-making (Zadeh,1965). Zadeh believes that human subjective thoughts, reasoning and perception of things around him have a certain degree of ambiguity in nature, so it is necessary to use fuzzy logical concepts

to describe the merits of things in order to make up for the past traditional set theory. Binary logic is used to describe the shortcomings of things, and to expand the relationship between elements and sets in traditional set theory. The membership function is used to represent the relationship between elements and sets (Zadeh,1975).

Fuzzy theory is applied to the measurement of semantic meaning. Fuzzy numbers usually expresses the method. The fuzzy numbers often used in research have the following types: Triangular fuzzy number, Trapezoidal fuzzy number, and Normal fuzzy number, among which triangular fuzzy number is the most common. The particularity of a triangular fuzzy number lies in its membership function, and the distribution of its possibilities is to form a triangle (Dubois & Prade,1978). Suppose $\tilde{t}$ is a triangular fuzzy number in function $\mu_{\tilde{t}}(x)$, expressed as $\tilde{t} = (t_1, t_2, t_3)$, when t_1 , t_2 and t_3 are real numbers and $t_1 \leq t_2 \leq t_3$. In related research, Hsiao and Tsai (2005) integrated triangular fuzzy numbers, neural networks and genetic algorithms to propose a method that can be used to automatically generate product shapes and evaluate product imagery. Chen, Lee, and Lin (2014) used the triangular fuzzy numbers in fuzzy theory to obtain the scores of 12 kinds of wooden floors in 6 sets of visual image adjectives. Wang et al. (2017) believes that in many practical applications, it is often difficult to evaluate the failure efficiency of events that have occurred in the past. A new fault tree analysis method based on triangular fuzzy numbers is proposed to evaluate the failure efficiency of past events more efficiently.

This research uses the evaluation of semantic variables to help consumers express their judgments, so as to determine the order of the importance of user needs and wheel type sample selection. As shown in Table 2, the seven levels of semantic variables are: (1) Very Low (2) Low (3) Medium Low (4) Medium (5) Medium High (6) High (7) Very High. For the entire semantic scale, if the semantic variable is represented by its corresponding triangular fuzzy value, as shown in Figure 4, the triangular fuzzy number can be used to describe the relationship between potential traits and semantic terms.

Table 2 Linguistic variables for the importance and the ratings.

Linguistic variables	Triangular fuzzy numbers
Very low(VL)	(0,0,1)
Low(L)	(0,1,3)
Medium low(ML)	(1,3,5)
Medium(M)	(3,5,7)
Medium high(MH)	(5,7,9)
High(H)	(7,9,10)
Very high(VH)	(9,10,10)

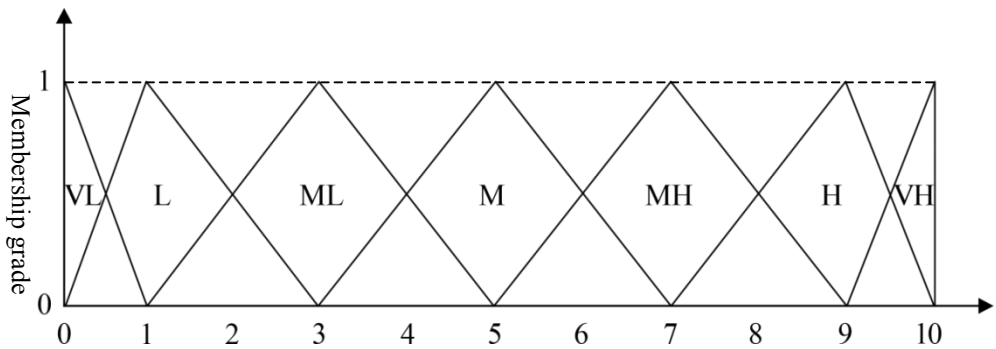


Figure 4. Membership functions of triangular fuzzy numbers.

