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A User Biology Preference Prediction Model Based on the Perceptual Evaluations of Designers for Biologically Inspired Design

Shijian Luo [1], Yufei Zhang [1,*], Jie Zhang [2] and Junheng Xu [1]

[1] Department of Industrial Design, Zhejiang University, Hangzhou 310027, China; sjluo@zju.edu.cn (S.L.); junheng.xu@gmail.com (J.X.)

[2] School of Design, The Hong Kong Polytechnic University, Hong Kong, SAR; jpeter.zhang@connect.polyu.hk or peterzhang1130@163.com

* Correspondence: yufei_zhang@zju.edu.cn

Received: 19 September 2020; Accepted: 10 November 2020; Published: 12 November 2020

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Abstract: Biology provides a rich and novel source of inspiration for product design. An increasing number of industrial designers are gaining inspiration from nature, producing creative products by extracting, classifying, and reconstructing biological features. However, the current process of gaining biological inspiration is still limited by the prior knowledge and experience of designers, so it is necessary to investigate the designer's perception of biological features. Herein, we investigate designer perceptions of bionic object features based on Kansei engineering, achieving a highly comprehensive structured expression of biological features forming five dimensions—Overall Feeling, Ability and Trait, Color and Texture, Apparent Tactile Sensation, and Structural Features—using factor analysis. Further, producing creative design solutions with a biologically inspired design (BID) has a risk of failing to meet user preferences and market needs. A user preference prediction support tool may address this bottleneck. We examine user preference by questionnaire and explore its association with the perceptual evaluation of designers, obtaining a user preference prediction model by conducting multiple linear regression analysis. This provides a statistical model for identifying the relative weighting of the perception dimensions of each designer in the user preference for an animal, giving the degree of contribution to the user preference. The experiment results show that the dimension "Overall Feeling" of the designer perception is positively correlated with the "like" level of the user preference and negatively correlated with the "dislike" level of the user preference, indicating that this prediction model bridges the gap caused by the asymmetry between designers and users by matching the designer perception and user preference. To a certain extent, this research solves the problems associated with the cognitive limitations of designers and the differences between designers and users, facilitating the use of biological features in product design and thereby enhancing the market importance of BID schemes.

Keywords: biologically inspired design; designer perception; user preference; Kansei engineering

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1. Introduction

Inspiration is of great significance for designers. Previous research has shown that stimulation by different forms of inspiration is beneficial for increasing the creativity of designers [1]. Biology provides a rich and novel source of inspiration for product design and leads to product innovation [2]. There is a lot of symmetry in biology, as shown in Figure 1, and designers are inspired by these symmetries to design bionic products with symmetry, as shown in Figure 2. The influence of symmetry on visual aesthetics and design has been pointed out in the literature [3]; consequently, biology with symmetry are worth considering as sources of inspiration in product design.

Figure 1. Symmetry in animals.

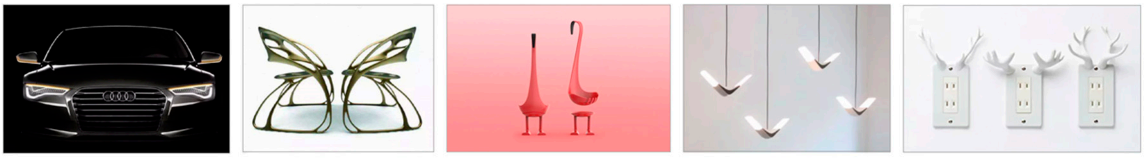


Figure 2. Symmetry in bionic products.

Currently, an increasing number of designers are gaining inspiration from nature—extracting, classifying, and reconstructing biological features according to the design mission and requirements—to produce creative products with a biological aura. To promote sustainable development in human society and the natural world, it is important to understand and learn from nature and become inspired by it, and performing biologically inspired design (BID) is a promising paradigm [4]. BID, also referred to in studies as biomimicry or bionics [5], is an innovative design method using the natural world as a source of inspiration to allow users to benefit from the charm of nature through bionic products [6]. In addition, bionic products can also stimulate the imagination of their users and generate a certain emotional resonance [7].

Most of the previous research on BID activities has focused on design methods and practices [8–16]. Design methods and practices can provide designers with relevant references to assist them in incorporating new alternatives into projects and exploring new procedures that will allow innovations. However, the methodology of BID is still primarily temporary and unplanned [5]. Thus, the research on BID is increasingly focused on the interpretation and transfer of biological features and the use of support tools to stimulate creative thinking in the design process, avoiding simple duplication of a source of inspiration [17–27]. Moreover, some studies have confirmed that the systematic study of biological features is meaningful: Cheong and Shu [28] found that biological phenomenon descriptions containing causal relations presented in text form are more likely to generate useful analogies to solve design problems. Salgueiredo et al. [26] found that mature and reliable BID requires knowledge from both biological and engineering fields to stimulate the conception of innovative solutions. However, current research mainly classifies biological features based on function–structure ontologies [29], which is adaptable for solution search [5] and based on the problem definition [17]. Most of these biological features are derived from the research and analysis conducted by experienced biological experts, which are relatively primitive and esoteric.

Based on the literature review, there is lack of studies on bionic object features from the perspective of designers and users to understand their perceptions and preferences. Most BID designers select bionic objects and their different characteristics based on their own experience, and new inspiration may originate from six aspects: form, structure, function, color, texture, and image [7]. However, designers have different experience and performance levels; the level of understanding of beginner designers can result in direct imitation, without necessarily a new inspiration [24]. In addition, it may cause the misinterpretation and misuse of biological features, owing to inadequate understanding.

As for user study, previous research has reported that designers and users have asymmetric responses to various design elements [30–33]. Designers choose a bionic object according to their own experiences, and it is easy to cause certain uncertainty in the design scheme, which cannot satisfy the user preference. Meanwhile, user preference is an important research direction [34] that has a positive market significance [35–39]. Simultaneously, the personalized needs of users are increasing, and researchers have reported asymmetry depending on socio-demographic characteristics such as area [40], age [41], gender [42], and culture [43]. In the following, some examples of bionic products are presented. As shown in Figure 3, three cars—from Chinese car brand Geely, Japanese car brand Mitsuoka, and German car brand Porsche—are respectively inspired by animals loved by local users (specifically, the Chinese national treasure, the panda; a large snake called Yamata-no-worochi in Japanese mythology; and the frog prince in the Grimm fairy tale of Germany).

