Application of colour feelings prediction formulas to the estimation of two-colour combination feelings of "Kimono"

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This research aimed to examine the applicability of the colour feelings prediction formulas developed by Nayatani *et al.* to the estimation of colour combination feelings of "kimono" by deeming "kimono" as a two-colour combination of *nagagi* and *obi*. Using illustrations of a woman wearing a "kimono", we conducted an evaluation experiment of colour combination feelings on "contrast", "floridness", "warmth", "pleasantness", "refinement", "beauty", and "lucidity" and analysed the correlation between the estimation values obtained by the colour feelings prediction formulas and the evaluation values. As a result, the following conclusions were reached.

1. The colour feelings prediction formulas are effective in estimating the colour combination feelings of "kimono", whereas the estimation accuracy of "contract" and "pleasantness" is lower than that of "floridness" and "warmth".
2. "Contrast" and "floridness" are highly similar feelings.
3. "Pleasantness", "refinement", "beauty", and "lucidity" are emotions that are similar to each other. Among these four types of colour combination feelings, "pleasantness" and "beauty" have the highest similarity, and "pleasantness" and "lucidity" have the lowest similarity.
4. The estimation value of "pleasantness" correlates better with the evaluation value of "lucidity" than with the evaluation value of "pleasantness".

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Introduction

"Kimono" is not only a traditional Japanese national costume but also a garment that is still practically used in modern life, although less frequently. "Kimono" is standardised clothing consisting of *nagagi* (ankle-length garment) and *obi* (sash belt). Therefore, its impression is influenced by elements, such as colours, patterns, and textures, rather than shapes. However, no research has been done to quantitatively analyse how colours, patterns, texture, and the like affect the impression of a "kimono".

Meanwhile, research on colour harmony has a long history [1-2], and models for predicting colour emotions and colour harmony using colourimetric values have been proposed [3-4]. Furthermore, based on the comparative review of the international visual evaluation experiment results on colour emotions and colour harmony, it has been made clear that colour emotions, such as warm/cool, light/heavy, and active/passive, are universal, whereas colour preference, such as like/dislike, is influenced by the cultural backgrounds of observers [5-6]. Therefore, we focused on the colour feelings prediction formulas developed by Nayatani *et al.*, which are the results obtained from Japanese observers [7]. This study aimed to examine the applicability of the colour feelings prediction formulas to the estimation of colour combination feelings of "kimono" by deeming "kimono" as a two-colour combination of *nagagi* and *obi*. This study is the first step to developing a colour combination design assistance tool for "kimono".

Colour feelings prediction formulas

From the mid-1960s to the early 1970s, the Colour-Harmony Committee was organised mainly by Nayatani and other experts in psychology, statistics, and physics. To establish an academic system for colour harmony, the Committee conducted large-scale evaluation experiments and rigorous analyses [8-11]. During the research period, a total of 682 observers participated in the experiments, and a total of 784 stimuli were evaluated.

Based on the results of the evaluation experiments of colour combination feelings using 38 rating scales, four major factors comprising the colour feelings of two- and three-colour combinations were extracted using the SD method, and they were named "contrast", "floridness", "warmth", and "pleasantness", respectively [10]. Moreover, the colour feelings prediction formulas were derived to estimate these factors from Munsell notation values. The prediction formulas were intended to estimate general colour emotions and colour harmony without assuming such specific applications as clothing, home appliances, architecture, and so on. The method for calculating the estimation values of the four major factors of colour combination feelings is shown below.

The estimation value of the "contrast" factor is expressed as the sum of the colour difference between the component colours and the value of higher Munsell Chroma among them, as shown in Formula (1):

$$x_{\mathrm{c,AB}} = 2\Delta E_{\mathrm{AB}} + 3C_{\mathrm{max,AB}} \tag{1}$$

where $x_{\mathrm{c,AB}}$ is the estimation value of the "contrast" factor, ΔE_{AB} is the colour difference between the component colours based on the Godlove colour difference formula [12], and $C_{\mathrm{max,AB}}$ is the value of higher Munsell Chroma in component colours.