2.4 Total utility value on triangular fuzzy numbers

In order to facilitate further comparison and analysis, the triangular fuzzy number in the membership function can convert into a crisp value by using the defuzzification, and the method used in the defuzzification is more commonly used "center of gravity", "maximum degree of membership" and "maximum set and minimum set method", among which "maximum set and minimum set method" are most commonly used. This study uses maximizing set and minimizing set method, which is used to calculate the weight of two triangular fuzzy numbers, and further derives the calculation method of returning the triangular fuzzy number to the total utility value. The absolute utility value used to calculate the fuzzy number is as follows:

Suppose that there are n triangular fuzzy numbers in the membership function of the triangular fuzzy number, which is defined as $\tilde{t}_i = (t_{i1}, t_{i2}, t_{i3})$, i=1, 2, ..., n, so it can be concluded that the minimum membership function $\mu_G(x)$ and the maximum membership function $\mu_M(x)$ are G and M, respectively. thus, the total utility value formula, that is, $U_T(\tilde{t}_i)$, of triangular fuzzy number $\tilde{t}_i$ is shown in Equation (1):

$$U_T(\tilde{t}_i) = \left[(t_{i3} - X_{\min})/((X_{\max} - X_{\min}) + (t_{i3} - t_{i2})) + 1 - (X_{\max} - t_{i1})/((X_{\max} - X_{\min}) + (t_{i2} - t_{i1}))\right]/2, i = 1,2,...,n \quad (1)$$

This research based on a questionnaire survey designed by fuzzy semantics theory to understand the consumer's visual image evaluation of 10 wheel types. The results are calculated by the numerical formula of the above fuzzy theory to calculate the visual image of each type of wheel. After the absolute utility value, the chart is drawn with various values, and the visual image of the 10 wheel types is further analyzed. The results can provide reference for the city bicycle related industry and consumers, in order to get the most suitable consumer demand.

3 Results and discussion

The 40 adjectives with the T test applied to the first factor analysis. After the principal component analysis, the first 16 adjectives whose absolute value of factor loading is greater than 0.6 are taken and the result of factor loading analysis is shown in Table 3.

Table 3 The 16 adjectives whose absolute values of factor loading were rank in the front.

Adjectives	Initial	Extraction	Adjectives	Initial	Extraction
Trimmed	1.000	0.769	Presentable	1.000	0.800
Regular	1.000	0.728	Rhythmic	1.000	0.834
Stable	1.000	0.723	Metrical	1.000	0.821
Interesting	1.000	0.785	Novel	1.000	0.747
Mechanical	1.000	0.729	Balanced	1.000	0.799
Ordered	1.000	0.849	Holistic	1.000	0.605
Individualized	1.000	0.774	Secure	1.000	0.771
Superior	1.000	0.740	symmetrical	1.000	0.689

The results of KMO and Bartliett tests after factor analysis showed that the KMO value was 0.735, indicating the datum was suitable; and Bartliett’s spherical test value was 633.345 (degree of freedom 136), which was significant, representing a common factor among the matrices of the parent population.

The total variation of Table 4 shows that the eigenvalue of six factors were greater than 1, and the total variance explained was 76.008%, as shown by the transform matrix in Table 5. It is very clear that no other factor components are covered; therefore, 16 adjectives (such as Table 5) and 6 components (such as Table 4) of this factor analysis will be used in the follow-up.

Table 4 Total variance explained.

Factor of component	Initial eigenvalues			Squares loading extraction			Transformed squares loading		
	Total	Variance (%)	Accumulative (%)	Total	Variance (%)	Accumulative (%)	Total	Variance (%)	Accumulative (%)
1	4.831	30.195	30.195	4.831	30.195	30.195	2.2642.198	14.152	14.152
2	2.062	12.886	43.081	2.062	12.886	43.081	2.1751.985	13.735	27.887
3	1.509	9.431	52.512	1.509	9.431	52.512	1.9841.556	13.593	41.480
4	1.329	8.304	60.816	1.329	8.304	60.816	2.2642.198	12.406	53.886
5	1.307	8.166	68.981	1.307	8.166	68.981	2.1751.985	12.398	66.284
6	1.124	7.026	76.008	1.124	7.026	76.008	1.9841.556	9.724	76.008

Table 5 Transformed component matrixes.

Adjectives	Component					
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Presentable	0.794	-0.022	0.088	0.013	0.388	0.100
Secure	0.789	0.290	0.171	-0.114	-0.011	0.151
Superior	0.675	0.194	0.345	0.317	0.005	-0.163
Balanced	-0.034	0.778	0.230	0.137	0.314	0.148
symmetrical	0.131	0.769	-0.002	0.118	0.244	0.080
Holistic	0.231	0.726	0.075	0.095	-0.089	0.040
Interesting	0.076	0.069	0.818	0.184	0.240	-0.114
Individualized	0.133	0.030	0.789	-0.099	0.073	0.344
Novel	0.406	0.233	0.713	0.016	-0.068	0.117
Trimmed	-0.023	0.356	0.131	0.790	-0.013	-0.003
Regular	-0.135	0.065	-0.110	0.753	0.269	0.233
Stable	0.446	-0.022	0.110	0.700	0.047	0.136
Metrical	-0.002	0.123	0.139	0.227	0.855	0.060
Rhythmic	0.253	0.196	0.068	-0.011	0.852	0.031
Ordered	0.035	0.324	-0.054	0.098	0.236	0.822
Mechanical	0.110	-0.036	0.304	0.206	-0.106	0.755