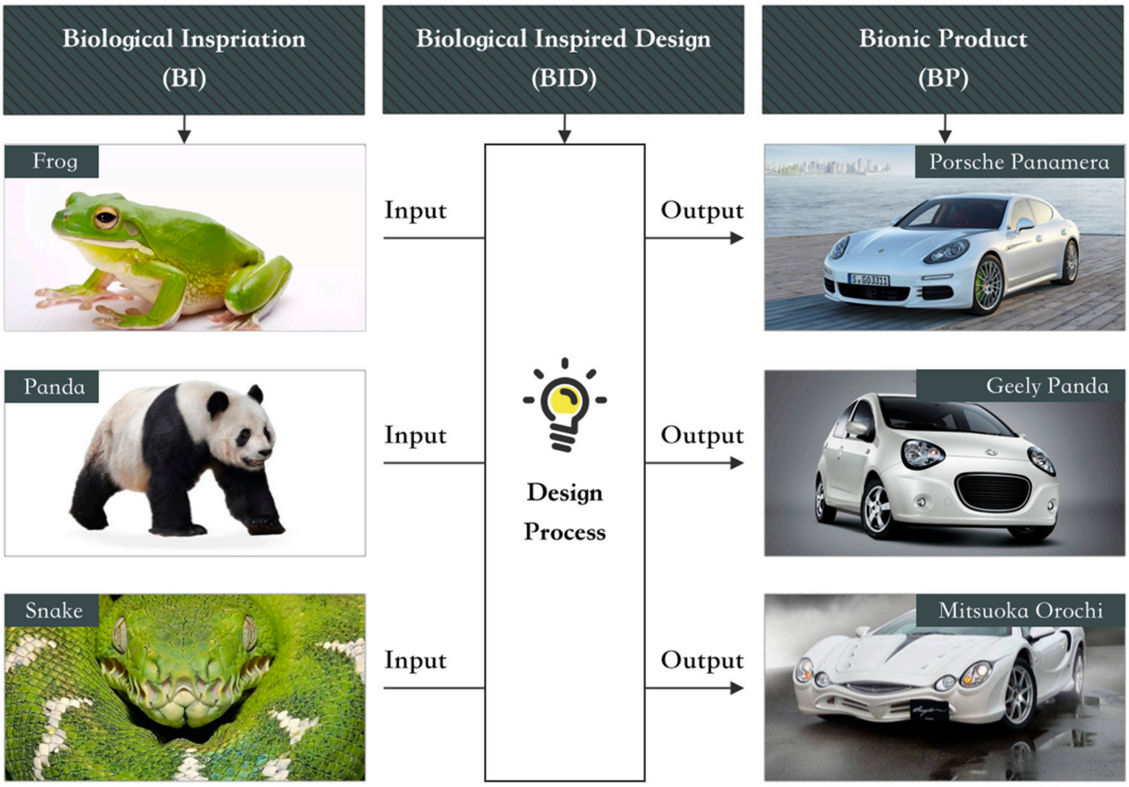


Figure 3. Bionic products inspired by biological inspiration from different countries.

User preference has a significant influence on the purchase decision of a user. If designers can learn about the trends of the differentiated preferences of users in advance, then the design can be targeted to meet the preferences of different groups, which will be of great significance for the success of the product [33,44]. However, user-centered approaches are increasingly time consuming and expensive with the number of participants [44–46]. For cost reduction, Mieczakowski et al. [47], Khalaj and Pedgley [48], and Renaud [44] proposed design reference models based on product form and function to predict user preference and user experience behavior. Marshall et al. [49] used personas and user datasets as tools for communicating user data to designers.

To create a successful BID and allow users to have the opportunity to experience nature through BID products, it is necessary to fully consider the perceptions and preferences of designers and users relating to bionic object features. In this study, we innovatively study biological features (using animals as a research case) from the perspective of designers and users: Through designer research, we obtain the designer's perceptual dimension of biological features and try to provide designers of different levels with structured biological knowledge; through user research of animals, we obtain the effective needs and preferences of users and apply them to design, trying to bridge the gap between designers and users, and avoid the uncertainty in the design scheme that occurs when designers choose bionics based on their own experience. To this end, we investigate the designer perception of bionic object features based on Kansei engineering, examine user preference, and explore its association with the perceptual evaluation of designers. Finally, we propose a user biology preference prediction model for biologically inspired design and attempt to predict the user preference trend in advance. This prediction model, as a tool for communicating quantitative user data to designers with no user involvement, provides an effective reference for cost savings in user research. This research was conducted to address the following three questions:

1. What is the designer perception of animals, and what dimensions of perception do designers take inspiration from?
2. What is the user preference for animals, and is there symmetry between male and female preference?
3. Is there a certain mapping between user preferences and the dimensions of designer perception mentioned above?

2. Materials and Methods

Herein, we studied designers' perception of animals and the dimensions of the perceptions which inspire designers. The exploratory factor analysis method was utilized to obtain the dimensions of designers' perception of animal features. Following this, we studied the user preference for animals, matched it with the multi-dimensional designer perception, explored their correlation, and obtained a predictive model of the user preference to quantify it.

2.1. Participants

To study designer perceptions and user preferences for animals, we invited two groups of people—BID designers and ordinary users—as participants.

1. Designers: These were participants in the first part of the procedure, which was a survey of designer perception. The 18 designers invited to participate in the interview were all from China, and they included 13 senior BID designers with more than 5 years of design experience and 5 junior BID designers with 1–3 years of design experience. The designer participants included 5 graphic designers (4 senior designers) and 13 industrial designers (9 senior designers). The 124 designers invited to participate in the questionnaire were from China. All designers had certain design experience with BID (79 males and 45 females). All designers who participated in the experiment received some compensation.
2. Users: These were participants in the second part of the procedure. A total of 345 people with consumption ability participated in the questionnaire survey of user preference, including 164 males and 181 females. They were all aware of the animal samples that would appear in the questionnaire and voluntarily participated in this survey.

2.2. Stimuli

Based on taxonomy, we selected 7 invertebrates and 19 vertebrates from the animal kingdom as samples and 3 invertebrates and 8 vertebrates from the animal kingdom as validation samples. These animals have symmetry in shape, structure, or texture. All the samples collected were of animals used as inspiration sources for BID in the current market, including the training (as shown in Figure 4) and testing (as shown in Figure 5) samples. Each sample was displayed as a picture, which was uniformly processed to have a white background by professional designers, avoiding the influence of environment or other irrelevant information in the image during the observation and enhancing the perceptions and preferences of the participants of the animal. Each picture showed the maximum possible different forms of the same animal.