The estimation value of the "floridness" factor is expressed as the sum of the "floridness" factors of each of the component colours, as shown in Formula (2):

$$x_{\mathrm{f,AB}} = x_{\mathrm{f,A}} + x_{\mathrm{f,B}} \tag{2}$$

where $x_{\mathrm{f,AB}}$ is the estimation value of the "floridness" factor of a two-colour combination, and $x_{\mathrm{f,A}}$ and $x_{\mathrm{f,B}}$ are the estimation values of the "floridness" factor of the component colours A and B, respectively. The estimation value of the "floridness" factor of a single colour is obtained from Formula (3):

$$x_{\mathrm{f,i}} = f(H_{\mathrm{i}}) + 0.2(V_{\mathrm{i}} + 0.5C_{\mathrm{i}})^2 \tag{3}$$

where $f(H_i)$ is the value determined by the Munsell Hue of a component colour i, and V_i and C_i are the Munsell Value and Munsell Chroma of the component colour i, respectively.

Subsequently, Nayatani *et al.* [7] proposed a method to obtain the estimation value of the "floridness" factor of a single colour using the multiple regression formula consisting of nine explanatory variables [Formula (4)]. In this study, however, we calculated the estimation value of the "floridness" factor using Formula (3), which correlates better with the results of the evaluation experiment of the colour combination feelings. The details are described in the Results and Discussion section.

$$x_{\mathrm{f,i}} = a_0 + \sum_{\mathrm{n=1}}^{9} a_{\mathrm{n}} x_{\mathrm{n,i}} \tag{4}$$

The estimation value of the "warmth" factor is expressed as the sum of the "warmth" factor for each component colour, as shown in Formula (5):

$$x_{\mathrm{w,AB}} = x_{\mathrm{w,A}} + x_{\mathrm{w,B}} \tag{5}$$

where $x_{\mathrm{W,AB}}$ is the estimation value of the "warmth" factor of a two-colour combination, and $x_{\mathrm{W,A}}$ and $x_{\mathrm{W,B}}$ are the estimation values of the "warmth" factor of the component colours A and B, respectively. The estimation value of the "warmth" factor of a single colour is obtained by Formula (6):

$$x_{\mathrm{w,i}} = b_0 + \sum_{\mathrm{n=1}}^{9} b_{\mathrm{n}}\, x_{\mathrm{n,i}} \tag{6}$$

where $x_{\mathrm{W,i}}$ is the estimation value of the "warmth" factor, b_0 is the constant, b_n is the partial regression coefficient, and $x_{\mathrm{n,i}}$ is an explanatory variable determined by the locations of component colours in the Munsell colour space and their combinations. Formula (6) is a revised version of the prediction formula with improved compatibility with computer processing [7].

When the area ratio of component colours A and B in a two-colour combination is α: $(1 - \alpha)$, Formulas (2) and (5) are expressed as follows:

$$x_{f,\mathrm{AB}} = \alpha x_{\mathrm{f,A}} + (1-\alpha) x_{\mathrm{f,B}} \tag{2'}$$

$$x_{\mathrm{w,AB}} = \alpha x_{\mathrm{w,A}} + (1-\alpha) x_{\mathrm{w,B}} \tag{5'}$$

The estimation value of the "pleasantness" factor is obtained by the multiple regression formula consisting of 11 explanatory variables, as shown in Formula (7):

$$x_{\mathrm{p,AB}} = c_0 + \sum_{\mathrm{n=1}}^{11} c_{\mathrm{n}} x_{\mathrm{n,AB}} \tag{7}$$

where $x_{\mathrm{p,AB}}$ is the estimation value of the "pleasantness" factor, c_0 is the constant, c_n is the partial regression coefficient, and $x_{\mathrm{n,AB}}$ is the explanatory variable determined by the locations of component colours in the Munsell colour space and their combinations.

For details on the composition of explanatory variables and partial regression coefficients of each prediction formula, please refer to Nayatani and Sakai [7].

Evaluation experiment of colour combination feelings

We prepared illustrations of a woman wearing a "kimono" with two-colour combinations by painting *nagagi* and *obi* with different colours (Figure 1) and showed the illustrations to the observers using an LCD (EV2116W-A; Eizo). The correlated colour temperature of the LCD's white point was set to 6500 K. The distance between the LCD and the observers was ~60 cm. The viewing angle of the displayed illustration was 20° (vertical) × 7° (horizontal). The background of the illustration was an achromatic colour equivalent to N5.

