The Research on Quantificational Method of Chromatic-Light Emotion in Automotive Interior Lighting

Jiaying Lu(✉) and Jiong Fu

Institute of Design Trend, Design School,
Shanghai Jiao Tong University, Shanghai, China
lujiaying@sjtu.edu.cn

Abstract. With the development of new lighting technologies, automotive interior ambient light extends from basic Illumination function to comfort and personalization function. However, the application of ambient lamp light lacks theoretical support and scientific quantitative basis, and has great blindness and randomness. How to use the emotion and preference aroused by chromatic-light scientifically is the key to solve the above problems. In the experiment, 12 chromatic-light stimuli were output with chroma and hue as variables. The emotions aroused by light were quantitatively studied by experimental psychological methods. By factor analysis, we obtained three monochrome affective factors: activity, evaluation and adaptability. In the correlation analysis of the influence of chromatic-light attributes on emotion, it was found that the chroma had the greatest influence on chromatic-light emotion, followed by the hue of chromatic-light. By analyzing the preference of chromatic-light, we find that yellow light is preferred.

Keywords: Automobile interior · Chromatic-light emotion · Chromatic-light preference · Quantitative research

1 Introduction

As the gaps of automobiles quality are becoming smaller and smaller, automobile interior decoration has become a key factor affecting consumers 'car purchase decision. As a part of interior decoration, interior lighting has attracted more and more attention. Functional ambient lighting system can meet the sensory needs of passengers in different environments. Car lights play a role in not only basic interior and exterior lighting but also customer experience and personalized areas.

The use of ambient lamp can convey the perception of physical space within the composition, Background design language, heighten the atmosphere in the car, improve the driving experience and the grade of the car, and play an important role in brand recognition, feature creation, style determination and many other aspects. Chromatic-light raises peoples' general concern, because it can bring people abundant emotion and emotional experience. With the development and application of new

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lighting technology, it provides a broader space for the creation of automobile interior atmosphere. However, due to the lack of basic research on the emotional recognition of chromatic-light, there is a great blindness and randomness in the design of automotive interior ambient light.

At present, the design of interior ambient lights of automobiles mainly relies on the experience and preferences of designer (such as lighting supervisors and lighting designers). Users usually choose their preferred ambient lights from the given lighting conditions. For example, the brand-new Mercedes-Benz E-Class car provides 64 different color ambient lights for owners to choose. However, this experiential feeling cannot be expressed in a scientific or quantitative way, not to say be used for reference by others. Furthermore, customers' inappropriate use of color and brightness will result in lighting effect which is contrary to the original intention of the design.

Then the fundamental reason for the above problems is the lack of a theoretical support and quantitative reference basis to guide the design of ambient light based on chromatic-light emotional perception. Literature studies mainly focus on two aspects: lighting emotional perception and color emotional perception.

Many studies have confirmed that light affects circadian rhythms, moods, preferences and cognition. In 2008, Vogels developed a method called Atmosphere Metrics, which quantifies the environmental atmosphere experienced by human observers through semantic differences [1–4]. She carried out a series of experiments, using factor analysis and other data analysis methods to compare the experimental results. The experimental results show that atmospheric perception can be defined in at least two aspects: comfort and liveliness. By changing the illumination condition variables and accumulating more data in different experimental environments, two other dimensions were found: tension and separation.

Russell and Pratt try to describe the concept of "emotional quality attributable to the environment" [5]. They developed a two-dimensional bipolar space, which can be described by two orthogonal dimensions: pleasant - unpleasant and exciting - sleepy or exciting - gloomy and painful, tense - relaxed.

However, most of the experiments defining lighting atmosphere perception use traditional lighting technology, which is different from automotive interior ambient lights. The ability of LED to adjust spectrum makes this research pay attention to the theory of color application at the same time. Since Spearman C. founded factor analysis method and Osgood C. E. established semantics difference analysis method, the research of color emotion has become more scientific and systematic. The single-color emotion research mainly focuses on extracting a few potential factors by SD method and factor analysis method to generalize the emotional scale of color [6–12], [13–15]. Although the scale of color emotions used by various researchers is different in quantity and content, some similar color emotional factors, such as warmth, activity and evaluation, have been founded.

However, from previous studies, it is not difficult to find that all the studies are only aimed at the small angle of object color observation and evaluation experiments. And these research results have only been expanded in fashion, fabric printing and dyeing, fashion color and other fields. It is unknown whether the quantitative research results of color emotion can be applied to the observation conditions of light color in automobile interior atmosphere.