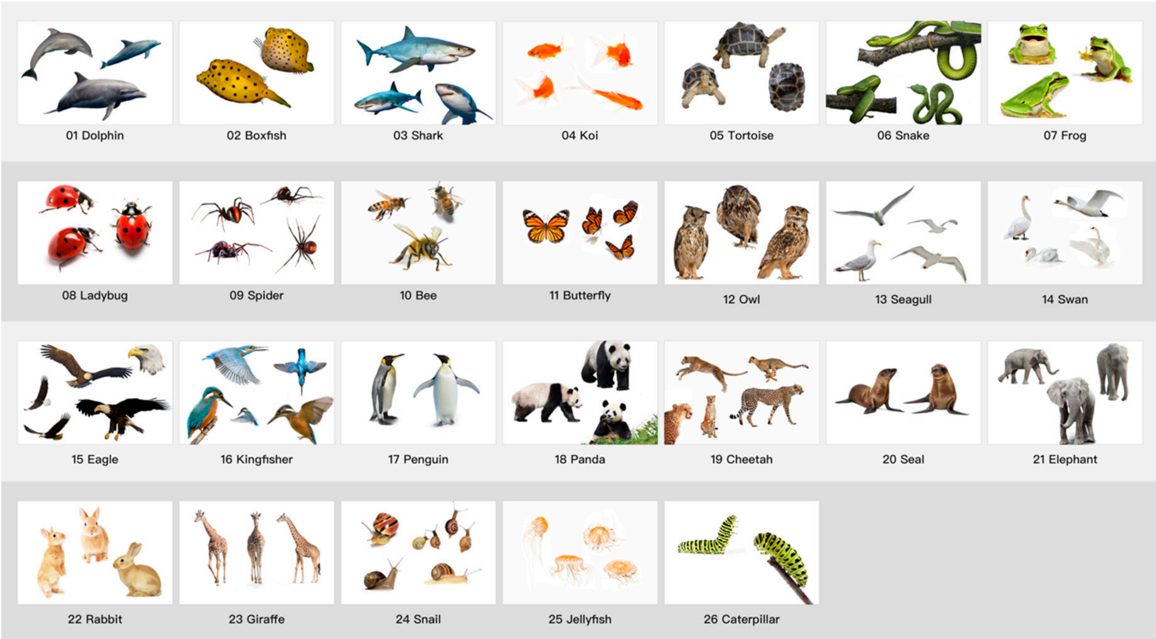


Figure 4. Animal samples for model establishment.

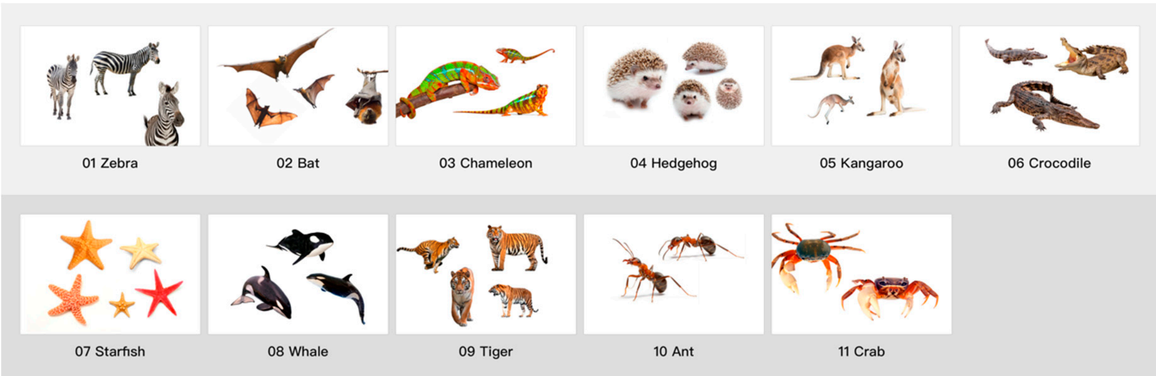


Figure 5. Animal samples for model validation.

2.3. Evaluation

Because our research object is biological inspiration, instead of specific products, we focused on designer perception to understand the dimensions from which biological inspiration will stimulate a designer and generate new thinking. Users do not directly feel the inspiration; they interact with the bionic product that is transformed, combined, and adapted from biological inspiration [50]. Therefore, we paid more attention to user preference for biological inspiration, to guide designers to a certain extent to perform user-centered design.

Therefore, this study comprised two parts: perceptual evaluation of designers and degree of user preference.

1. Designers.

In this step, we explored the interests and perceptions of designers by means of a 30-min interview to obtain perceptual descriptions from designers for 26 animal samples and perception items. The participants were required to sit in front of an experimental display cabinet at a certain distance and observe the animal samples sequentially according to the number. The participants described the animal features observed in short sentences based on their perceptions, recorded as R by an implementer, where R = {rm | m = 1, 2, . . . , M} and rm is the original sentence number, as material for the next experiment. The recorded descriptions, R, from the 13 senior designers were provided to a group of experts. According to the rules of semantics, the experts merged similar descriptions and deleted those with semantic ambiguities and low correlation to summarize a suitable set of perception items for this study, which were recorded as I, where $I = \{i_t \mid t = 1, 2, \ldots, T\}$.

From the interview step, a total of 365 original perceptual descriptions of animals were collected. Subsequently, a team of seven experts of BID collaborated to compress these descriptions from the designers using semantic rules. For example, the description of a perception, "This animal feels very secure and can depend on it, like a big brother" was rewritten as "This animal looks reliable." Following this compression activity, the final scale included 21 items, which are provided in Appendix A. The experts examined the initial model by evaluating the definition and wording of each item to ensure they represented relevant animal perception metrics [51].

Subsequently, the items, I, were mixed and converted into a questionnaire to study the perceptions of animals. The questionnaires were distributed to a certain number of designers, such that the sample size was ideally 5–10 times the number of items [52]. Designers were asked to observe 26 animal samples and score them on a seven-point scale in the questionnaire [53], with the anchor points ranging from "strongly disagree" to "strongly agree", according to their perceptions.

2. Users.

In this step, users were required to observe the 26 animal samples in the questionnaire and score their preferences for each animal. A seven-point scale with choice questions was employed to determine the extent of preference in this questionnaire, with the anchors ranging from "extremely dislike" to "extremely like."

