A Colour Preference Model for Three-Dimensional Colour-Form Combinations

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ABSTRACT

This study is to investigate 20 imagery scales, including preference that is affected by both colour and 3D forms. Twelve forms were used, including three basic forms (cube, sphere and tetrahedron) together with gradations between them. Twelve colours were selected to cover 11 basic colour terms (black, white, grey, red, green, yellow, blue, brown, pink, orange, and purple) together with a cyan colour to give a good coverage in the colour space. The results showed that only 'clean' and 'simple' imageries are required to develop a preference model. The results also showed that the most disliked colour is in the region of brown and the liked colour in the region of blue. In term of form, basic form is more preferred than intermediate forms. Finally, the imagery-based and colorimetric-based preference models were developed with good performance.

1. INTRODUCTION

Appearance of object involves physical attributes such as colour, form, gloss and textures. These appearance attributes contribute to the overall imagery and affect the preference for objects. An object can be associated with adjectives that describe its imagery, such as warm, cool and active. Many studies[1-3] were carried out to investigate imagery scales affected by colour. These results revealed that colour imagery consists of three imagery factors such as warm-cool, soft-hard and clear-greyish found by Kobayashi[1]; activity, potency and warm-cool by Sato *et al*[2]; colour activity, colour weight and colour heat by Ou *et al*[3]. However, a limitation in these studies is the use of the colour patches to investigate the imagery. This is considered to be impractical for product designers, who would always apply colour on a three-dimensional form. Thus, this study investigated the imagery that is affected by both colour and 3D form. The results were also used to develop preference models based upon both colorimetric values and imagery scales.

2. METHOD

A psychophysical experiment was carried out to study imagery scales for colour-form combinations. Nineteen imagery scales together with preference given in Table 1 were used in the experiment. These were selected from a large collection of adjectives by Osgood *et al*[4] and are associated with colour and form impression. Seven observers with normal colour vision took part in the experiment (4 males and 3 females with an average age of 27 years old). They were either staff members or students in our research unit.

Table 1: The twenty imagery scales used in this study.

No.	Scale	No.	Scale
1	Passive—Active	11	Angular—Rounded
2	Light—Heavy	12	Dangerous—Safe
3	Old—New	13	Masculine—Feminine
4	Dirty—Clean	14	Ugly—Beautiful
5	Sad—Happy	15	Simple—Complex
6	Stale—Fresh	16	Empty—Full
7	Cruel—Kind	17	Weak—Strong
8	Small—Large	18	Humorous—Serious
9	Cool—Warm	19	Classical—Modern
10	Soft—Hard	20	Dislike—Like

In the experiment, each observer was presented with 144 colour-form combinations, generated by 12 forms and 12 colours. The size of three basic forms (cube, sphere and tetrahedron) was produced according to the study by Wei *et al*[5]. Their results showed a same visual size for a tetrahedron with a length of 16.2cm in each side and a volume of 500cm^3, a cube with a length of 10cm in each side with a volume of 1000cm^3 and a sphere with a radius of 6.2cm and a volume of 1000 cm^3. The actual volumes used in this study were 1000, 1000 and 500 cm^3 for cube, sphere

and tetrahedron, respectively. The intermediate forms were produced according to the mathematical gradation, as illustrated in Table 2.

Table 2: Twelve three-dimensional forms used in this study.

Type	Code	Type	Code	Type	Code
	Cube (C)		Sphere (S)		Tetrahedron (T)
	CS1		ST1		TC1
	CS2		ST2		TC2
	CS3		ST3		TC3

The 12 colours were selected to cover Berlin and Kay's [6] 11 basic colour terms (black, white, grey, red, green, yellow, blue, brown, pink, orange, and purple) together with a cyan colour to give a better coverage in the colour space. Each colour was selected within the colour range of the basic colours according to Lin *et al*'s study[7]. These 12 colours were selected from the ICI Dulux matt paint range. They were measured by a GretagMacbeth CE-7000A spectrophotometer with the conditions of large aperture, UV and specular included. The CIELAB values were calculated under CIE D65 and 1964 standard colorimetric observers, as shown in Table 3.

Table 3: Twelve colours were used in this study.