With the above in mind, this study uses factor analysis method and semantic difference analysis method to study interior atmosphere perception under monochrome illumination of automotive interior atmosphere lamp, quantitatively measures and parameterizes the color emotion aroused by it through experimental psychology method, finds out the cognitive regularity characteristics of people's color light through statistical analysis, and obtains the basic emotional scale of chromatic-light perception.

2 Method

2.1 Experimental Setup

Commercial white LEDs and a Telelumen® multi-LED system was used in the present study as test light sources. The latter is a lighting system comprising 16 narrow-band LEDs, which is capable of constructing a spectral power distribution (SPD) of many light sources.

The material atmosphere of automobile interior was simulated by automobile central control plastic parts (length 0.7 m, width 0.3 m), automobile interior leather samples (length 0.4 m, width 0.4 m) and automobile interior fabric samples (length 0.4 m, width 0.4 m). In this study, the material atmosphere of automobile interior was used as the observation object under ambient lighting environment. Material samples are provided by automotive interior suppliers, and the area ratio of different materials in the samples is the same as the proportion of practical one. The observer sat one meter away from the experimental device for observation and evaluation, as shown in Fig. 1.

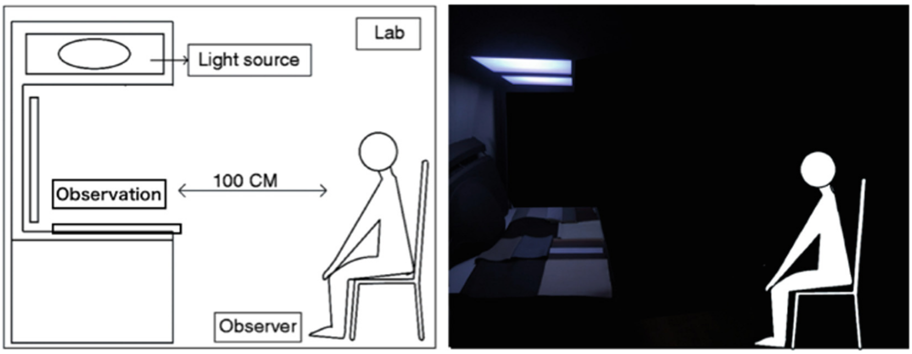

Fig. 1. Environment for visual assessment.

2.2 Lighting Parameters

With hue and Chroma as variables, there are 12 conditions in the whole experiment. Table 1 lists the experimental parameters of chromatic-light properties used under each condition. Because in the design of automobile interior ambient lamp, the brightness can be adjusted by users themselves, and the brightness range is small, only 0–25 cd/m^2. So, in this experiment, only chroma and hue are variables, and the brightness is kept at about 25 cd/m^2.

Table 1. Specifications of the twelve experimental conditions.

Conditions	Symbols	L*	C*	h*	a*	b*
1	C71C	25.5	71	205.72	−3.85	−70.90
2	C60C	24.4	60	205.72	−3.26	−59.91
3	C100 M	25.1	100	337.3	−40.89	−91.26
4	C60 M	25.1	60	337.3	−24.53	−54.76
5	C100Y	25.3	100	103.67	65.56	75.51
6	C60Y	25.6	60	103.67	39.33	45.31
7	C100R	25.1	100	36.26	13.13	−99.13
8	C60R	24.0	60	36.26	7.88	−59.48
9	C100G	24.8	100	148.75	−45.79	−88.90
10	C60G	24.8	60	148.75	−27.48	−53.34
11	C100B	25.2	100	305.72	−55.24	−83.36
12	C60B	24.8	60	305.72	−33.15	−50.01

2.3 Observers

In the experiment, 26 observers including 13 males and 13 females. Their ages ranged from 20 to 25 years with a mean of 23.2 years. They were all Chinese students at the Shanghai Jiao Tong University. All of them had normal color vision according to the Ishihara test.

2.4 Questionnaire

We designed a questionnaire, referring to the problems used in the study of lighting atmosphere perception and color emotion, to study the interior atmosphere perception under monochrome illumination of automobile interior atmosphere lamp. Ten native Chinese (university staff or students) with normal eyesight participated in the study. Participants were asked to choose perceptual terms describing the experimental environment. It is common in Chinese words that one word can have multiple meanings. To make sure that the meaning of the scale was precise, word pairs are used in this study.