3. Results and Discussion

3.1. Analysis of Designer Perceptions

3.1.1. Gender Variance Analysis

From the questionnaire survey in the first step, we obtained 107 valid questionnaires, the results of which are shown in Figure 6. To facilitate data display and define the dimensions of the designers' perceptions of the animals, all the descriptions were translated into Kansei words [54], e.g., "This animal looks reliable." was summarized as "reliable", and "This animal looks cute." was summarized as "cute".

In Figure 6, the mean values of the perceptions of the designers are displayed in the form of a heat map by block (i, j) of the ith perception items for the jth animal, where $i = 1, 2, \ldots, 21$ and $j = 1, 2, \ldots, 26$. Prior to the exploratory factor analysis, it was necessary to test whether there was a significant difference between the perceptions of males and females. Hence, an independent sample t-test was conducted to analyze the differences in the perceptions of different animals from the perspective of gender. Because these blocks account for only 11.7%, the results showed that differences in the gender of designers had no significant effect on perceptions of the animals listed, which indicates symmetry of designer perception between males and females.

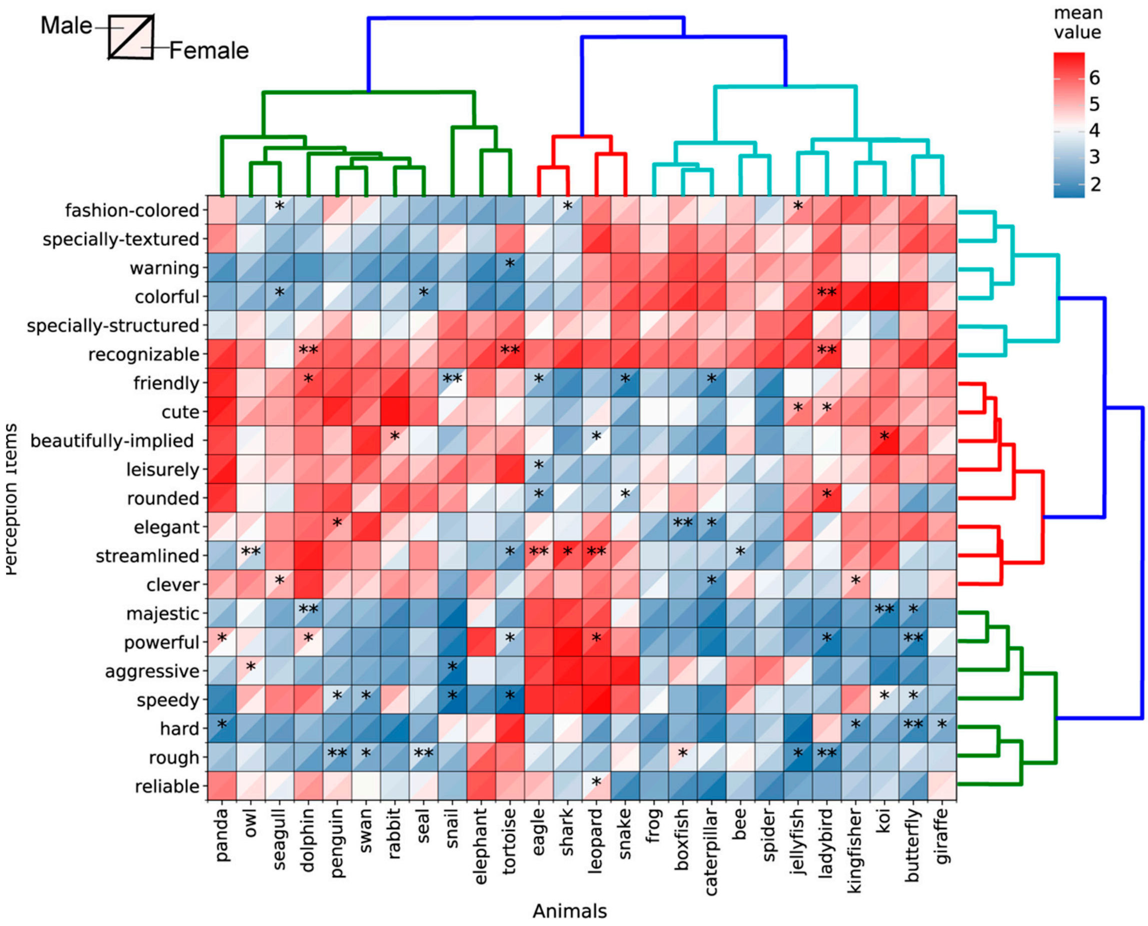


Figure 6. Gender variance analysis results of perception items. (Significant differences: p values of less than 0.05 are represented by blocks with "*", p values of less than 0.01 are represented by blocks with "**", and p values of less than 0.001 are represented by blocks with "***". A significant difference (p value less than 0.05) implies that in regard to animals, there is a significant difference between the perceptions of males and females).

3.1.2. Exploratory Factor Analysis

Although the user preference can be represented in a perceptual space where each Kansei word has an independent dimension, it is extremely complex to determine the relationship between the designer perception and the user preference in such a 21-dimensional semantic space. Moreover, there may be potential correlations between the semantic items [55–57]. Hence, in this study, a exploratory factor analysis (EFA) of the questionnaire results presented in Figure 6 was conducted to probe these potential correlations and examine the factor structure of the 21-item instrument. The results of the KMO (Kaiser-Meyer-Olkin) and Bartlett's test showed that the correlation coefficient achieved a significance level of 0.82 (sig = 0.000), indicating that exploratory factor analysis could be performed.

The data provided by the questionnaires of the 107 participants were examined by principal component analysis as an extraction technique and using maximum variance rotation to better identify the factors. A total of five factors with eigenvalues exceeding 1 were extracted; these can summarize the dimensions of designer perceptions of biological features.

Figure 7 shows the resulting factor structure and component factor loadings. We focused on those with an absolute value of factor loading exceeding 0.5 [58], as shown in white to red, and removed two items with factor loadings below 0.5. Finally, there were 19 items in total. These items were distributed well among the five distinct factors, with corresponding explanatory variance percentages of 19%, 16%, 14%, 9%, and 8%. They collectively explained a variance percentage reaching 66%. According to the suggestion by Hair et al. [58], in social sciences, a method that accounts for 60% of the variance in a dataset is considered satisfactory. There were no items with a significant loading of 2 or more factors. The hypothesis that five components are sufficient was tested. The root mean square of the residuals (RMAR) was 0.06 with empirical chi square of 3712.8 with prob < 0. Rotating the EFA solution by the varimax criterion yields new components now named RC*i* (where $i = 1, 2, \ldots, 5$) to indicate that the Principal Components (PCs) have been rotated.

