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A Colour Design Tool Based on Empirical Studies

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Abstract

A colour design tool targeted at both unskilled consumers and professional designers is currently under development, on the basis of psychophysical studies into semantic associations of colour, the cultural influences and colour harmony. From experimental results for single-colour associations, 3 underlying factors were identified: "warm-cool", "heavy-light" and "active-passive", which were found to agree well with those identified by earlier research. For colour-combination associations, an "additive property" of colour association was discovered: the semantic score of a colour combination can be determined by averaging semantic scores of each constituent colour in that combination. According to the experimental results, there were 4 general patterns of colour harmony: similarity in hue and chroma, difference in lightness, high lightness and the hue effects. While the proposed colour design tool is still in its development stage and has a number of shortcomings, the system is believed to provide practical assistance and support not only for unskilled users but also for designers.

Keywords

colour design; colour harmony; colour association; cross-cultural study; e-shopping; colour decision-making; design process; psychophysical method

The increasing popularity of e-shopping has led to a trend for consumers to design colour schemes for products that they are purchasing. To assist such unskilled individuals in selecting colours from a vast amount of colours available to choose from, there are numbers of support tools available on the Internet, such as Adobe Kuler (http://kuler.adobe.com/). Most of these tools are based on conventional colour harmony theories such as "complementary", "analogous", "split complementary", "triadic" and "tetradic" (e.g. 1-2). While these online systems provide the user with possibilities of generating potentially harmonious colour schemes, they are incapable of giving advice as to whether a colour scheme suits the design requirements. With such systems, an unskilled user still needs to make colour decisions on their own without confidence.

The aim of the present project is to develop a colour design tool that helps unskilled individuals to solve colour selection problems by providing evaluation and testing of selected colour schemes in terms of semantic associations (e.g. feminine/masculine or warm/cool) and colour harmony. To achieve this, existing studies in these areas were surveyed, and a series of psychophysical experiments were conducted to derive quantitative models for use in the proposed colour design tool. Discussions of the developed system are provided at the end of the paper.

Literature Survey

A literature survey was conducted in the areas of semantic associations of colour and colour harmony. Studies of colour associations are thought to be crucial to the success of a colour design tool, as semantic associations of any design elements have been a useful method for designers to communicate with their clients. Colour harmony, on the other hand, has long been regarded as a representation of aesthetic aspects of colour, and thus becomes a requirement for a practical colour design system. The literature reviews are summarised in the following.

Existing research into single-colour associations

Empirical studies of single-colour associations are typically concerned with discovering underlying factors of any structural models of relationships between colour and semantic words. Conventionally, the method of semantic differential introduced by Osgood et al. (3) and the factor analysis first devised by Spearman (4) were used to accomplish such work.

For instance, Wright and Rainwater (5) used the factor analysis to study 48 colour-association scales and they identified 6 underlying factors: happiness, showiness, forcefulness, warmth, elegance and calmness. Hogg (6) identified 4 factors: impact, usualness, evaluation and warmth. The results showed that the factor "evaluation" was associated closely with the scale "pleasant-unpleasant". In a more recent study, Hogg et al. (7) identified 5 factors: dynamism, spatial quality, emotional tone, complexity and evaluation.

In his well-known "colour image scale" research, Kobayashi (8) identified 3 factors: warm-cool, soft-hard and clear-greyish. These 3 factors were found to agree well with those identified in a recent study by Sato et al. (9): warm-cool, potency and activity. The 3 factors, identified by both research, showed high correlations with hue, lightness and chroma, respectively.

In these studies, a few common factors seem to emerge, such as "warmth" and "evaluation". This suggests that there may be universal factors for colour associations, and that these factors are likely to be culture-independent, as the studies mentioned above were based on experimental data obtained in different countries, including the UK, US, Germany and Japan. This will be discussed in the present paper.

Existing research into colour-combination associations

Compared with the number of studies on single-colour associations, there were only a few investigations into colour-combination associations. For instance, Hogg (6) studied 12 colour associations for colour pairs, from which he identified 4 underlying factors: active-potency, evaluative, emotional tone and usual/obvious. Taking advantage of using the NCS (i.e. Natural Colour System), Sivik (10) investigated 100 semantic words, from which he identified 5 factors: evaluation, articulation, lightness, warmth and an unnamed factor that was correlated closely with 3 original scales "usual", "traditional" and "popular".