The questionnaire uses a total of 52 word pairs (bipolar scale). As shown in Appendix 1, the translation from English to Chinese may not be accurate. However, by using word pairs instead of single words, we can make sure that each Chinese term has a clear definition. In addition, the questionnaire asked the subjects to describe subjectively each monochrome light condition with three aspects: brightness (high, medium, low), chroma (high, medium, low), such as “this is a purple light with medium brightness and low chroma”.

2.5 Procedure

The observer entered the laboratory and participated under independent lighting condition (D65 luminance: 25 cd/m^2, LED). This is a neutral condition, different from any experimental condition. A 30-s neutral condition occurs during the transition between two continuous conditions to eliminate the visual effects of the previous monochrome light. After each experimental condition appeared, the observer responded to the questionnaire after 30 s of adaptation. Each observer was randomly assigned a total of 13 conditions (12 different monochrome light conditions plus repetition condition D65).

In the experiment, for each experimental condition, the observer used 52 emotional scales to describe the presented color stimulus with five levels of semantic difference, and then evaluated the next color stimulus in turn. The experimenters asked questions orally and each observer answered them orally. This was done to reduce the workload for each observer and to avoid the visual adaptation caused by white paper used to record data.

3 Results and Discussions

3.1 Gender Differences in Perception

Statistical analysis of the experimental data was carried out to investigate the difference of perception of monochrome light atmosphere between male and female observers. Variance analysis showed that there were significant gender differences in conditions C100M ($P = 0.000$), C100Y ($P = 0.001$), C60Y ($P = 0.000$), C100B ($P = 0.000$), C60B ($P = 0.000$).

Combining with the subjective description of monochrome light, we found that men are more sensitive to brightness than women. Therefore, under the condition of C100 M, men generally believe that the monochrome light has high brightness and more stimulation. In the monochrome light descriptions of yellow and purple phases, we find that men tend to perceive warm red and yellow phases, and their descriptions of yellow and purple phases are generally accurate. Women are prone to feel the cold blue-green color. Most women think that yellow light is biased towards green light and purple light is biased towards blue-white light.

3.2 Factor Analysis

In order to improve the feasibility of future wider color gamut monochrome experiments, we used dimensionality reduction factor to simplify the emotional scale. We used Principal component analysis to extract factors from 52 affective scales, and used the maximum variance method of vertical orthogonal rotation to perform factor rotation. Seven common factors were obtained. The affective scale of the same common factor is clustered by Pearson product difference correlation analysis, and the affective scale is finally reduced to 26 pairs. According to Osgood's Semantic Difference Method, these 26 pairs of emotional scales are divided into three groups according to their semantics, as shown in Table 2.

Table 2. 26 emotion scales in the experiment.

Factors	Emotion scales
Activity	Cool-warm, cheerful-detached, feminine-masculine, lovely-sharp, rational-emotional, dynamic-static, calm-angry, relaxed-nervous, keen-dull
Potentiality	Comfortable-uncomfortable, inviting-isolated, pleasant-unpleasant, peaceful-defiant, active-inactive, inspiring-dejected, bright-dim, shallow-deep, dedicated-abstracted
Evaluation	Simple-luxurious, elegant-rugged, deluxe-low, stable-disturbed, beautiful-ugly, advanced-backward, like-dislike, traditional-modern

26 pairs of subjective evaluation experimental data of emotional scale were analyzed. KMO is the KMO value of Kaiser-Meyer-Olkin sampling suitability measurement statistic. The larger the KMO value, the more common factors between variables, the more suitable for factor analysis. The KMO value here is 0.914 and KMO > 0.9, which is suitable for factor analysis.

Table 3 lists the factor loads of each scale. Five main factors were extracted from the principal component analysis, accounting for 70.423% of variance. They were labeled as factors 1 to 5, with differences of 33.585%, 20.619%, 8.027%, 4.216% and 3.976%, respectively. For each factor, eigenvalues are calculated to indicate the importance of the factor. The factors with more than one eigenvalue are all listed in Table 3, although some variances are small (the variance of factor 4–5 is less than 7%).

Table 3. Factor loadings of atmosphere dimensions using 26 scales.

