Effect of spatial colour sequence with minimum distance on human colour impression and its model

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Abstract: The present study investigates the effect of the fundamental six-colour (cyclic) sequence on human colour impression. The different effects of two spatial sequences are investigated under the consideration of a hexagonal diagram that is a projection of RGB colour space from white to black. The hexagonal diagram corresponds roughly to the hue circle indicated by both hue and saturation in an HLS system. The projected route area indicates the magnitude of naturalness (as in rainbows) for colour sequences. The minimum sequence is similar to the order of colours in rainbows, whereas the non-minimum sequence is completely different. Therefore, a human colour impression model is proposed using the projected route area indicated by both hue and saturation. It is clarified that the majority of subjects of nearly all ages has a natural impression when the minimum route area is large. In addition, the human colour impression is compared with the human colour impression model. This model is intended to be employed in order to design commodities, goods, buildings, and towns to have the most effective colour sequence.

Keywords: spatial colour sequence, minimum distance, human colour impression, natural–unnatural, RGB colour space, hexagonal diagram, route area, HLS (hue, lightness, saturation) system, human colour impression model

1   INTRODUCTION

The different effects of temporal colour sequences of several colours on human colour impression have been examined in a previous study [1]. These effects were investigated for subjects in an analysis of colour sensation to determine whether a several-colour cyclic sequence has a minimum distance in red, green, and blue (RGB) colour space. Several terms are commonly used to describe the character and associative meanings of colours [2]. The degrees of pairs of terms applied to colour sequences, such as natural–unnatural, were investigated herein. The term 'natural' expresses a human colour impression that invokes calm, flowing, and relaxed feelings,

whereas the term 'unnatural' expresses a human colour impression that invokes intense, tight, and unpleasant feelings. Well-ordered colour signal sequences having a minimum distance (minimum sequences) were found to elicit responses of a degree of naturalness. In contrast, randomly ordered colour signal sequences having no minimum distance (non-minimum sequences) were found to elicit responses of a degree of unnaturalness. Two terms were adopted, natural and unnatural, based on questionnaires given to 31 subjects. Two terms, natural and complex (or unnatural), were also described in reference [3].

The human colour impression experiments of the present study are explained in detail, and human colour impression and the human colour impression model are compared using the projected route area based on the experimental results. This model will provide spatial colour sequences for emotional control, coordination, and similar applications.

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2 METHODS

2.1 Colour sequences

A system of the three primary colours, red, green, and blue (RGB) is presented in a cubic colour space. The system of three primary colours is used in the present study. As Fig. 1 shows, blue, cyan, green, yellow, red, magenta, white, and black are abbreviated as B, C, G, Y, R, M, W, and S, respectively. For example, six fundamental colour coordinates are selected as (r_1, g_1, b_1), (r_2, g_2, b_2), …, (r_6, g_6, b_6), where r_n, g_n, and b_n are the red, green, and blue components, respectively, of the nth colour. It is possible to compute the minimum distance of coordinates. The minimum sequences having the same colours are presented as a six-colour (cyclic) sequence. Four types (type A: six fundamental colours; type B: five
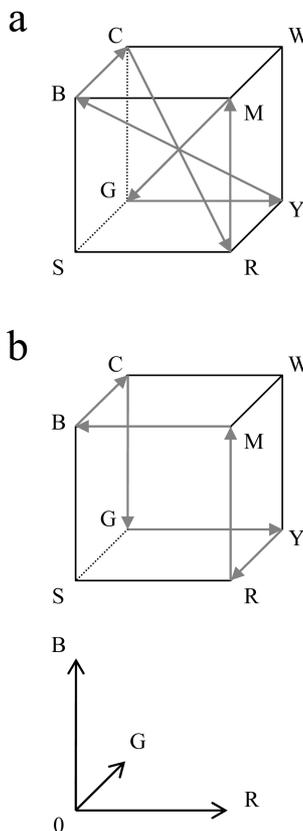

Fig. 1 Two typical routes (a: non-minimum and b: minimum) of the type A colour sequence in the RGB colour space

Table 1 Number of subjects in the experiment

No. of subjects	Male	Female	Age
130	58	72	6–85

fundamental colours and orange; type C: six intermediate colours; type D: six magenta–blue relevant colours) were prepared as spatial colour sequences with minimum distance [4]. The minimum cyclic route is blue, cyan, green, yellow, red, magenta, and blue again in type A. In a cubic colour space (Fig. 1), RGB values are ranged from 0 to 255. In type A, for example, the sum of the distances is 2290 for the non-minimum route (BCRMGY&B) a) and 1530 for minimum route (BCGYRM&B) b). The distance of the minimum route is clearly smaller than that of the non-minimum route.