In a colour-association study for both single colours and colour pairs, Hogg (11) investigated 4 scales: pleasant-unpleasant, warm-cold, strong-weak and usual-unusual. He found that the semantic scores of "warm-cold" and "strong-weak" for a colour pair could be well predicted by the arithmetic mean of respective semantic scores for individual colours in that pair. This is perhaps the most important finding in this area and will be further verified in the present paper.

Existing research into colour harmony

There is a long tradition of research into colour harmony (e.g. 1-2, 12-17). However, none of the studies was found acceptable either in explaining the concept of colour harmony (18) or in providing accurate prediction (19-22). For instance, perhaps the most common assumption of creating harmony is a systematic selection of colours from a hue circle or from a specific "path" within an ordered colour space, e.g. those proposed by Goethe (12), Ostwald (13), Munsell (14) and Itten (2). Note this is only an assumption, which seems to be true only if the selected colours are presented in an ascending or descending sequence of hue, lightness or chroma. As Granville (8) pointed out, "it is the smooth visual progression through colour space that gives the harmonious results, not that the colours bear some unique harmonious relationship to each other."

Another approach to studying colour harmony was based on analysing interrelationships of colours, e.g. those by Chevreul (1) and Moon and Spencer (15-17). The general idea behind such studies was that colours could harmonise when they were complementary or analogous in either hue, lightness or chroma. While the definitions of "complementary" and "analogous" vary from study to study, they were determined by considering the effect of colour contrast between each constituent colour in a combination. The theories in this category have been tested experimentally, but none of them were found to be acceptable in providing an accurate prediction of harmony (20-22).

As a result, some artists claimed that there were no laws of colour harmony (e.g. 21) and that colour harmony was important only for scientists (23). However, the poor predictive performance of existing theories was perhaps due to the difficulties that the earlier studies encountered, e.g. a wide disagreement over the definition of colour harmony, a large number of factors that may influence colour harmony and a lack of modern colour-science techniques for the earlier studies.

Psychophysical Experiments

Following these reviews, we had some thoughts of how to plan psychophysical experiments:-

- According to existing studies of colour associations (e.g. 3-9), there seems to be universal factors of colour associations. This was examined in the present research using quantitative approach, as will be shown in Experiment 1. (24)
- Hogg (11) found that for "warm-cold" and "strong-weak" there was a strong link between semantic scores for single colours and those for colour

pairs, i.e. the average of the former could well predict the latter. We saw this as an important finding and thus conducted a test on this, as will be shown in Experiment 2. (25)

- A number of studies (e.g. 19-22) have shown that the existing theories of colour harmony were unacceptable in providing accurate prediction. To develop an empirical model of colour harmony, we used modern colour-science techniques in a visual assessment of harmony, as will be presented in Experiment 3. (26)
- The above experiments used only up to 2-colour combinations as the stimuli and each colour had the same size. To ensure these findings are feasible in the proposed colour design tool, we conducted Experiment 4 using 3-colour combinations with various sizes and sequences. (27)
- To see whether there are any cultural effects on semantic associations of colour and if yes, what these effects are, we conducted the fifth experiment in 6 countries: Britain, France, Germany, Spain, Sweden and Taiwan. (28)

What follows summarises the experimental results and main findings.

Experiment 1: Single-colour associations

The aim of the first experiment was to investigate semantic associations for single colours. Twenty NCS colour patches (3" by 3" in size, as shown in Figure 1) were used in the experiment as the stimuli, presented against a medium-grey background under a D65 daylight simulator in a viewing cabinet, situated in a darkened room. The experimental set-up is shown in Figures 2 (a) and (b).

Thirty-one participants, including 14 British and 17 Chinese with normal colour vision took part in the experiment. Each participant was presented individually with the 20 colour samples in a random sequence, and was asked to rate each colour using 10 semantic scales: warm-cool, heavy-light, modern-classical, clean-dirty, active-passive, hard-soft, tense-relaxed, fresh-stale, masculine-feminine and like-dislike. Torgerson's Law of Categorical Judgement (29) was used to transform the experimental data into interval scales.