Scales	Total variance				
	Factors 1	Factors 2	Factors 3	Factors 4	Factors 5
Stable-disturbed	**0.808**	−0.276	0.086	0.043	0.078
Peaceful-defiant	**0.798**	−0.262	−0.091	0.104	−0.038
Relaxed-tense	**0.792**	0.265	0.095	0.196	0.046
Comfortable-uncomfortable	**0.788**	−0.076	0.096	0.300	−0.002
Pleasant-unpleasant	**0.762**	0.260	0.302	0.145	−0.050
Like-dislike	**0.704**	−0.024	0.234	0.326	0.194
Inviting-isolated	**0.680**	0.420	−0.082	0.190	−0.103
Beautiful-ugly	**0.677**	0.112	0.407	0.275	0.203
Elegant-rugged	**0.624**	−0.019	0.416	0.129	0.031
Calm-angry	**0.529**	−0.495	0.254	−0.075	0.135
Cool-warm	−0.034	**−0.891**	0.126	−0.073	0.013
Feminine-masculine	−0.013	**0.853**	−0.056	−0.094	−0.218
Cheerful-detached	0.141	**0.834**	0.084	0.091	−0.013
Lovely–sharp	0.314	**0.793**	−0.052	−0.146	−0.100
Rational-emotional	0.205	**−0.781**	0.114	0.209	0.164
Dynamic-static	−0.181	**0.664**	0.046	0.331	0.025

(*continued*)

Table 3. (*continued*)

Scales	Total variance				
	Factors 1	Factors 2	Factors 3	Factors 4	Factors 5
Simple-luxurious	0.466	**−0.541**	−0.343	0.239	−0.135
Advanced-backward	0.391	−0.029	**0.692**	0.239	0.140
Traditional-modern	0.273	−0.008	**−0.664**	−0.095	0.330
Deluxe-low	0.485	−0.054	**0.657**	0.086	0.189
Keen-dull	0.333	−0.316	**0.587**	0.421	−0.109
Bright-dim	0.273	0.023	0.213	**0.814**	−0.015
Active-inactive	0.435	0.347	0.156	**0.590**	−0.046
Inspiring-dejected	0.314	−0.107	0.448	**0.477**	−0.019
Dedicated-abstracted	0.394	−0.277	0.135	**0.459**	0.267
Shallow-deep	−0.038	0.267	0.037	−0.006	**−0.858**
% of Variance	33.585%	20.619%	8.027%	4.216%	3.976%
Cumulative%	33.585%	54.204%	62.231%	66.447%	70.423%

Considering the low variance explanations of factors 4 and 5, only factor 1–3 are considered as important perceptual dimensions. These will be used for the following analysis. It can be seen from Table 3 that the high load of Factor 1 is related to the sense of stability, relaxation, comfort and aesthetics. For factor 2, cool - warm, feminine - masculine, enthusiasm - indifferent, lovely - sharp, rational - emotional, dynamic - static, simple - luxurious, these emotional scales have a high factor load. For factor 3, advanced - backward, traditional - modern, advanced - low, keen - dull, these emotional scales have a high factor load. The three factors are adaptability factor, vitality factor and evaluation factor.

3.3 The Influence of Chromatic-Light Parameters

Pearson product difference correlation analysis of color attributes (luminosity value L*, chroma value C* and chroma angle H*) with emotional scales and emotional factors of color light will reveal the full impact of lighting conditions on scales. However, a complete design (2 (brightness) 2 (CCT) 6 (hue) will require at least 24 monochrome conditions. In this study, only chroma and hue were taken as variables, including all 52 groups of emotional scales. All 12 conditions had the same illumination (about 25 cd/m^2), two chromas (high and low) and six hues (RGBCMY). Therefore, the influence of lightness value L* on emotional scales was very limited.

Table 4 lists the scales significantly affected by the parameters, with significant effects ($p < 0.05$) and almost significant effects ($0.05 < P5 < 0.1$) marked in bold. The results show that the chroma values of chromatic-light are not significantly correlated with the six emotional scales of “cold-warm”, “feminized-masculinized”, “warm-indifferent”, "lovely-sharp", "dynamic-static", "simple-luxurious". They are all significantly correlated with other emotional scales, especially with evaluation and adaptability factors. It can be seen that the chroma of chromatic-light has an important influence on the evaluation of the overall atmosphere of automobile interior.

The hue of chromatic-light mainly affects the emotional scale of the evaluation factors. It is worth noting that many chromatic-light emotions are affected by the comprehensive properties of chromatic-light, such as the emotional scale of the evaluation factors and the "graceful-rough" of the adaptability factors. In order to create the emotional atmosphere of the above-mentioned chromatic-light, both hue and chroma of the chromatic-light should be taken into account. The "beautiful-ugly" emotional scale is affected by three attributes at the same time, that is, people's evaluation of the beautiful chromatic-light is also affected by hue, chroma, and luminosity.

Table 4. Correlation analysis of chromatic-light emotions and parameters.