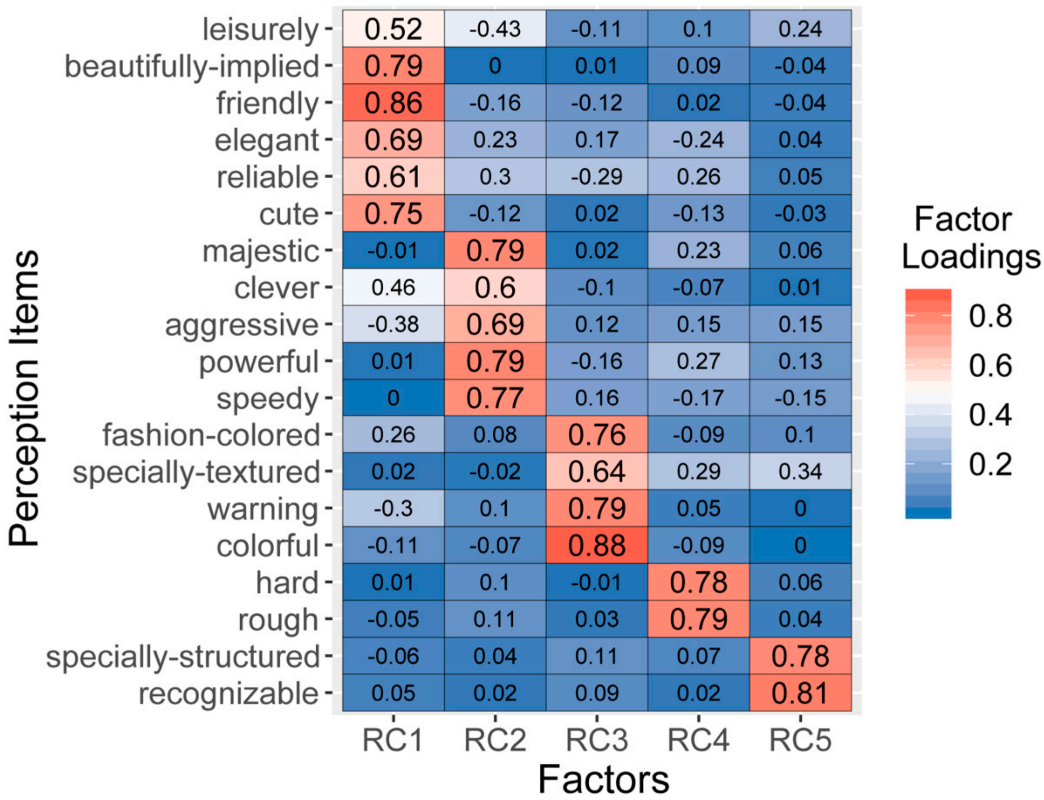


Figure 7. Exploratory factor analysis results of the perception items.

To ensure satisfactory reliability of this instrument, a reliability analysis was performed on the data, and the Cronbach's α value was determined to be 0.773; this shows high reliability according to the recommendations of DeVellis [59].

The content described by several items contained in the same common factor can be used to define this dimension; the induction process is shown in Figure 8, and based on the preceding analysis, the figure suggests that the designers' perceptions of the animals can be described by five potential dimensions. The first dimension of this model is RC1: Overall Feeling; it consists of the items "leisurely", "beautifully-implied", "friendly", "elegant", "reliable", and "cute". These dimensions characterize the temperament and disposition of an animal; they emphasize that the designers focus on the overall impression of an animal.

The second dimension of this model is RC2: Ability and Trait, and it comprises the items "majestic", "clever", "aggressive", "powerful", and "speedy". This dimension characterizes the ability and traits of an animal, such as cleverness, power, and speed. This dimension reveals that designers expect to project these distinctive abilities and traits into the design, to ensure that the product is unique.

The third dimension of this model is RC3: Color and Texture, and it involves the items "fashion-colored", "specially-textured", "warning", and "colorful". This dimension describes the perceptions evoked by the visual characteristics of the color and texture of an animal. This dimension reveals the strong visual perception introduced by distinct colors and textures.

The fourth dimension of this model is RC4: Apparent Tactile Sensation, and it incorporates items "hard" and "rough". This dimension presents the feeling of touch which the designers perceive on the basis of the animal's image.

The final dimension of this model is RC5: Structural Features, and it includes the items "specially structured" and "recognizable". This dimension claims that an unusual structure and a recognizable shape are beneficial for deepening the designer perception.