Figure 1: Example of illustration used in the experiment.

During the experiment, lights were turned off, and the room was kept in semidarkness. With respect to 102 pairs of two-colour combinations systematically selected by the Colour-Harmony Committee in the Munsell colour space [8], we calculated the estimation values of each of "contrast", "floridness", "warmth", and "pleasantness" using the colour feelings prediction formulas and sorted the colour combinations in descending order of estimation value for each factor. After that, we extracted 13 pairs of two-colour combinations with equal intervals in estimation value and selected 41 patterns of two-colour combinations, excluding overlapping colour combinations. A total of 82 colours comprising 41 selected patterns of two-colour combinations were displayed on the aforementioned LCD to measure colours using a colour luminance meter (CS-100; Konica Minolta), and the measured values were converted to the Munsell notation values (Figure 2).

The two combined colours are connected with a dashed line. In Figure 2, the selected pairs of colour combinations are evenly distributed in the Munsell colour space. By distinguishing the inverted two-colour combinations of *nagagi* and *obi*, a total of 82 patterns were displayed. Furthermore, one of the 41 two-colour combinations was displayed twice in a nonsequential order to check the evaluation stability of the observers. Consequently, the observers evaluated the stimuli 84 times in total, including the overlapping colour combinations.

The observers evaluated "contrast", "floridness", "warmth", and "pleasantness of the displayed stimuli based on a seven-point rating scale. Additionally, among the 38 rating scales selected by the Colour-Harmony Committee, they also evaluated "refinement", "beauty", and "lucidity", which are the rating scales with a high factor loading to the "pleasantness" factor [13], in the same manner. These scales were added in consideration of rating difficulties caused by the ambiguity of the word "pleasantness". Table 1 shows the seven bipolar scales used in this study.