In the present paper, only the minimum sequence is employed in each type, and the subjects compared the sequences as shown in Figs 2(a)–(c). As shown in Fig. 2, three types of sequences, denoted as a, b, and c are displayed. The sequences are toroidal, linear, and circular. A linear sequence of six colours was used in a previous study [4]. The circular sequences obviously differ from the toroidal sequences with respect to impression, even when the six colours are presented in the same order. It is believed that subjects feel that the six colours mix near the centre of the circle in the circular sequence. The subjects compared four sequences, denoted types A through D, for each sequence type.

2.2 Experiments

A total of 130 undergraduate, graduate students, employees, and participants of a university festival volunteered for the experiments of the present study (see Table 1). The subjects sat in a chair and were requested to watch a display continuously. Using a graphical user interface (GUI) for the questionnaire, the subjects compared the sequences as shown in Figs 2(a)–(c). Different sequences consisting of six colours, denoted types A–D, were presented during several minutes. One colour sequence that the subject had a natural impression was selected from the four minimum sequences (see Figs 2(a)–(c)). The experiments were performed in an isolated area in order to restrict visual cues to the display.

2.3 Equipment

A Sharp 11.3" liquid crystal display was used to present the stimulus pattern. The display resolution was 1024×768 pixels/60 Hz.

3 EXPERIMENTAL RESULTS

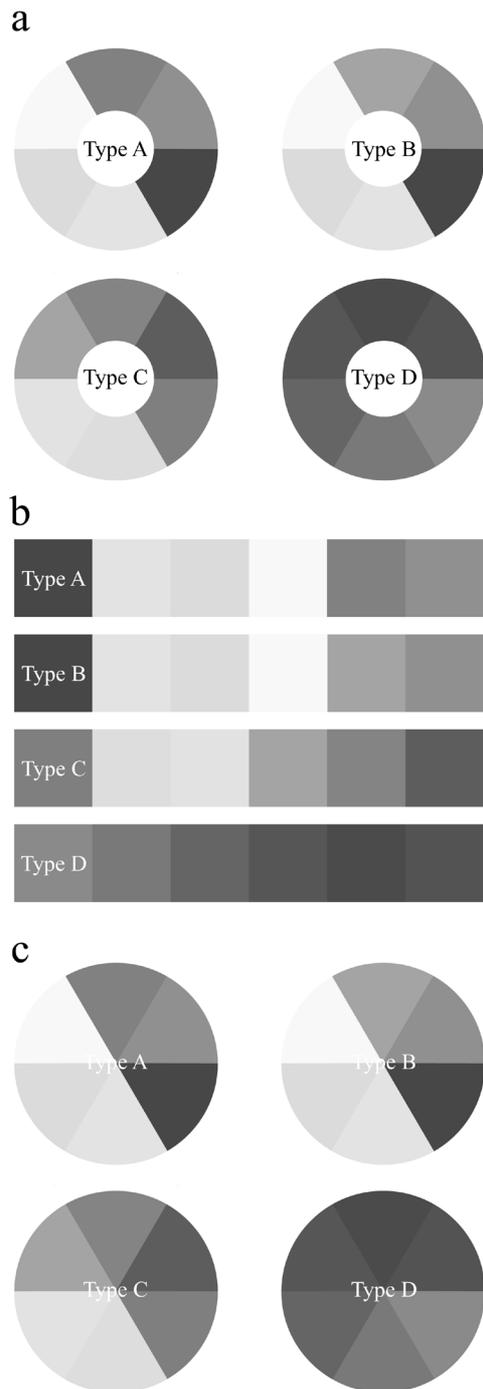This experiment was conducted in order to determine whether the colour impression for spatial colour

Using a GUI for the questionnaire, the selection of the sequence type (minimum sequence) that gave the subject a natural impression was investigated. The minimum cyclic route is blue, cyan, green, yellow, red, magenta, and blue again in type A. Six sets (BCGYRM), (MBCGYR), (RMBCGY), (YRMBCG), (GYRMBC), and (CGYRMB) are treated as the same minimum sequence.

Table 2 lists the characteristics of each type of input and the responses of 130 subjects. The minimum projected route distance and the maximum projected route area in each type are listed in Table 2 sections (a) and (b). In Table 2 section (c), the majority (more than approximately 66 per cent) of the subjects prefer the minimum sequence of type A or type B. The projected route distances are directly proportional to the projected route areas for the minimum sequence in this case (see also Fig. 5 below).