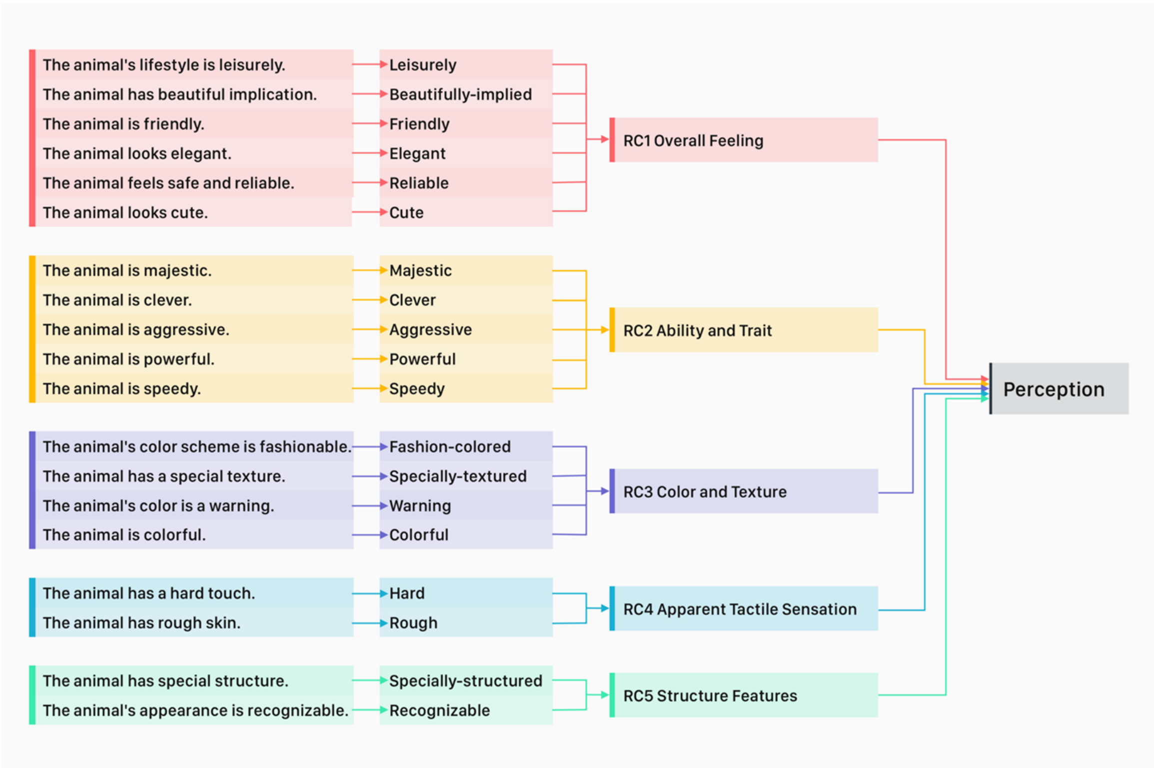


Figure 8. Illustration of the exploratory factor analysis results of designers' perception evaluations.

The interview demonstrates that senior designers can accurately describe animal characteristics with complete and positive sentences, develop effective biological inspiration, and even immediately provide preliminary creative solutions based on animal pictures under observation. In addition, the biological features described by the senior designers are rich and detailed, because they can perceive a complete picture, combined with prior knowledge to expand the association to tell more information than the picture conveys, such as for the parts of Overall Feeling and Ability and Trait listed in the results.

Designers have different levels of perception of familiar and unfamiliar animals, and their ability to obtain inspiration is also different, especially in the two dimensions RC1 and RC2. For familiar animals, designers can accurately describe biological characteristics, such as for the koi, which has an auspicious definition in traditional Chinese culture, as mentioned by almost all the designers. Regarding penguins, some designers considered them to be slow; therefore, they do not use penguins as bionic objects for products, such as cars, that have requirements for speed. In fact, penguins swim at a speed similar to that of whales. This is an example of a "misunderstanding" that is likely to cause misuse and loss of inspiration. For RC3, RC4, and RC5, the relevant animal features could be obtained by observing the pictures, and there were fewer mistakes in the perceptions.

As shown in Figure 6, there was no significant difference between male and female designers. Based on the extreme degree of scoring, we found that female designers are more sensitive to items such as "elegant", "friendly", "rough", "hard", "recognizable", and "specially-structured". Only for the item "streamlined" did the male designers present higher sensitivity.

However, the BID activities were restricted because different designers have different levels of perceptions and abilities to obtain inspiration from different situations. The model for the designers' perception of the biological features proposed in this study summarizes the experience of the perception of animals. It divides the animal features for BID into five dimensions: Overall Feeling, Ability and Trait, Color and Texture, Apparent Tactile Sensation, and Structural Features, as shown in Figure 8. It can provide designers with supplemental information when the BID experience is insufficient, which helps to increase the effectiveness and richness of inspiration acquired from animals.

The five dimensions obtained from the research happen to correspond to knowledge of modeling, color, material, structure, and function, which designers are expected to consider in product design. The proposed model assists designers in rapidly fixing the corresponding animal features required in product design and generating inspiration. It serves as a bridge to provide a structured presentation of animal features for BID, simplify the search and transfer of features, and assist in improving design efficiency. This is consistent with the results of the interview experiment. In the interview, we found that even without a specific design task, the designers naturally associate biological features with product design in their descriptions, and they actively seek inspiration that can be transformed into designs.

3.2. Analysis of User Preference

From the survey conducted in the step of examining user preference degree, the user preference survey, we obtained 310 valid questionnaires. For the group of users, it was necessary to use an independent sample *t*-test to analyze the differences in preferences for different animals from the perspective of gender. The results of the user preferences and their differences are shown in the boxplots in Figure 9; these indicate that users of different genders presented significant differences in terms of preference concerning the animals listed, and the ratio of significant differences was 11/26. In this sense, the asymmetry of user preference between males and females can be clearly appreciated.

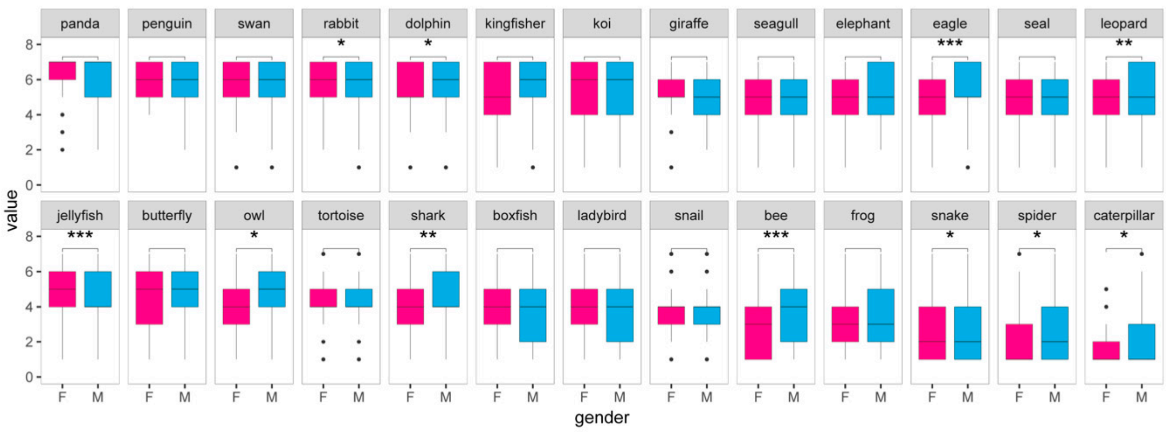


Figure 9. Gender variance analysis of users (F = female, M = male). (Significant differences: p values of less than 0.05 are represented by boxes with "*", p values of less than 0.01 are represented by boxes with "**", p values of less than 0.001 are represented by boxes with "***". These imply a significant difference in terms of animal preference between males and females).

Besides this, we found that favorite animal of the users was the panda, the most representative animal of China, and there are numerous bionic products on the market that used pandas as biological inspiration. Aside from pandas, the users showed a "very" liked level for dolphins, koi, seagulls, swans, eagles, kingfishers, penguins, elephants, rabbits, and giraffes. Sharks, turtles, butterflies, owls, cheetahs, seals, and jellyfish were animals the users liked comparatively. The animals preferred by the users were concentrated in the fish, bird, and mammal categories. The least favorite of the users was the caterpillar. Snakes and spiders were the animals that the users disliked very much. The box fish, frog, ladybug, bee, and snail were the animals that the users disliked comparatively. The animals that the users did not like were concentrated in the categories of arthropods (insects), invertebrates, reptiles, and amphibians. The above preference order may be influenced by the national culture.