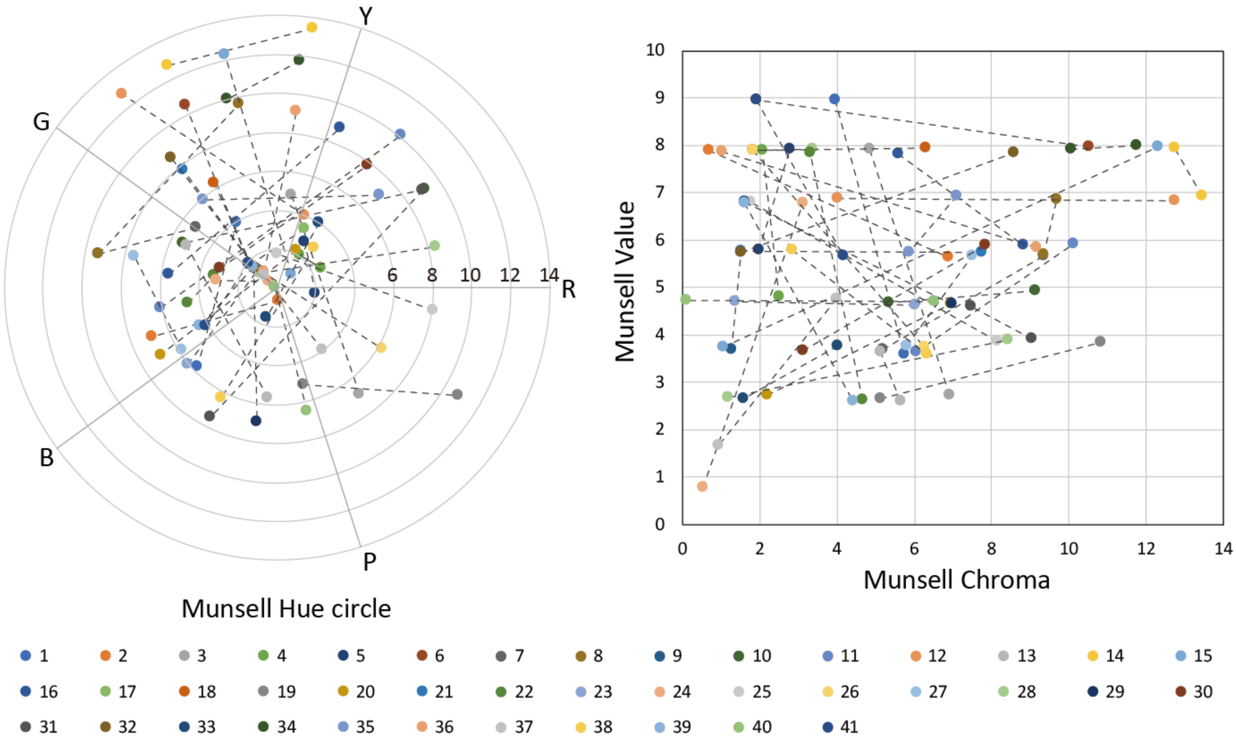

Figure 2: Two-colour combinations used in the experiment.

Colour-feeling scale	Word pair
Contrast	Striking / Vague
Floridness	Florid / Sober and tasteful
Warmth	Warm / Cool
Pleasantness	Pleasant / Unpleasant
Refinement	Refined / Unrefined
Beauty	Beautiful / Ugly
Lucidity	Lucid / Unclear

Table 1: Bipolar scales used in this study.

After the observer completed his or her evaluation of all rating scales with respect to a colour combination of “kimono”, the next colour combination was displayed after a 2s interval (only N5 background was shown). The colour combinations of “kimono” were presented in random order.

The observers were students and faculty members of a “kimono” vocational school, comprising 43 females and 2 males whose average and median ages were 33.5 and 22 years, respectively. They had normal colour vision and visual acuity (including corrected vision).

Results and discussion

The evaluation values of all observers were transformed into the interval scale by applying Torgerson’s law of categorical judgment [14]. The results showed that, for any of “contrast”, “floridness”, “warmth”, “pleasantness”, “refinement”, “beauty”, and “lucidity”, the correlation coefficient with the mean evaluation value before the scale transformation was >0.99. From this, it can be considered that the mean evaluation value for each stimulus is the interval scale. In addition, because the dispersion of evaluation among the observers can be displayed, we used the mean evaluation values for examination in this study.

Figure 3 shows the mean evaluation values for each stimulus sorted in descending order and the histograms of the mean evaluation values.