In the hexagonal diagram (Fig. 3), for example, the projected minimum route is formed by (BCGYRM&B) and the projected minimum route area is the inside enclosed by route (BCGYRM&B) in type A. It is visually recognized that the projected route distance and route areas are decreasing from type A to type D in Fig. 3. For instance, the projected minimum route of type A indicates a hexagon (with filled points) of (BCGYRM&B). Circles correspond to the hue circle in the HLS (hue, lightness, and saturation) system.

The relationship between the number of subjects, the projected route distance, and the projected route area are examined in Fig. 4. The number of subjects who responded for the toroidal sequences is denoted by squares, that for the linear sequences is denoted by triangles, and that for circular sequences is denoted by circles. This trend indicates exponential approximation. It is clear that the majority of the subjects assigned (had the impression) 'natural' to the minimum sequence of a long projected route and a large projected route area (see Table 2).

Figure 5 shows the proportional relationship between projected minimum route distance and minimum route area. This trend indicates a linear approximation. The characteristics are dependent on each type.

Fig. 2 Three types of colour sequences, a: toroidal, b: linear, and c: circular

sequences can be expressed by simple adjectives, such as 'natural'. One possible tour (60) in the three-dimensional RGB colour space was used. Four (circuitous) routes were selected based solely on minimum distance. One suitable colour sequence that gave the subject a natural impression was selected from the four minimum sequences (see Figs 2(a)–(c)).

4 HUMAN COLOUR IMPRESSION MODEL

In this section, the effect of the six-colour sequence on human colour impression is investigated. In order to investigate the different effects of two sequences, a hexagonal diagram that is a projection of RGB colour space from white (black) to black (white) is

Table 2   Characteristics of each type of input and responses

Type	(a) Route distance	(b) Route area	(c) Total response (%)	(d) Toroidal	(e) Linear	(f) Circular
A	1247.6	112320	33.6 (131/390)	51	35	45
B	1210.7	102960	33.1 (129/390)	39	45	45
C	1080.4	84240	23.6 (92/390)	27	34	31
D	518.8	6822	9.7 (38/390)	13	16	9

(a) The projected route distance is the minimum; (b) the projected route area is the maximum; (c) total responses (number of subjects that selected the minimum sequence of each type as a natural colour sequence); (d) responses for toroidal sequences; (e) responses for linear sequences; and (f) responses for circular sequences.
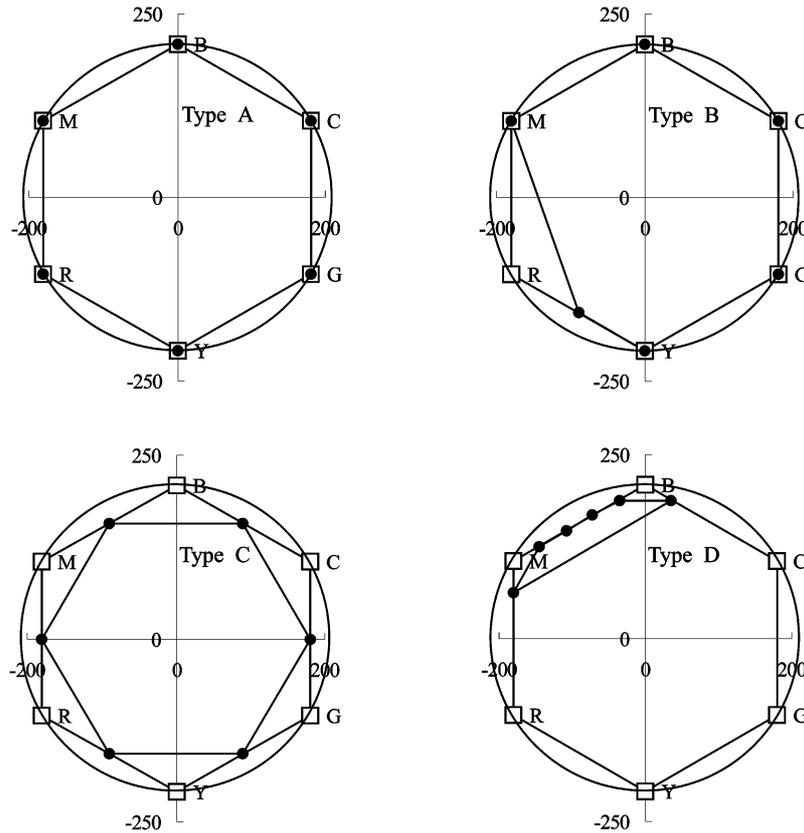
Fig. 3   Projected route area on a hexagonal diagram

considered. The hexagonal diagram in Figs 6(a) and (b) (see Fig. 1) corresponds roughly to the hue circle (top view) indicated by both hue and saturation (except for lightness) in the HLS system. Numbers denote the order of each colour corresponding to the arrows from the previous colour to the present (target) colour.