Because the user preference experiment samples were collected from animals that are used as inspiration sources for BID in the current market, the difference in the user preferences for each animal also proved that there is a discrepancy between the perceptions of users and designers.

3.3. Prediction Model Establishment

It is possible and relevant to quantify the user preference for animals and confirm the potential relationship and impact between the perceptions of designers and the user preference. The perceptual data of the designers obtained using the questionnaire were used as independent variables, and the user preference data were used as the dependent variables. Due to the asymmetry of user preference in terms of gender, a stepwise regression method was used to construct respective user preference prediction models for males and females. The relationship between the user preference values and the dimensions of the designers' perceptions from the viewpoint of gender is shown in Figure 10. We found that user preference had a linear relationship with RC1, with Pearson correlation coefficients of R = 0.9 and 0.84 for female and male users, respectively, which explains the degree of linear correlation between the dependent and independent variables [60].

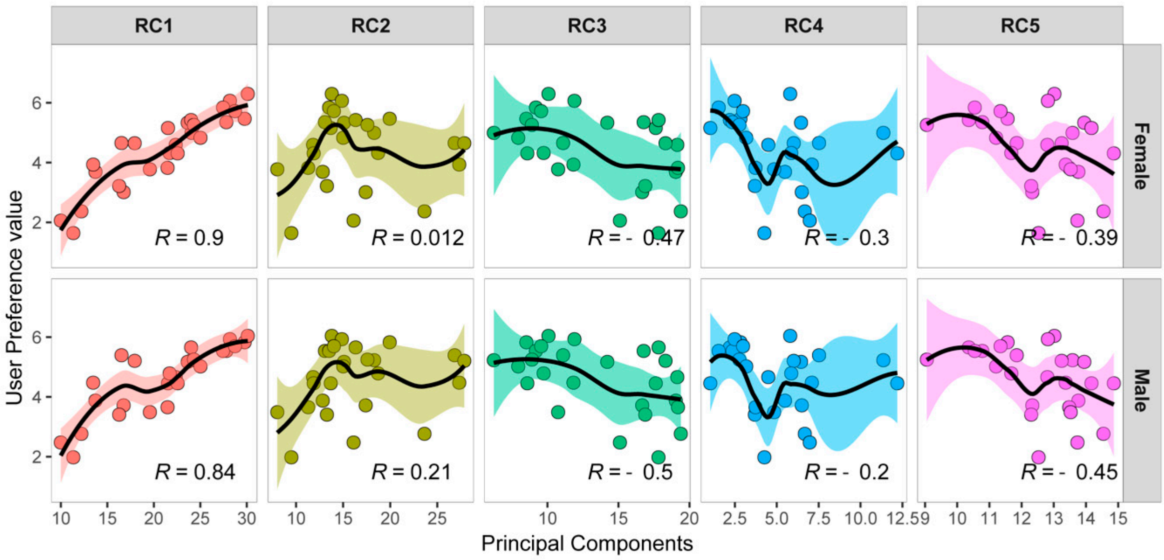


Figure 10. Correlation analysis results between user preference and designers' perceptions. (The black line indicates the smooth curve obtained using the local polynomial regression fitting (LOESS) method).

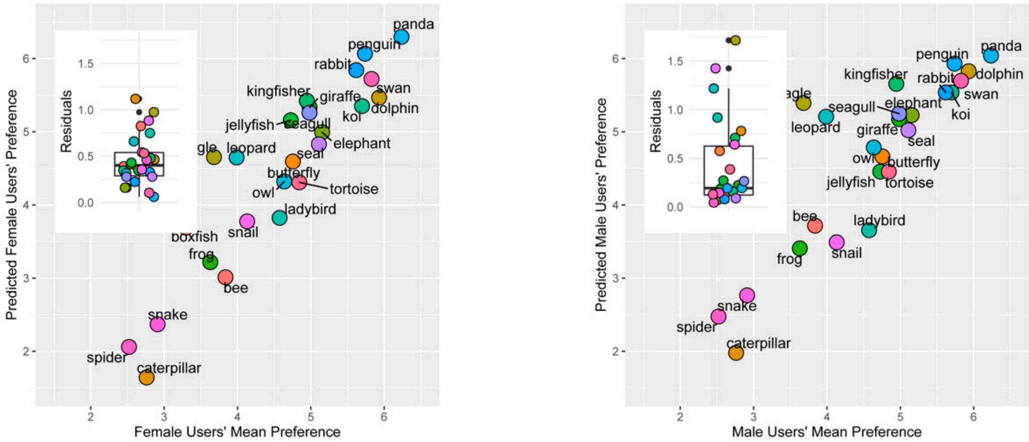
When the model contains one independent variable, RC1, the user preference can be explained well. The final regression model equation for females is expressed in Equation (1). The residual standard error was 0.514 on 25 degrees of freedom (DFs), multiple R-squared was 0.9881, and adjusted R-squared was 0.988. The F-statistic was 2071 on 1 and 25 DFs, with a p value of $<2 \times 10^{-16}$.

$$y = 0.241 \times RC1 \tag{1}$$

The final regression model equation for males is expressed in Equation (2). The residual standard error was 0.5888 on 25 degrees of freedom, multiple R-squared was 0.985, and adjusted R-squared was 0.985. The F-statistic was 1655 on 1 and 25 DFs, with a p value of $<2.2 \times 10^{-16}$.

$$y = 0.247 \times RC1 \tag{2}$$

The user preference prediction model can predict the degree of preference of males and females for animals when RC1 is inputted. Comparisons between the user preference predicted values and the actual values for females and males are shown in Figure 11a,b, respectively; the residual for females was 0.454, and that for males was 0.408.



(**a**) (**b**)

Figure 11. Comparisons between the predicted and actual user preference degrees: (**a**) females, (**b**) males.