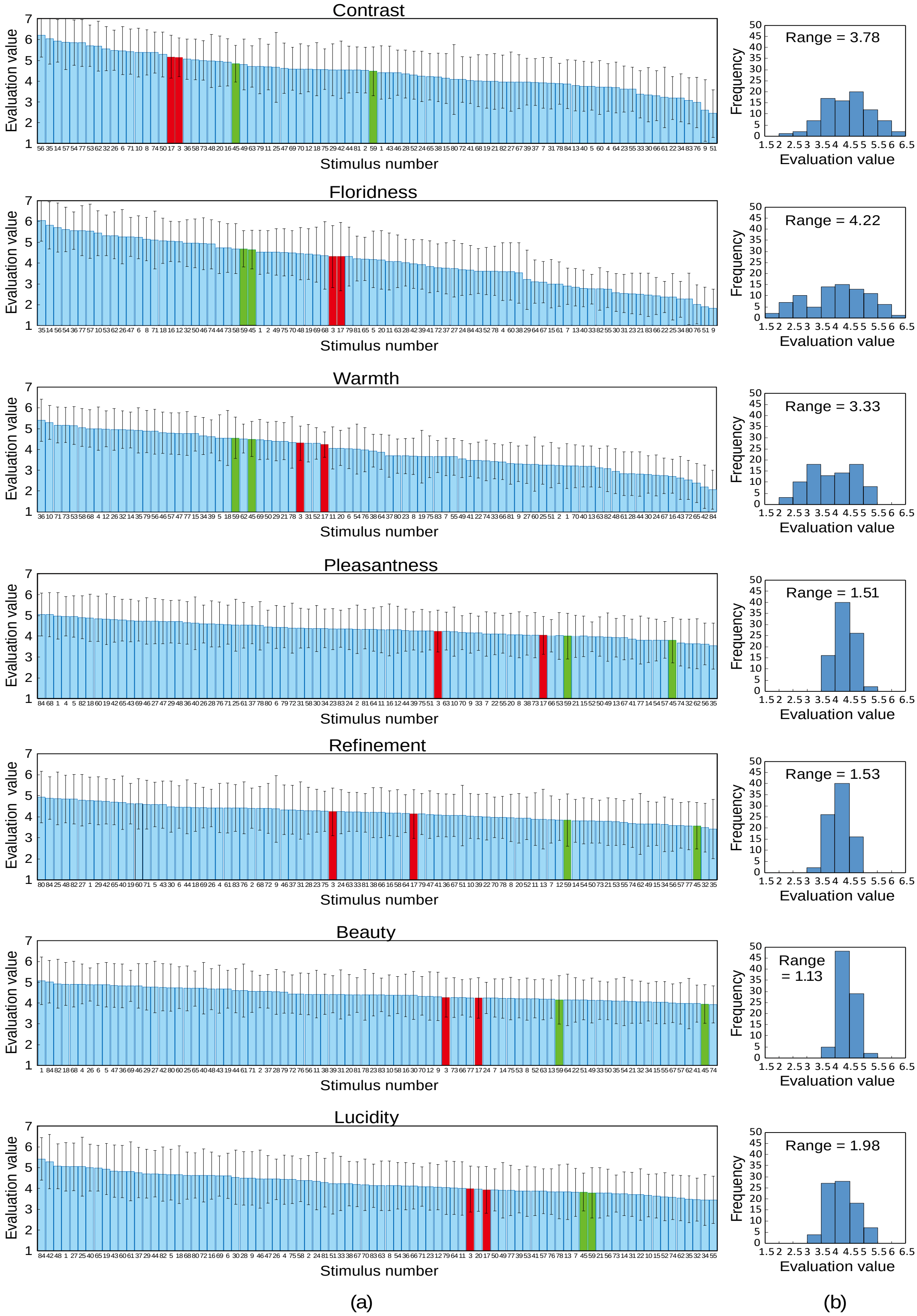

Figure 3: Mean evaluation values for each stimulus sorted in descending order and the histograms of the mean evaluation values.

The error bars in Figure 3(a) indicate the standard deviation. Figure 3(b) shows that "pleasantness", "refinement", "beauty", and "lucidity", which are aesthetic evaluations, have smaller ranges compared to "contrast", "floridness", and "warmth". The red and green bars in Figure 3(a) represent the evaluation values for the stimuli displayed twice (Nos. 3 and 17, 45, and 59). The stimuli displayed twice are shown in Figure 4. When the observers stably evaluated the stimuli of the same colour combination, stimuli Nos. 3 and 17 and stimuli Nos. 45 and 59 were each ranked adjacent to each other.

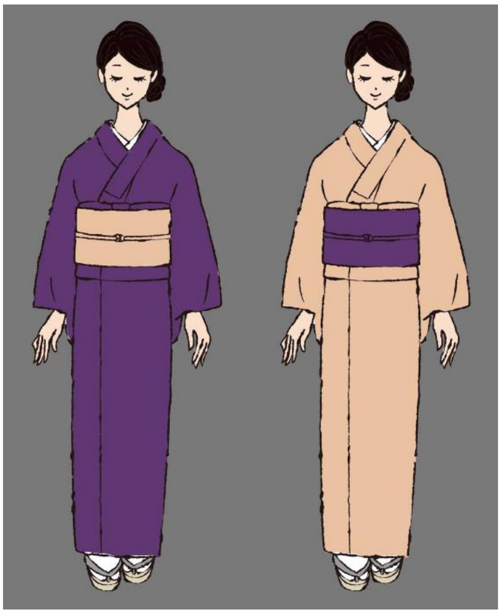

Figure 4: Stimuli displayed twice. Nos. 3 and 17 (left), Nos.45 and 59 (right).