If the projected route distance is nearly the minimum, each saturation is large (each point is far from the center), and neighbouring colours are not too close to each other (on the hexagon), then the projected route area is assumed to be large. The route area indicates the magnitude of naturalness (as a rainbow effect) for colour sequences. The minimum sequence is similar to the order of rainbow colours, which are composed of the following wavelengths [5]: violet (400–430 nm), indigo (440–460 nm), blue (470 nm), green (505 nm), yellow (575 nm), orange (590–620 nm), and red (>630 nm), where orange is yellow–red, indigo is dull blue, and violet is purple–blue. On the other hand, the non-minimum sequence is completely different from the order of rainbow colours.

Although the six colours used in the previous study [4] are not distributed as rainbow colours (violet, indigo, blue, green, yellow, orange, and red), and the six-colour cyclic sequences are not continuous sequences having gradation, a human colour impression model is proposed using the route area indicated by both hue and saturation. This model
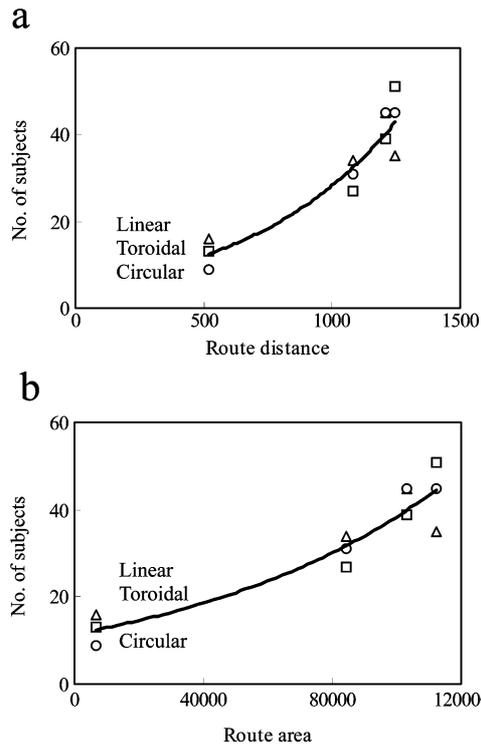
a

b

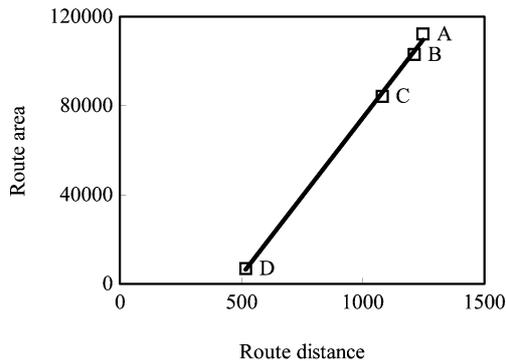**Fig. 4** Relationship between projected route distance, route area, and number of subjects

Fig. 5 Relationship between projected minimum route distance and minimum route area

[**6–8**] invokes natural impressions when the route area is large (Fig. 6(b)) and unnatural impressions when the route area is small (Fig. 6(a)).

5 MODELLING RESULTS AND DISCUSSION

In the hexagonal diagram (Fig. 6), two typical projected routes and projected route areas of the human colour impression model are investigated using six fundamental colours (at the six corners). Each colour has maximum saturation, and the projected neighbouring colours are widely spread in this case. For instance, the non-minimum route (blue, cyan,
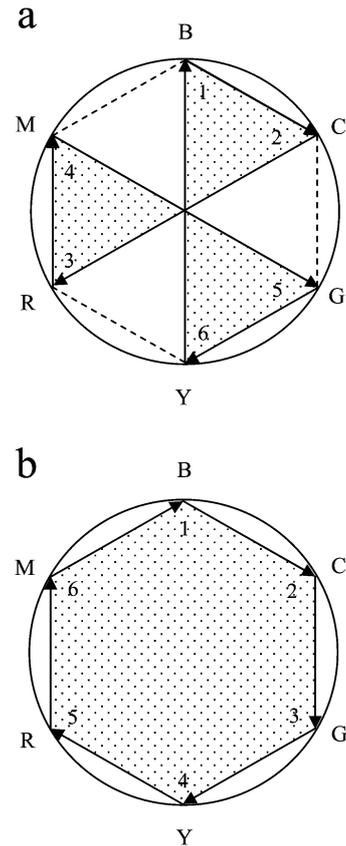
a

b

Fig. 6 Two projected routes (indicated by arrows) and projected route areas (indicated by dotted regions) for six fundamental colours in the type A colour sequence

red, magenta, green, yellow, and blue again), shown in Fig. 6(a), includes the order of complimentary colours, but this is not so for the maximum route. The minimum route (blue, cyan, green, yellow, red, magenta, and blue again) is shown in the hexagon of Fig. 6(b). The movement order is clockwise. The dotted regions show the projected route areas. If the sides are of unit length, then the ratio of the non-minimum projected route distance to the minimum projected route distance is 1.5, and the ratio of the non-minimum route area to the minimum route area is 0.5.