3.1 Renaming results of factor analysis

In this research, we first obtain a description of the word vocabulary suitable for the evaluation of wheel type visual image, a total of 110 adjectives, so factor analysis was applied to select adjective groups, which included 16 adjectives and six factors. Therefore, at this stage, the factors are renamed through the association of the words in the various factor groups. The results are shown in Table 6, There are six adjective phrases, including Superior and Presentable, Holistic and Balanced, Novel and Individualized, Trimmed and Stable, Rhythmic and Metrical, and Mechanical and Ordered for the following consumers questionnaire survey on the visual evaluation of the 10 types of wheels.

3.2 Evaluation of visual images for wheel type

The 10 wheel types of urban bicycle in Table 1 were collected. Combining with the aforementioned six visual image adjective phrases, the triangular fuzzy number scale, in Table 2 were applied to the scale questionnaire design, and a questionnaire survey for consumers' visual evaluations of the 10 types of wheels was conducted. The seven-level scales are Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium High (MH),

High (H) and Very High (VH). The questionnaires were collected through the above seven evaluation levels, and the corresponding scores were obtained based on the triangular fuzzy numbers. As a result, 90 valid samples were obtained, and the subjects (male 50, female 40) were 20-40 years old, and urban bicycles were often used in daily life. The mean scores of visual evaluations of each wheel type are listed in Table 7 by fuzzy numerical computation. The visual evaluations of those wheel types were then sorted and diagrams were plotted by triangular fuzzy numbers, as shown in Figure 5.

Table 6 Factor renaming list.

Factor	Adjective groups	Factor naming	Code
Factor 1	Presentable; secure; superior	Superior and Presentable	S&P
Factor 2	Balanced; symmetrical; holistic	Holistic and Balanced	H&B
Factor 3	Interesting; individualized; novel	Novel and Individualized	N&I
Factor 4	Trimmed; regular; stable	Trimmed and Stable	T&S
Factor 5	Metrical; rhythmic	Rhythmic and Metrical	R&M
Factor 6	Ordered; mechanical	Mechanical and Ordered	M&O

Table 7 The sequence and means of the visual evaluations of the species of wheel type.

Wheel species	Superior and Presentable	Holistic and Balanced	Novel and Individualized	Trimmed and Stable	Rhythmic and Metrical	Mechanical and Ordered
XM	(4.0 5.9 7.6)	(3.9 5.9 7.7)	(3.9 5.8 7.5)	(3.4 5.3 7.1)	(4.5 6.4 8.1)	(4.4 6.3 8.0)
MB	(4.9 6.8 8.4)	(4.9 6.8 8.4)	(4.9 6.8 8.4)	(4.9 6.8 8.4)	(4.8 6.7 8.3)	(4.7 6.6 8.3)
HB1	(3.8 5.6 7.3)	(4.5 6.4 8.1)	(4.3 6.1 7.9)	(2.9 4.6 6.4)	(4.0 5.9 7.6)	(4.2 6.1 7.9)
OF	(4.4 6.4 8.2)	(4.9 6.8 8.5)	(4.6 6.6 8.3)	(3.8 5.7 7.5)	(4.5 6.4 8.2)	(4.2 6.2 8.0)
YH	(4.2 6.1 7.8)	(4.5 6.4 8.0)	(4.2 6.1 7.8)	(4.1 6.0 7.8)	(4.7 6.6 8.2)	(4.4 6.3 8.1)
OT1	(4.5 6.4 8.1)	(4.7 6.6 8.3)	(4.3 6.3 8.0)	(4.8 6.7 8.3)	(4.6 6.5 8.2)	(4.2 6.1 7.9)
HB2	(3.1 4.8 6.6)	(3.2 5.0 6.8)	(4.0 5.9 7.5)	(4.2 6.1 7.8)	(3.4 5.3 7.1)	(3.4 5.2 7.0)
OT2	(3.1 4.9 6.6)	(3.5 5.2 6.9)	(3.9 5.7 7.4)	(4.1 5.9 7.5)	(3.4 5.3 7.0)	(3.7 5.5 7.2)
BG	(4.9 6.7 8.4)	(4.7 6.5 8.1)	(5.1 7.0 8.5)	(5.5 7.2 8.5)	(4.9 6.7 8.3)	(4.7 6.5 8.1)
OT3	(4.0 5.7 7.4)	(3.6 5.4 7.1)	(3.4 5.1 7.0)	(4.8 6.6 8.0)	(3.9 5.7 7.5)	(3.6 5.4 7.2)