Factor	Scales	Chromatic-light parameters		
		L*	C*	H*
Adaptability	Stable-disturbed	0.063	0.241**	-0.038
	Peaceful-defiant	0.083	0.213**	0.010
	Relaxed-tense	0.024	0.165**	0.001
	Comfortable-uncomfortable	0.070	0.242**	−0.053
	Pleasant-unpleasant	0.055	0.157**	−0.038
	Like-dislike	0.032	0.267**	−0.054
	Inviting–isolated	0.064	0.077	0.048
	Beautiful-ugly	0.096*	0.297**	−0.129**
	Elegant-rugged	0.050	0.218**	−0.147**
	Calm-angry	0.076	0.253**	−0.098*
Activity	Cool-warm	0.040	−0.040	0.166**
	Feminine–masculine	0.106*	−0.051	−0.039
	Cheerful-detached	0.012	−0.041	0.063
	Lovely–sharp	0.044	0.059	0.026
	Rational-emotional	0.031	0.144**	−0.038
	Dynamic–static	−0.019	−0.006	−0.023
	Simple–luxurious	−0.083	0.029	0.072
Evaluation	Advanced–backward	0.021	0.171**	−0.190**
	Traditional-modern	0.068	−0.078	0.119*
	Deluxe–low	0.045	0.249**	−0.173**
	Keen–dull	0.015	0.145**	−0.132**

Note: * Relevance reached $P < 0.05$ significant level (double tail test); ** Relevance reached $P < 0.01$ significant level (double tail test).

To sum up, the chroma of chromatic-light is an important factor affecting the emotional expression of chromatic-light in automobile interior atmosphere, followed by the hue of chromatic-light. In this experiment, the brightness of chromatic-light is not a variable, and its influence will be further discussed in future experiments as a variable.

3.4 Analysis of Chromatic-Light Preference

We used Pearson product difference correlation coefficient r to analyze the correlation between chromatic-light preference and other 25 chromatic-light emotions. The results in Table 5 show that there is a high correlation between chromatic-light preference and chromatic-light emotion "comfort-discomfort", "beauty-ugliness". The correlation coefficients are all above 0.7. In addition, it has a high correlation with the chromatic-light emotions such as "happy-unhappy", "relaxed-tense", "positive-negative",

Table 5. The relationship between chromatic-light preference and other scales.

Scales /	Beautiful-.837**	Cool-.125**	Bright-.358**	Pleasant-.528**	Relaxed-.536**
Scales /	Active-.616**	Inspiring-.411**	Keen-.323**	Dedicated-.414**	Peaceful-.583**
Scales /	Comfortable-.706**	Calm-.449**	Stable-.568**	Inviting-.427**	Cheerful-.179**
Scales /	Feminine-.095*	Lovely-.239**	Rational-.166**	Deluxe-.628**	Elegant-.590**
Scales /	Advanced-.333**	Traditional - −0.012	Dynamic-.180**	Simple - 0.061	Shallow--0.054

"peaceful-provocative", "stable-restless", "high-level-low", "elegant-rough". However, there is little or no correlation between "feminization-masculinization", "tradition-modernity", "simplicity-luxury", "superficiality-depth" and chromatic-light preference.

That is to say, when a color light environment can arouse people's feeling of comfortable, beautiful, happy, relaxed, positive, peaceful, elegant and other emotion, then the chromatic-light environment is adorable, on the contrary, if the chromatic-light arouses the above negative emotional feelings, then the chromatic-light is not adorable.

Linear regression was used to analyze the relationship between monochrome light preference and affective factors in different hues. The results showed that high-chroma red light could evoke strong positive feelings of vigorous emotional factors. Low-chroma red light can evoke positive feelings of some evaluative emotional factors, such as "high-low". High-chroma yellow light evokes a better sense of adaptability and intimacy, while low-chroma yellow light does not produce significant emotional response. High-chroma green light makes people respond strongly to adaptive emotional feelings and is prone to evoke provocative and uncomfortable feelings. Low-chroma blue light is more likely to evoke positive dynamic emotional feelings and adaptive emotional feelings, and is considered to be static and elegant chromatic-light. Purple light can cause positive evaluative emotional feelings, in addition, low-chroma purple light can arouse adaptive feelings.