The factor analysis identified 3 underlying factors of the 10 scales: warm-cool (WC), heavy-light (HL) and active-passive (AP). These 3 factors were found to agree well with those found by Kobayashi (i.e. warm-cool, soft-hard and clear-greyish) (8) and those by Sato et al. (i.e. warm-cool, potency and activity) (9). High correlations were found between each factor and colour appearance attributes such as hue, lightness and chroma. Predictive models for these factors were accordingly developed using CIELAB colour system (30), as given in the following:

$$WC = -0.5 + 0.02(C^*_{ab})^{1.07}\cos(h_{ab} - 50°) \quad (1)$$

$$HL = -2.1 + 0.05(100 - L^*) \quad (2)$$

$$AP = -1.1 + 0.03\left[(C^*_{ab})^2 + (L^* - 50)^2\right]^{\frac{1}{2}} \quad (3)$$

where L^*, C^*_{ab} and h_{ab} are lightness, chroma and hue angle in CIELAB, respectively.

These models mean that if an object's colour is known in terms of hue, lightness and chroma, its associated semantic feelings can be well predicted using these equations. Note, however, in our daily life colours are never seen in isolation. For instance, in this experiment, each single colour patch in the viewing cabinet was presented against a background colour - a medium grey; participants of the experiment were not watching a single colour, but actually a combination of a colour sample and the background. It is thus inappropriate to apply the models alone to any colour design. Having said that, we saw these models as a fundamental basis for any further studies into colour associations, and for this reason we conducted Experiment 2, as will be shown in the following.

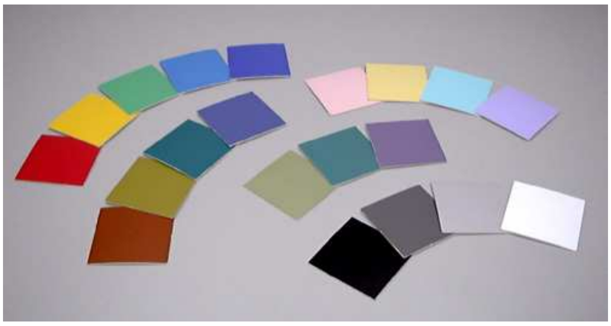


Figure 1 The 20 colour samples used in Experiments 1 and 2

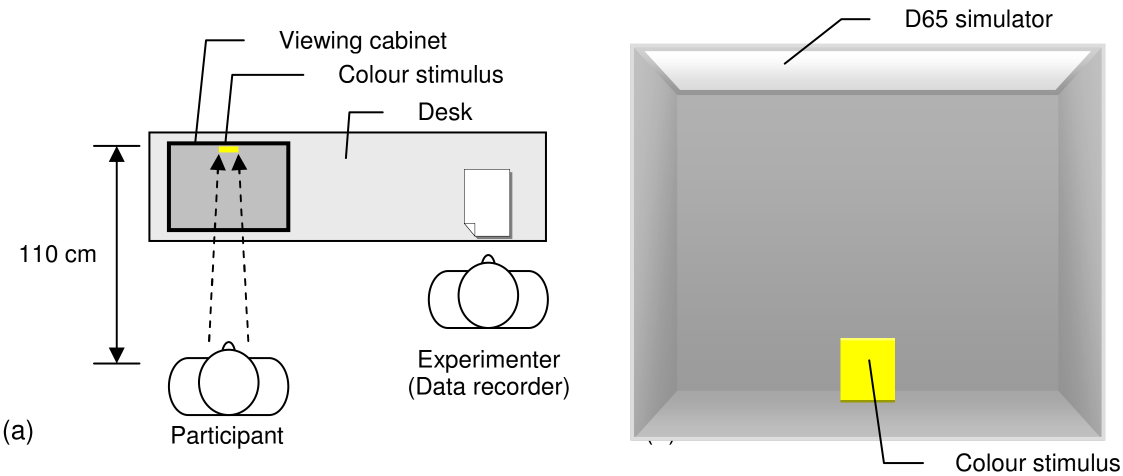


Figure 2 Device set-up for Experiment 1: (a) top view and (b) participant's view

Experiment 2: Colour-combination associations

The second experiment focused on semantic associations for two-colour combinations. The experimental procedure was exactly the same as that for Experiment 1 except that the stimuli used here were 190 colour pairs instead of 20 single colours, and that an eleventh scale "harmonious-disharmonious" was added into the visual assessments. The 190 colour pairs were all possible two-colour combinations generated by the 20 colours that were used in Experiment 1.