	L*	a*	b*	C*	*h*
White (W)	98.7	-0.3	1.3	1.4	105
Black (Bk)	29.9	-0.1	-0.6	0.6	255
Grey (Gy	78.3	0.2	-1.0	1.0	279
Red (R)	47.8	50.2	31.0	59.0	32
Green (G)	56.1	-43.8	22.9	49.4	152
Yellow (Y)	84.1	8.9	85.1	85.6	84
Blue (Bl)	51.7	-4.8	-35.2	35.5	262
Brown (Br)	48.7	20.7	27.5	34.5	53
Pink (Pk)	75.2	31.8	7.7	32.8	14
Orange (O)	63.3	41.7	55.2	69.2	53
Purple (P)	47.7	30.0	-22.5	37.5	323
Cyan (Cy)	60.8	-39.2	-8.6	40.1	192

In the experiment, the samples were assessed following a random sequence on a mid-grey background with an L* of 59. They were illuminated by a D65 simulator from the ceiling with a luminance level of 96cd/m^2. The viewing distance was about 45 cm from each observer's eyes to the samples with a 0/45 illumination/viewing geometry. In the experiment, the colour-form combinations presented were judged using a 7-step scale in relation to the 20 imagery scales by each observer. English was used during the experiment and the definition of each imagery scale was also provided.

3. MODELLING THE PREFERENCE

For each colour-form combination, the categorical scores for the 7 observers were averaged. These average values were used to represent panel results. The average scores of 'like-dislike' imagery scale for 144 colour-form combinations are plotted against different forms as illustrated in Fig 1. The score of each colour was drawn with different symbol to correspond to different colour. In general, observers prefer the blue and purple colour to brown colour. In term of form, it can be seen that basic forms are more preferred than intermediate forms.

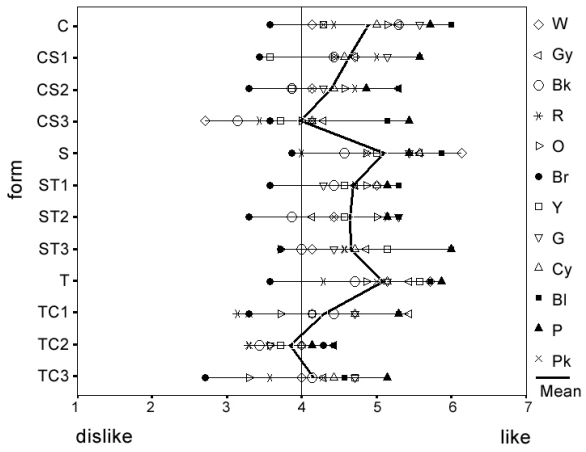

Figure 1: The average scores of preference are plotted against different forms.

Furthermore, the scores of 'like-dislike' were modelled by imagery scores and colorimetric values together with form-related parameters. The coefficient of correlation (r) and coefficient of variation (CV) were used to determine the performance of preference models. The CV equation is given below:

$$CV = 100\sqrt{\frac{\sum (X_i - Y_i)^2}{N}} \Big/ \overline{Y} \qquad (1)$$

where X_i and Y_i are the prediction and the scores of 'like-dislike' for each sample i, respectively; N is the number of sample and $\overline{Y}$ is an average of Y_i. For CV of 0, it represents the predictions are agreed perfectly with the scores of 'like-dislike'.

Table 4: The correlation coefficients (r) were calculated between preference and the other imagery scales.

passive active	light heavy	old new	masculine feminine	sad happy	stale fresh	cruel kind	small large	classical modern	dangerous safe
0.33	-0.37	0.51	0.25	0.48	0.53	0.25	-0.33	0.13	0.30
angular rounded	soft hard	dirty clean	ugly beautiful	simple complex	empty full	weak strong	humorous serious	cool warm	dislike like
0.07	-0.16	0.59	0.86	-0.45	-0.09	-0.05	-0.16	-0.32	1.00

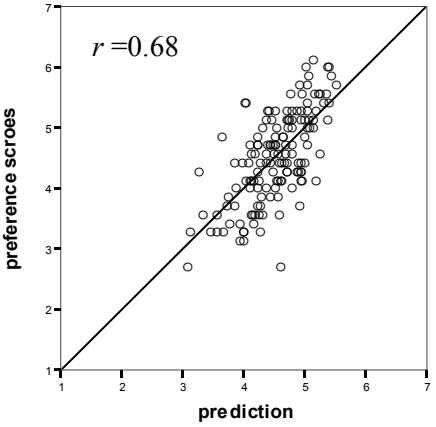

Figure 2: The scores of 'like-dislike' are plotted against those predicted by equation 1.

The coefficient of correlation (r) was first calculated to examine the relationship between the preference and the other imagery scales, as given in Table 4. The results show that 'beautiful-ugly' has the highest r of 0.86, followed by 'clean-dirty' 0.59, 'fresh-stale' 0.53, 'new-old' 0.51, 'happy-sad' 0.48 and 'complex-simple' -0.45, indicating that 'beautiful', 'clean', 'fresh', 'new', 'happy' and 'simple' imageries have positive correlation to preference. These imagery scales were used to fit the score of preference. Statistical analysis was carried out to find significant terms contributing to preference. Finally, equation 2 was developed to formulate preference with great performance.

$$P = 2.72 + 0.52 \times CD - 0.22 \times CS \qquad (2)$$

where CD and CS are 'clean-dirty' and 'complex-simple', respectively.