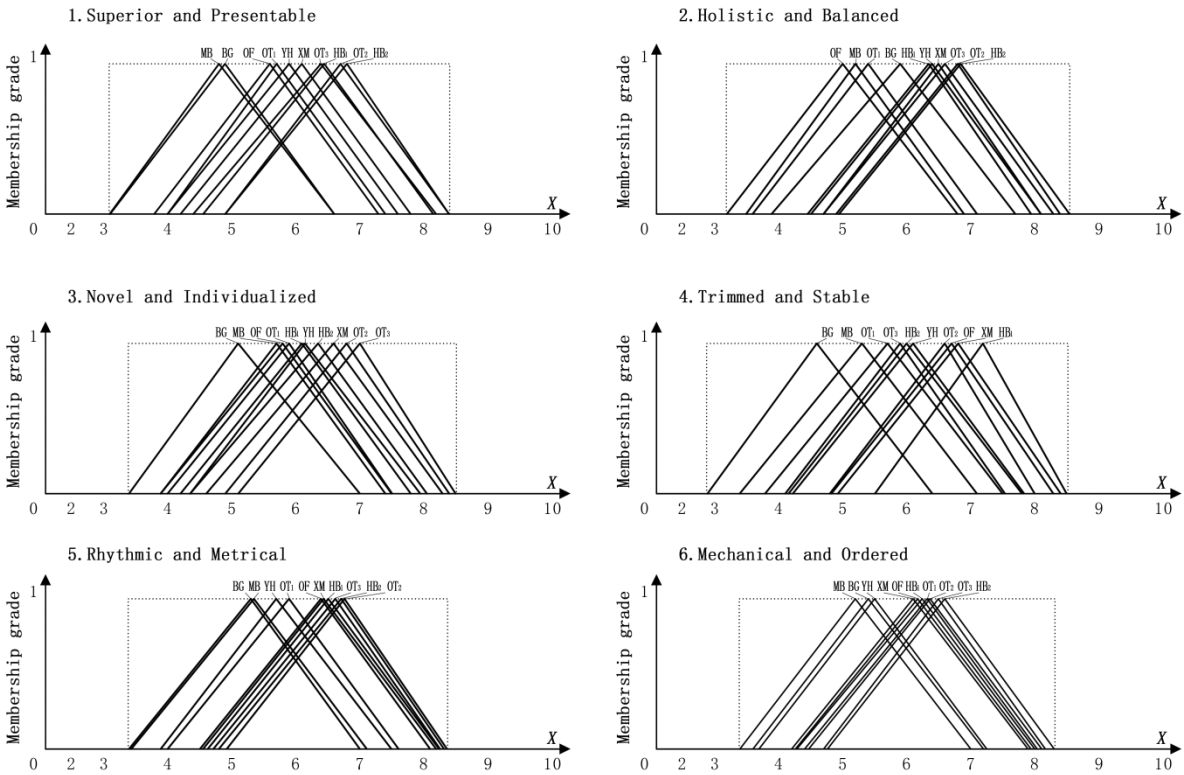
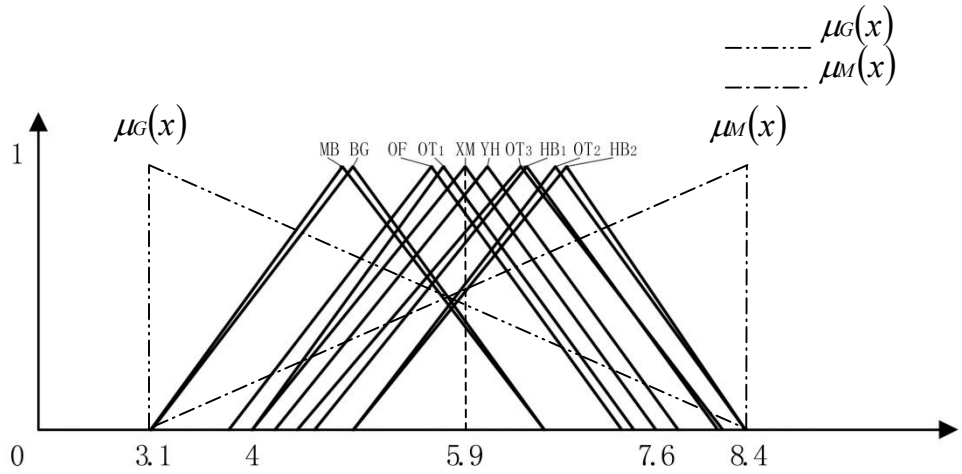