The experimental results show that the semantic score of each colour pair can be determined by averaging semantic scores of each constituent colour in that pair, as can be illustrated by the following equation:

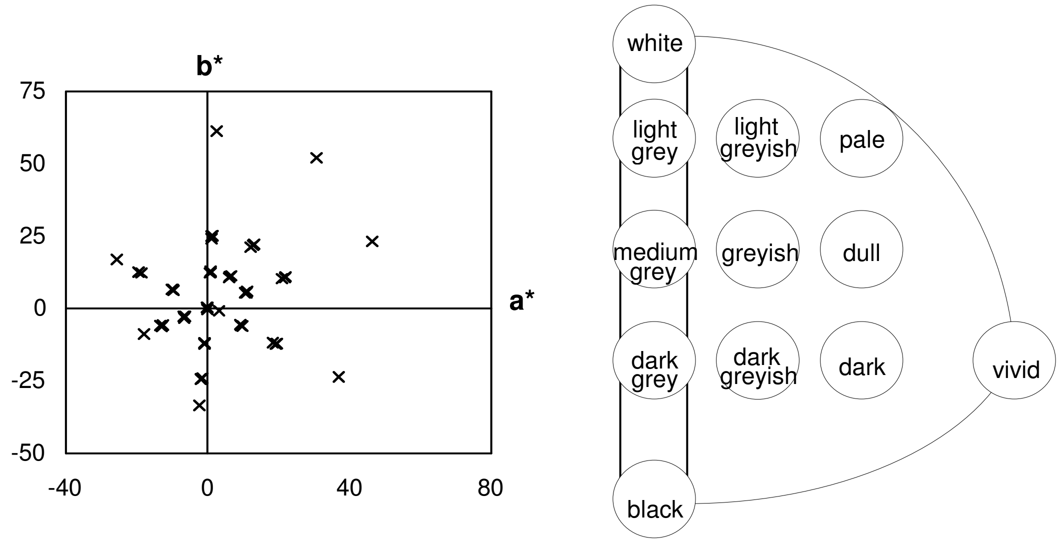
$$E = (E_1 + E_2)/2 \quad (4)$$

where E represents a semantic score for a colour pair made by colours 1 and 2; E_1 and E_2 are semantic scores for the 2 colours.

This "additive property" agrees well with Hogg's experimental results (11), in which similar phenomena were identified for scales "warm-cold" and "strong-weak". Note this finding applied to all semantic scales used in the present experiment, except for "harmonious-disharmonious" and "like-dislike". According to the experimental data, these 2 scales were highly correlated with each other, having a correlation coefficient of 0.85. This suggests a strong connection between a viewer's liking for a colour combination and the degree of harmony that this combination appears.

Experiment 3: Colour harmony

The third experiment investigated harmony for two-colour combinations. A total of 1431 colour pairs were used as the stimuli. These colour pairs were all possible two-colour combinations generated by 54 colours, which were selected systematically in CIELAB space, as illustrated in Figures 3 (a) and (b). Each colour pair was presented individually against a medium-grey background on a calibrated computer display, situated in a darkened room. Figure 4 shows a screen layout for the experiment.



(a) (b)

Figure 3 Distribution of the 54 colour samples used in Experiment 3 in (a) CIELAB colour space and (b) an equal-hue plane

Figure 4 Screen layout for Experiment 3

Seventeen participants naïve to the study, including 11 males and 6 females, took part in the experiment. Each participant finished all the 1431 colour pairs using the categorical judgement method (29). The experimental results show following common patterns about colour harmony:-

(a) *Equal-hue and equal-chroma*. Any two colours varying only in lightness tend to appear harmonious when presented adjacent to each other.

(b) *High lightness*. The higher the lightness value of each constituent colour in a colour pair, the more likely it is that they will appear harmonious.

(c) *Unequal lightness values*. Small lightness variations between the constituent colours in a colour pair may reduce the harmony of that pair.

(d) *Hue effect*. Among various hues, blue is the one most likely to create harmony in a two-colour combination; red is the least likely to do so. In addition, bright yellows more often create harmony in two-colour combinations than dark yellows (i.e. khaki colours).