To sum up, the hue and chroma of chromatic-light have a great influence on active emotional feelings. Warm chromatic-light causes positive active emotion, while cold chromatic-light causes negative active emotion. The evaluative emotional feeling of chromatic-light is mainly affected by the hue of chromatic-light. The evaluative emotional feeling aroused by yellow and green chromatic-light is weak, while the evaluative emotional feeling aroused by purple chromatic-light is stronger. As for the adaptive emotional feeling, it is mainly affected by the chroma of chromatic-light. Thus, in the actual design of automobile interior ambient lamp, when a chromatic-light source is selected to create atmosphere, the desired atmosphere can be achieved as long as the chroma and hue of chromatic-light are controlled.

4 Conclusion

The purpose of this study is to study the perception of interior atmosphere under monochrome light of automobile interior atmosphere lamp, reveal the differences between different genders, and finally find out the influence of color parameters on interior atmosphere perception.

By quantifying 12 monochrome light stimuli, visual evaluation experiments were carried out on 52 chromatic-light emotional scales. Through principal component analysis and correlation analysis clustering, 26 emotional scales were finally obtained for experimental analysis. Through factor analysis, three affective factors were obtained: activity, evaluation, adaptability.

In addition, the relationship between chroma, hue and chromatic-light emotion is also analyzed. The results show that the chroma of the chromatic-light has the greatest influence on the chromatic-light emotion in this study, followed by the hue of the chromatic-light. In this study, the subjects' favorite pure color is yellow light, and the least favorite pure color is green light.

In the design of automotive interior ambient lamp, the brightness can usually be adjusted by the user himself, and the range of brightness is small, so it is not a variable in this study, we will do further exploration in future experiments. In addition, in visual evaluation, due to the limitation of sample size, the conclusion of chromatic-light preference differences caused by regional and age differences cannot be well supported. In future research, the capacity of different samples should be increased, and we will study the chromatic-light preference differences in depth.

Appendix 1

No	Scales in English	Scales in Chinese	No	Scales in English	Scales in Chinese
1	**uninhibited**-inhibited	自由的-拘束的	27	bright-dim	明亮的-昏暗的
2	**exciting**-sag	振奋的-萎靡的	28	keen-dull	敏锐的-迟钝的
3	**pleasant**-unpleasant	愉快的-不快的	29	dedicated-abstracted	令人专注的-无关紧要的
4	elegant-rugged	优雅的-粗犷的	30	arousing-**lethargic**	令人清醒的-昏昏欲睡的
5	close-**terrifying**	向往的-恐惧的	31	rational-emotional	理性的-感性的
6	advanced–backward	先进的-落后的	32	**cool-warm**	凉爽的-温暖的
7	like-dislike	喜欢-不喜欢	33	confident-hesitating	可信赖的-犹豫的
8	artistic-**business-like**	文艺感的-商业感的	34	lovely-sharp	可爱的-锐利的
9	spiritual-vulgar	脱俗的-俗气的	35	optimistic-sad	开朗的-忧郁的
10	natural-artificial	天然的-人工的	36	open	开放的-私密的
11	comfortable-**uncomfortable**	舒适的-不适的	37	energetic-tired	精力充沛的-疲乏的
12	delightful-**oppressive**	舒畅的-压抑的	38	active-inactive	积极的-消极的
13	soft-hard	柔软的-坚实的	39	classical-fashion	古典的-时尚的
14	inviting–isolated	容易接近的-有距离感的	40	deluxe–low	高级的-低级的
15	cheerful-**detached**	热情的-冷漠的	41	noble-tawdry	高贵的-卑俗的
16	busy-deserted	热闹的-冷清的	42	shallow-deep	浮浅的-深沉的
17	fresh-corrupt	清爽的-浑浊的	43	**relaxed-tense**	放松的-紧张的
18	light-colorful	清淡的-浓艳的	44	urban-countryside	都市的-田园的
19	ethereal-heavy	轻的-重的	45	dynamic–static	动态的-静态的
20	strong-weak	强劲的-无力的	46	traditional-modern	传统的-现代的
21	forward-retreat	前进-后退	47	steady-impetuous	沉稳的-浮躁的
22	simple–**luxurious**	朴素的-豪华的	48	calm-angry	冷静的-愤怒的
23	peaceful-defiant	平和的-挑衅的	49	sweet-bitter	甜美的-苦涩的
24	beautiful-ugly	美丽的-丑陋的	50	suitable-unsuitable to automotive interior	适合-不适合（汽车内饰）
25	expand-shrink	膨胀-收缩	51	nimble-clumsy	敏捷的-笨拙的
26	feminine–masculine	女性化的-男性化的	52	stable-disturbed	安定的-不安的

Note: The bold terms marked with an asterisk were used by Vogels.

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