Figure 5. The triangular fuzzy numbers of the 10 species of wheel type in each visual evaluation. All abbreviations for wheel type species are referred to Table 1.

The triangular fuzzy numbers of each visual evaluations of 10 wheel types were converted into the absolute utility value of evaluation. Based on the data in Table 7 and Figure 6, the absolute utility value formula of the triangular fuzzy number $\tilde{t}_i$ is used. The abbreviation of the wheel name is shown in Table 1. For example, the calculation of sample 1 (XM) in the visual evaluation of "Superior and Presentable" is as follows:

$$U_T(\tilde{t}_i) = [(t_{i3} - X_{\min})/((X_{\max} - X_{\min}) + (t_{i3} - t_{i2})) + 1 - (X_{\max} - t_{i1})/((X_{\max} - X_{\min}) + (t_{i2} - t_{i1}))]/2, i = 1,2,\ldots,n \quad (1)$$

Incorporate $\tilde{t}_1 = (4.0, 5.9, 7.6)$, $X_{\max} = 8.4$, $X_{\min} = 3.1$ into Equation (1) to calculate $U_T(\tilde{t}_1)$, the result is：



$$U_T(\tilde{t}_1) = [(7.6 - 3.1)/((8.4 - 3.1) + (7.6 - 5.9)) + 1 - (8.4 - 4)/((8.4 - 3.1) + (5.9 - 4))]/2 = 0.4240$$

Figure 6. The triangular fuzzy numbers of the 10 species of wheel type in the visual evaluation of "Superior and Presentable". Abbreviations for wheel type species are referred to Table 1.

The total utility values of the visual evaluations of 10 wheel types after calculation are shown in Table 8.

Table 8 The visual evaluation values of 10 species of wheel type.

Superior and Presentable	Holistic and Balanced	Novel and Individualized	Trimmed and Stable	Rhythmic and Metrical	Mechanical and Ordered	Superior and Presentable
XM	0.4240	0.5018	0.4729	0.4002	0.5766	0.5617
MB	0.6410*	0.6268*	0.6160	0.6419*	0.6196	0.6065*
HB1	0.4761	0.5722	0.5217	0.3529	0.5020	0.5344
OF	0.5852	0.5591	0.5856	0.4975	0.5788	0.5462
YH	0.5440	0.5700	0.5164	0.5377	0.6045	0.5640
OT1	0.5863	0.6004	0.5425	0.6163	0.5916	0.5344
HB2	0.3679	0.3803	0.4845	0.5489	0.4158	0.4030
OT2	0.3732	0.4071	0.4608	0.5221	0.4124	0.4446
BG	0.6321	0.5875	0.6435*	0.6279	0.6232*	0.5929
OT3	0.5000	0.4335	0.3821	0.6143	0.4776	0.4328

** highest scores of species in each evaluation factor For abbreviations of visual images, refer to Table 1.*

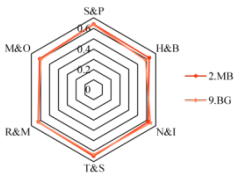
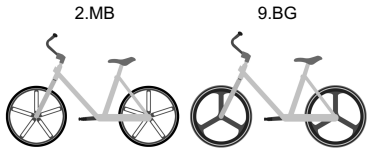
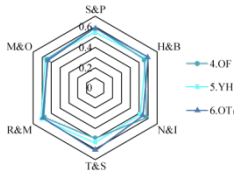
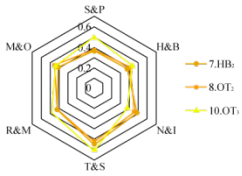
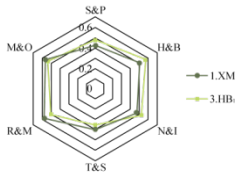
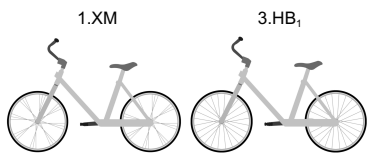
The above results showed:

Figure 5 shows that the visual evaluations of different wheel types of urban bicycle has less extent of difference in trimmed and stable, superior and presentable, and holistic and

balanced. However, the extents of difference were greater in novel and individualized, rhythmic and metrical, and mechanical and ordered. In Figure 8, the Mobye(MB) wheel type has high scores, and the four evaluations of “superior and presentable”, “holistic and balanced”, “trimmed and stable” and “mechanical and ordered” are the highest. In addition, the Bluegogo(BG) wheel type receiving the highest scores in "novel and individualized" and "rhythmic and metrical".

The scores of the visual evaluations of the 10 wheel types of urban bicycle were further applied to the creation of radar charts for the comprehensive comparison of wheel type. By qualitative classification, four groups with relative visual evaluations were summarized. The results are shown in Figure 9: (a) The overall visual image of MB and BG is similar, and the scores are higher in various visual image evaluations. (b) The overall visual images of OF, YH and OT_1 are similar, and the scores are in the second highest group in the visual image evaluations. (c) HB, OT_2 and OT_3 have similar overall visual images, and are more "superior and presentable" and "trimmed and stable". (d) The visual images of XM and HB_1 are similar, and they are more "mechanical and ordered", "rhythmic and metrical", "novel and individualized", and "trimmed and stable". The detailed visual characteristics of the four groups are described in Table 9.

Table 9 The six wheel type groups, respectively, with similar comprehensive visual evaluations.

Group	Radar chart	Wheel Type Species	Visual characteristics
1			The absolute utility values of MB and BG in the six vocabulary groups are in the first group. The number of spokes is small and the width of each spoke is thick.
2			The absolute utility values of OF, YH and OT_1 in the six vocabulary groups are in the second group. The number of spokes is very large, and the layout is uniform and changes regularly.
3			They are biased towards "superior and presentable" and "holistic and balanced". The rims of HB_2 and OT_2 are wider, and the spokes are regularly arranged in an interlaced manner. The OT_3 has a total of four spokes , narrow near the rim.
4			They are biased towards "mechanical and order", "rhythmic and metrical", "novel and individualized" and "holistic and balanced". The number of spokes is large, the layout is uniform, and they are arranged in a regular pattern.

4 Conclusions

This study integrates expert questionnaire survey, factor analysis and fuzzy theory into the research of visual image of wheel types in the urban bicycles. The accuracy of image vocabulary selection affects the authenticity and objectivity of this study. Therefore, this study firstly screens a large number of vocabulary words by means of expert questionnaires, and then reduces the quantity of adjectives through factor analysis. Factor analysis is an objective and effective method for the selection of visual image adjectives. It can quickly reduce the number of adjectives of wheel type, which greatly simplifies the questionnaire between 2D wheel type and visual images. In addition, the semantic variable scale of fuzzy theory is suitable for the measurement and statistics of psychological sensory values. The fuzzy number can obtain accurate absolute utility value after appropriate defuzzification, which is convenient for comparative analysis of the results. However, there are many ways of statistical analysis of psychological sensory values, such as a quantitative- Itheory, neural network, grey theory, rough set theory and support vector machine. Therefore, in view of the research of product image, appropriate research methods should be selected to ensure the scientific and rational research purposes.

The research results show that each type of wheel has its own unique visual image, and the different types of wheels have distinguished in trimmed and stable, superior and presentable, and holistic and balanced, while little differ in the novel and individualized, rhythmic and metrical, and mechanical and ordered. In addition, the overall visual imagery of some wheel types has similarities, for example, MB and BG of the first group, XM and HB_1 of the fourth group. Therefore, the overall visual images of some wheel types of urban bicycle in the same group are similar and replaceable in design and application.

The research results can be applied to the design service. Later, more different types of wheels can be collected or designed. Through the research method of this paper, the value of visual evaluations can be further obtained, so that a urban bicycle assisted design system can be established. On the contrary, because there are differences in life styles among different regional groups, the aesthetic needs preferences are also different. If designers accurately grasp the visual image preferences of urban residents, through the established auxiliary design system they can design the appearance of urban bicycle which is more in line with the psychological demands of consumers. In addition, the results of this study are also applicable to the design of urban electric bicycles. As for future research, we can further study the color visual image of the wheels.

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