On the basis of these patterns, a quantitative model of colour harmony was developed, as given in the following:

$$CH = H_C + H_L + H_H \tag{5}$$

in which

$$H_C = 0.04 + 0.53\tanh(0.8 - 0.045\Delta C)$$

$$\Delta C = [(\Delta H^*_{ab})^2 + (\Delta C^*_{ab}/1.46)^2]^{\frac{1}{2}}$$

$$H_L = H_{Lsum} + H_{\Delta L}$$

$$H_{Lsum} = 0.28 + 0.54\tanh(-3.88 + 0.029L_{sum}) \text{ in which } L_{sum} = L^*_1 + L^*_2$$

$$H_{\Delta L} = 0.14 + 0.15\tanh(-2 + 0.2\Delta L) \text{ in which } \Delta L = \left|L^*_1 - L^*_2\right|$$

$$H_H = H_{SY1} + H_{SY2}$$

$$H_{SY} = E_C\left(H_S + E_Y\right)$$

$$E_C = 0.5 + 0.5\tanh\left(-2 + 0.5C^*_{ab}\right)$$

$$H_S = -0.08 - 0.14\sin(h_{ab} + 50°) - 0.07\sin(2h_{ab} + 90°)$$

$$E_Y = \left[\left(0.22L^* - 12.8\right)/10\right]\exp\left\{\left(90° - h_{ab}\right)/10 - \exp\left[\left(90° - h_{ab}\right)/10\right]\right\}$$

where L^*, C^*_{ab} and h_{ab} are CIELAB lightness, chroma and hue angle, respectively.

Figure 5 provides a simple illustration of what this model means. Suppose we are looking for a colour to be combined with a cyan in order to generate a harmonious colour pair. According to Principle (a), the colours lying on the vertical line that goes through this cyan (i.e. the line containing the blue and the red arrows) are most likely to create harmony with the cyan. According to Principle (b), the colours located in the direction of the blue arrow are better choices than those following the red arrow. According to Principle (c), the colours within the range of the yellow arrows should be avoided as they are too close (in terms of lightness) to the example cyan colour. Thus, colours on the line of the blue arrow and above the yellow-arrow region are the preferred solutions.

Note, however, that the model was developed using only two-colour combinations, in the form of flat colour patches placed side by side on a medium-grey background, and that the experimental participants were all Chinese students studying in the UK. Therefore, this model may not necessarily apply to all kinds of colour combinations, shapes, textures, or to all age groups and all sorts of cultural backgrounds.

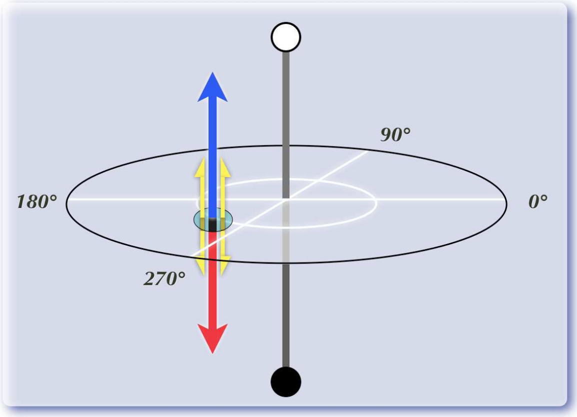


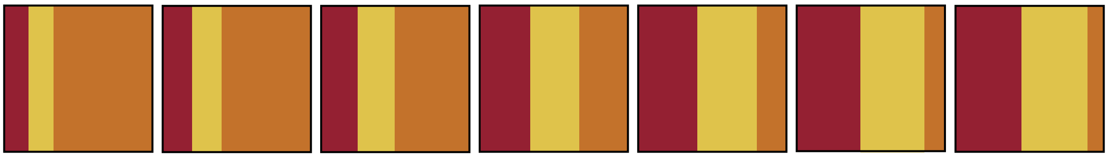
Figure 5 A graphical representation of the colour harmony model in CIELAB colour space

Experiment 4: Effects of colour sequence and area proportion

To see whether the models developed in the previous experiments also apply to different experimental conditions, we carried out an experiment using three-colour combinations as the stimuli, each containing constituent colours with various sizes.