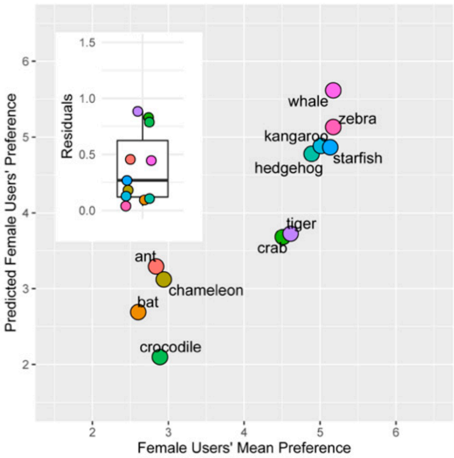
It is feasible to predict user preference from the designers' perceptual evaluations. Because animals, instead of products, are considered, the biological features are complex; they also include personality, ability, and image in addition to form, structure, function, texture, and color. The designers' perceptions also provide the possibility of achieving a highly comprehensive structured expression of biological features. In this study, we conducted exploratory research on user preference and designer perception and finally obtained a user preference prediction model by conducting multiple linear regression analysis. This provided a statistical model for identifying the relative weightings of the perceptual dimensions of each designer in the user preference for an animal. The results of the multiple linear regression analysis present the relative importance of each dimension, i.e., the degree of contribution to the user preference, which provides qualitative data. According to Equations (1) and (2), the specific user preferences of females and males can be calculated separately, yielding quantitative data. One of the advantages of quantitative data is that they can provide an objective basis for design decisions, whereas qualitative data can provide relevant suggestions for design directions [61].

The utility of the perception dimension level yields its relative importance in positively influencing the user preference. Using the predictive model, we found that user preference has a very high correlation with RC1. This result suggests to designers that it is beneficial to pay more attention to the biological knowledge related to RC1 when considering user preference during the inspiration period. As shown in Figure 10, both male and female consumer preferences were positively correlated to RC1 and RC2, whereas they were negatively correlated to RC3, RC4, and RC5. Notably, users tended to prefer animals that have a better overall feeling and excellent traits, and users may prefer more common animals regarding color, texture, touch, and structure, instead of animals with very bright colors or very distinctive structures.

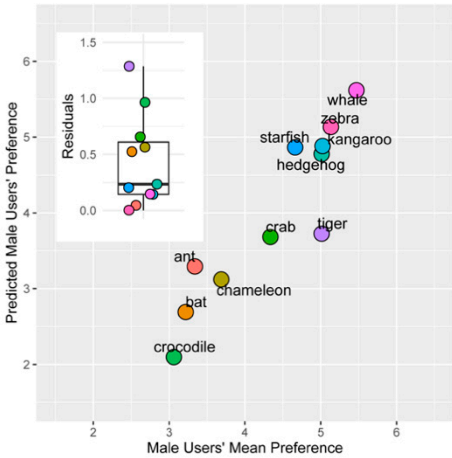
4. Prediction Model Validation

Using validation samples, the designer perception data obtained in the first step were input into the prediction model proposed in this study to obtain the predictive values of the user preference degrees for males and females. Subsequently, we compared the predicted values with the actual preference data of males and females from the second step.

From the two-step questionnaire described in Section 2, we obtained 52 valid responses from designers and 185 valid responses from users. Comparisons of the predicted values and actual values of user preference for females and males are shown in Figure 12a,b, respectively. The figures show that the predicted and experimental values of user preference are similar. In the boxplot, the residual for the predicted and experimental preference values of female users is 0.384, whereas the residual for male users' predicted and experimental preference values is 0.433. The verification results indicate that the prediction model obtained in this study is ideal and can be applied to predict user preference for animals.



(a)



(b)

Figure 12. Comparison between the predicted and actual user preference degrees: (**a**) females, (**b**) males.

5. Conclusions

In this study, the designer perceptions and user preferences for animals were the objects of our research. We conducted research and discussed the scenario existing in BID activities where designers have different levels of perceptions and abilities to acquire inspiration. Based on designer perception, five dimensions of biological features were proposed: Overall Feeling, Ability and Trait, Color and Texture, Apparent Tactile Sensation, and Structural Features. The asymmetry in the animal preferences of male and female users and their mapping with designer perceptions were studied, and consequently, user preference prediction models for males and females for biologically inspired design were suggested. The experiment results showed that the dimension "Overall Feeling" (RC1) of designer perception is positively correlated with the "like" level of user preference and negatively correlated with the "dislike" level of user preference, indicating that this prediction model bridges the gap caused by the asymmetry between designers and users by matching designer perception and user preference. Using this model, designers can effectively obtain rich and structured biological features and generate inspiration. Simultaneously, the model can predict user preference for biology based on designers' perceptual evaluations, providing designers with useful references and quantitative preference data on users and avoiding the selection of bionic objects based on their own personal preferences. Finally, there is no user involvement, which can save costs. In addition, this study advances design research to the initial stage of design, the inspiration acquisition stage, considering the issue of user preference before BID.

However, there are still some limitations in this research: The proposed model is based on animals, and the features of other creatures were not involved. Moreover, because all the materials were from the Internet, they could not be completely unified. Furthermore, all the users were from China, and their preferences may be influenced by their national culture.

A future research direction is to supplement the designers' perceptions and user preferences for other types of biological features and improve the management, retrieval, data analysis, and knowledge reasoning of the biological knowledge base to form a more complete base to support BID. Another research direction is to improve the efficiency and connotation accuracy of BIDs in industrial design.

Author Contributions: S.L. designed the study, provided the research materials, and gave advice on experiment design and manuscript writing. Y.Z. and J.Z. designed and performed the experiments, analyzed the experimental data, and wrote the manuscript. J.X. performed the experiments and designed the figures. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China (No. 51675476 and No. 52075478).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Perception items compressed by semantic rules.

i_t	Perception items compressed by semantic rules	Frequency
i_1	The animal's appearance (whole or partial) is recognizable.	75
i_2	The animal looks cute.	66
i_3	The animal is friendly.	47
i_4	The animal has a special texture.	38
i_5	The animal is clever.	35
i_6	The animal's color scheme is fashionable.	33
i_7	The animal looks elegant.	31
i_8	The animal is aggressive.	31
i_9	The animal is colorful.	29
i_{10}	The animal has a hard touch.	27
i_{11}	The animal has a special structure.	25
i_{12}	The animal is speedy.	24
i_{13}	The animal feels safe and reliable.	23
i_{14}	The animal has a round shape.	18
i_{15}	The animal is streamlined.	18
i_{16}	The animal is powerful.	17
i_{17}	The animal has beautiful implication.	16
i_{18}	The animal is majestic.	16
i_{19}	The animal's color is a warning.	15
i_{20}	The animal's lifestyle is leisurely.	14
i_{21}	The animal has rough skin.	13

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