The results showed that only 'clean' and 'simple' imageries are sufficient to fit preference. The experimental data of 'like-dislike' is plotted against those predicted by equation 2 with an r of 0.68 and a CV of 12%, as shown in Figure 2. Overall, the agreement between the preference scores and predictions is quite good.

The second approach to model the preference was based on the colorimetric values. Again, the coefficient of correlation (r) was used to examine the relationship between preference and the colorimetric value, including lightness (L^*), chroma (C^*), hue angle (h), redness-greenness (a^*) and yellowness-blueness (b^*), together with form-related parameters, including basic form (B), volume (V) and surface area (A), where B is determined whether a form is basic or not. If it is a basic form, B=1 and B=0 for the intermediate forms. The results are shown in Table 5.

Table 5: The correlation coefficients (r) were calculated between preference and colorimetric values together with form-related parameters.

L*	***a****	***b****	***C****	***h***	***B***	***V***	***A***
0.02	-0.21	-0.37	-0.05	0.48	0.38	-0.24	-0.19

The results show that hue angle has the highest r of 0.48, followed 0.38 of B and -0.37 of b^*. This indicates that preference has positive relation to h and B, and negative relation to b^*. The experimental data of 'like-dislike' is plotted against the hue angle, as shown in Figure 3. It can be seen that the highest peak of trend is located around blue-purple region, the lowest around yellow (brown) region. Additionally, equation 2 implies that 'simple' imagery evokes preference, confirming B parameter is significant. Hence, hue angle and B parameter were involved to fit the preference, as shown in equation 3.

$$P = 3.22 + 0.03\sqrt{(a^*-15)^2 + (b^*-32)^2} - 0.37\cos(h - 133°) + 0.66B \qquad (3)$$

Equation 3 implies that hue angles of 65º (a^*=15, b^*=32) and 313º (133º + 180º) represent the most disliked colour and liked colour, respectively; also observers prefer basic forms to intermediate forms. The experimental data of 'like-dislike' is plotted against those predicted by equation 2 with an r of 0.72 and a CV of 13%, as shown in Figure 4.

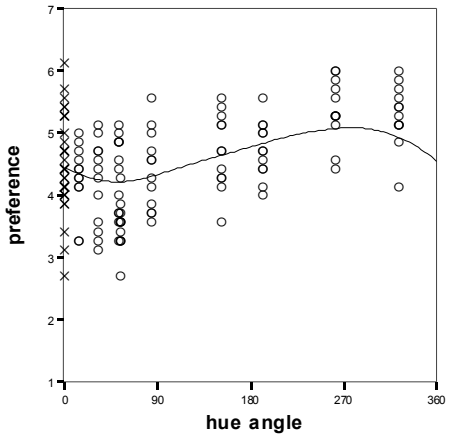

Figure 3: The scores of preference are plotted against hue angle.

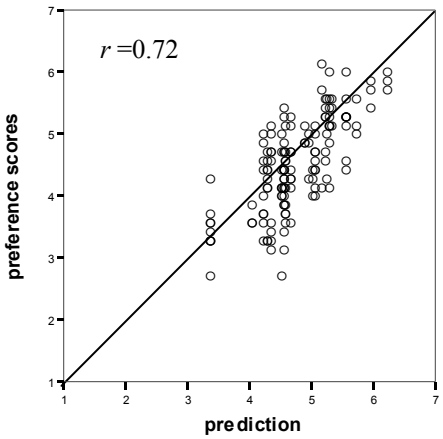

Figure 4: The scores of preference are plotted against those predicted by equation 2.

4. CONCLUSIONS

In this study, a psychophysical experiment was carried out to investigate the preference of colour-form combinations. Twelve colours and 12 three-dimensional forms were assessed on 20 imagery scales by 7 observers. In general, observers preferred blue and purple, and dislike brown colour. Furthermore, the preference models based on imagery scales and colorimetric values were developed. The imagery-based preference model showed that the imageries of 'clean' and 'simple' are sufficient to model preference. A colorimetric-based preference model was developed and revealed that the preference is mainly affected by hue angle and slightly by form-related parameter, indicating that observers do not like the colour-form combinations in the region of yellow, especially brown, but like them in the region of blue; also basic forms are more preferred. The predictions of both preference models were agreed with the experimental results.

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