The experimental procedure was exactly the same as that for Experiment 3 except that the stimuli used here were 420 three-colour combinations with various sizes, rather than 1431 two-colour combinations with the same size; in addition, the present experiment used "warm-cool", "heavy-light", "active-passive" and "harmonious-disharmonious" as the testing scales.

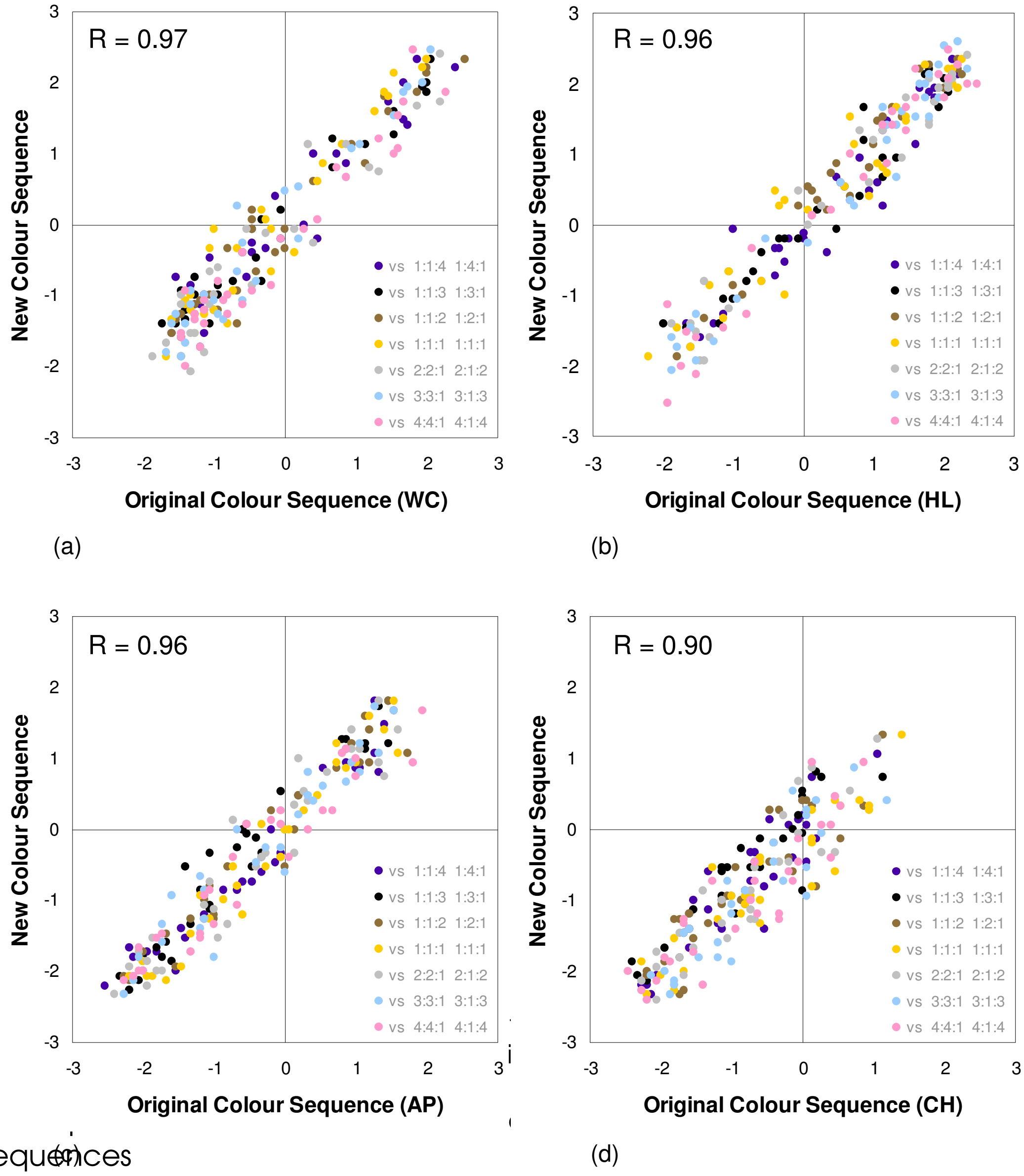
(a)



(b)

Figure 6 Layout designs for (a) original sequences (1:4:1), (1:3:1), (1:2:1), (1:1:1), (2:1:2), (3:1:3) and (4:1:4); (b) new sequences (1:1:4), (1:1:3), (1:1:2), (1:1:1), (2:2:1), (3:3:1) and (4:4:1).