The distances are only calculated in RGB colour space, and not in HLS colour space, because hue represents the angle in degrees. However, hue, lightness, and saturation of the HLS system are available for analysis of colour sensation. In the present study, hue and saturation, rather than lightness, are important. Almost no difference exists between the projected routes in the RGB system and those in the HLS system.

In the previous simulation results for six fundamental colours of type A [**4**], the relationship between

the order of projected route distances and route areas shows a decreasing trend having fluctuations (see Fig. 7). These fluctuations become larger for increasing order.

The simulation results for six colours indicate that as the route distance (dotted line) increases, the route area (solid line) decreases, and numerous fluctuations occur. The result for six magenta–blue relevant colours (type D) is not equal to that for six fundamental colours (type A). The results for six fundamental colours and those for six magenta–blue relevant colours differ. However, the relationship for each type shows a similar trend. It was clarified that the characteristics of colour sequences, for which the colour impression of the subject becomes 'natural', exists in the dashed rectangle of Fig. 7.

This implies that the route area indicates the magnitude of naturalness (vertical arrow in Fig. 7) for colour sequences in our model. In addition, the route area is roughly proportional to the response of subjects [6–8]. The present study clarifies that the majority (more than approximately 66 per cent) of subjects choose the minimum sequence of type A or type B (rather than that of type D), when considering the 'natural colour sequence'.

6   CONCLUSIONS

In the present paper, a human colour impression model that indicates the degree of perceived naturalness was proposed using the projected route area. Simulation results suggest that if the projected route distance is minimum, or nearly minimum, then the human colour impression becomes 'natural', otherwise the human colour impression becomes 'unnatural'. The projected route distances are directly
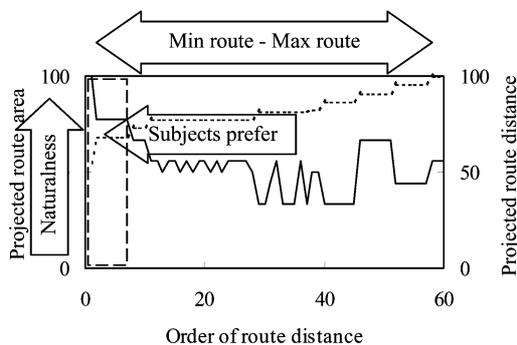

Fig. 7   Relationship between projected route distance (dotted line), projected route area (solid line), and order of projected route distance (from the 1st to 60th route) for six fundamental colours in the type A colour sequence
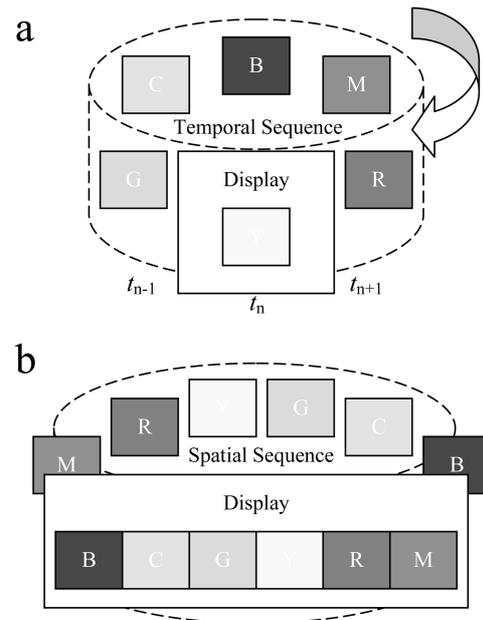

Fig. 8   Relationship between temporal and spatial information

proportional to the projected route areas. However, the route area roughly shows an exponential trend to the response of subjects in this case.

The proposed model will also enable the design of a row of suitable colours (as spatial information in Fig. 8(b)) for the control of feeling and emotion (for example, in signboards, tile floors, or gardening), as well as design using colour signal sequences (as a temporal information in Fig. 8(a)) [9], [1] based on single colour effects [10].

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