The 420 stimuli consisted of 30 original three-colour combinations, each having 14 layout designs including various area proportions and different colour sequences. Figures 6 (a) and (b) show an example for combinations of red, orange and yellow. The 30 original three-colour combinations were generated randomly by the 54 colours used in Experiment 3. Fifteen Chinese participants, including 7 males and 8 females, took part in the experiment.



F ... m-

T ... our sequences

for all the 4 semantic scales, with a correlation coefficient of 0.97 for "warm-cool", 0.96 for "heavy-light", 0.96 for "active-passive" and 0.90 for "harmonious-disharmonious". These are shown in Figures 7 (a) to (d), respectively.

We used the experimental data to test the "additive property" of colour associations as illustrated in Eq. (4). The results show strong evidence that the additive property not only works for two-colour combinations with equal size, but also for three-colour combinations with different colour sizes, with a correlation coefficient between visual results and predicted values of 0.85 for "warm-cool", 0.92 for "heavy-light" and 0.82 for "active-passive". The additive property can thus extend into a more general form: the semantic score of a colour combination can be determined by averaging semantic scores of each constituent colour in that combination, whatever the area proportions for constituent colours. A similar additive property was found to apply to harmony for combinations of 3 colours, with a correlation coefficient of 0.81 between visual results and predicted values.

These findings mean that the models of colour associations and harmony developed in previous experiments, i.e. Eqs. (1) - (3) and (5), are practically useful for colour selection, especially in the evaluation stage of colour design. These models are thus adopted in the proposed colour design tool.

Experiment 5: Effects of cultural difference on colour associations

To see whether there are any cultural effects on colour associations, visual assessments were carried out in 6 countries: Britain, France, Germany, Spain, Sweden and Taiwan. The experimental procedure was exactly the same as that for Experiment 3 except that the stimuli used here were 190 colour pairs instead of 1431 colour pairs, and that the semantic scales used here included "warm-cool", "heavy-light", "active-passive" and "like-dislike". The 190 colour pairs were exact reproductions of those used in Experiment 2. To ensure accurate colour reproductions on different computer monitors, the GOG characterisation method (31) was used. A total of 123 participants, including 12 British, 30 Taiwanese, 21 French, 20 German, 20 Spanish and 20 Swedish, took part in the experiment.

Table 1 Correlation coefficients of semantic scores between the 6 countries

		British	Chinese	French	German	Spanish	Sweden	Mean
Warm-cool	British		0.83	0.82	0.83	0.86	0.80	
	Chinese			0.90	0.85	0.87	0.82	
	French				0.88	0.88	0.82	
	German					0.92	0.91	
	Spanish						0.89	
	Mean	0.83	0.85	0.86	0.88	0.88	0.85	0.86
Heavy-light	British		0.90	0.88	0.87	0.87	0.84	
	Chinese			0.92	0.93	0.90	0.92	
	French				0.90	0.89	0.87	
	German					0.88	0.96	
	Spanish						0.85	
	Mean	0.87	0.91	0.89	0.91	0.88	0.89	0.89
Active-passive	British		0.79	0.80	0.81	0.86	0.86	
	Chinese			0.91	0.91	0.88	0.84	
	French				0.94	0.88	0.90	
	German					0.90	0.91	
	Spanish						0.93	
	Mean	0.82	0.87	0.89	0.89	0.89	0.89	0.87
Like-dislike	British		0.73	0.66	0.78	0.05	0.69	
	Chinese			0.64	0.79	0.26	0.76	
	French				0.66	0.06	0.41	
	German					0.14	0.65	
	Spanish						0.06	
	Mean	0.58	0.64	0.49	0.60	0.12	0.51	0.49

As a result, the experimental data were found to agree well between the 6 countries for scales "warm-cool", "heavy-light" and "active-passive", while significant differences were found in the "like-dislike" scale, especially between Spanish data and those obtained from the other 5 countries. The findings are summarised in Table 1.

The experimental data suggest a main difference between Spanish results and the remaining participant groups: the Spanish participants tended to prefer colour pairs with small lightness difference, while the other participants tended to prefer colour pairs with large lightness difference.

The reason that only "like-dislike" showed significant differences between these countries is likely that the liking for colours is a reflective-level cognitive process and is perhaps more subjective, and that scales "warm-cool", "heavy-light" and "active-passive" involve only reactive-level cognition and are perhaps more difficult to be conditioned by cultures.

Developing a Colour Design Tool

As mentioned earlier in this paper, existing colour scheming tools were found to have a number of shortcomings:-

- There is no evaluation of colour selection in the existing tools in terms of either semantic associations or harmony. Evaluation can be seen in any design process models: from Archer's model (32) during 1960s to Design Council's recent Double Diamond model (33). In our view, evaluation by a design support tool plays an even more crucial role in the design process that involves unskilled users (i.e. consumers) who have little confidence about whether the colours selected suit specific requirements.
- Some of the tools do recommend potentially harmonious colour schemes, but the recommendations are based on theories rather than empirical research.
- These tools use device-dependent colour spaces such as display RGB and CMYK. This makes it impossible for the user to accurately reproduce selected colours and thus lacks practical value. Device-independent colour systems such as CIELAB, Munsell or NCS should be used instead.

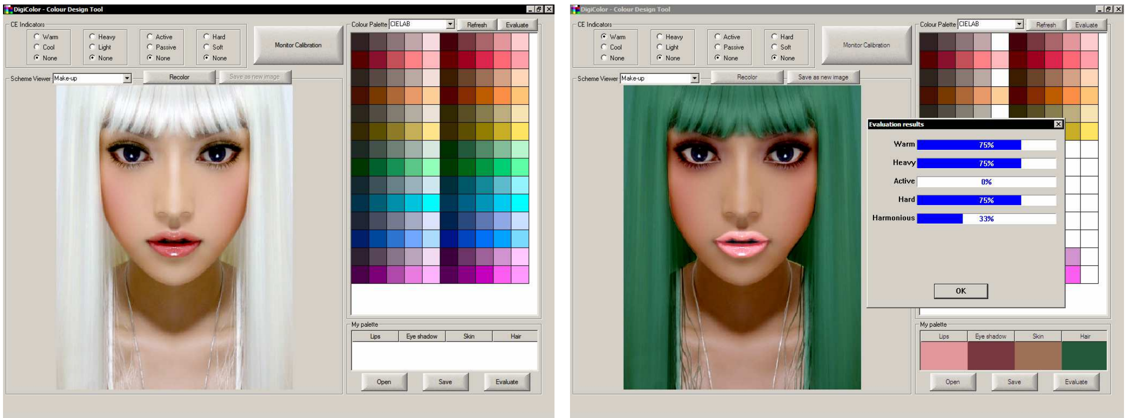
To develop a colour design tool that overcomes the above problems, we integrated quantitative models derived in the present research with modern imaging technologies. A first version of the system is shown in Figures 8 (a) and (b). This system allows the user to filter out an original, vast colour palette into a smaller amount of colours by specifying semantic feelings (e.g. warm/cool), and to create harmonious colour schemes by selecting colours recommended by the harmony model derived in this study. The software also allows the user to test colour schemes by presenting simulated coloured images of the design, together with quantitative evaluation (provided by the software) of selected colour schemes in terms of semantic associations and harmony.

Note, however, this is only the first version and several defects were already found in the system:-

- The evaluation of colour selection provided by the system is helpful in defining design problems (i.e. to develop a harmonious colour scheme associated with specific semantic feelings), but does not seem to be helpful in exploring new ideas.

- Models of colour associations and harmony may only apply to specific layout designs (as the experimental stimuli are all based on flat colour patches rather than natural images) or specific industry sectors (as the experiments did not consider any effects of contexts).
- Lack of consideration of other design elements such as shape, texture and product functionality.

There are other issues worth our attention, such as how the system can influence the design process involving unskilled users/professional designers, how the system may affect current colour education and how the system may influence marketing activities. It is believed that the system can at least provide some practical assistance and support for both unskilled individuals and designers.



(a) (b)

Figure 8 The first version of the colour design tool, taking cosmetics as an example: (a) before and (b) after colouring

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