When looking over Figure 3(a), higher stability is observed in the evaluation of "floridness", "warmth", and "lucidity", whereas there is a tendency of lower stability in the evaluation of "contrast", "pleasantness", "refinement", and "beauty". However, due to the dispersion of evaluation values among the observers, there were no statistically significant differences in the mean evaluation values for stimuli Nos. 3 and 17 and stimuli Nos. 45 and 59 in all seven rating scales. In addition, because the positions of the red bars (stimuli Nos. 3 and 17) and green bars (stimuli Nos. 45 and 59) are apart in any rating scale, we can see that the colour combination feelings change when the colour combinations are inverted between *nagagi* and *obi*. This might be due to the impact of the area effect of the component colours because the area of *nagagi* was ~8.7 times larger than that of *obi* in the displayed stimuli. Moreover, there is also a possibility that the context of *nagagi* and *obi* of "kimono" had an impact on it. For further examination of the area effect of component colours in colour combination, the evaluation values were compared between stimuli with inverted colour combinations of *nagagi* and *obi* (Figure 5). In any rating scale, there was a significant correlation at the 1% level between the evaluation values of the stimuli with inverted colour combinations. This suggests that colour combination feelings do not change substantially even if two-colour combinations of "kimono" are inverted. However, "contrast", "floridness", and "warmth" have smaller correlation coefficients between the stimuli with inverted colour combinations compared to the aesthetic evaluations of "pleasantness", "refinement", "beauty", and "lucidity", suggesting that the impact of the area effect of colour combination on them is relatively large.

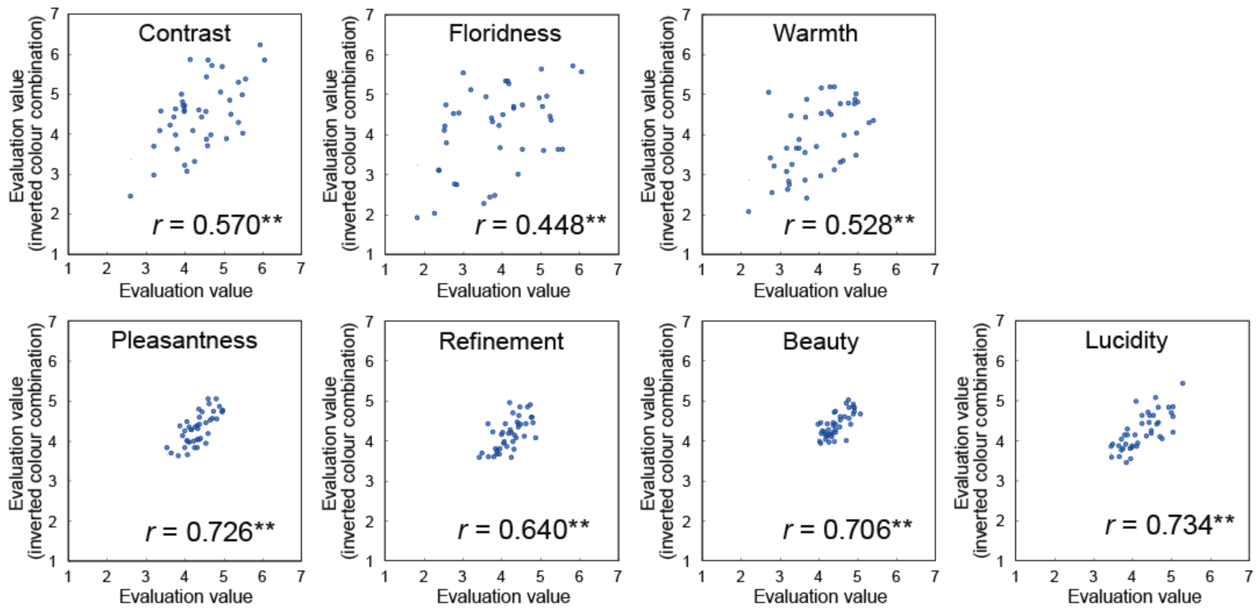

Figure 5: Comparison between stimuli with inverted colour combinations of nagagi *and* obi.

When we calculated the correlation matrix for the evaluation values of each of "pleasantness", "contrast", "floridness", "warmth", "refinement", "beauty", and "lucidity", as shown in Table 2, whereas a strong correlation was observed between "pleasantness", "refinement", "beauty", and "lucidity", "pleasantness" had a particularly strong correlation with "beauty" (*r* = 0.88). There was also a strong correlation between "floridness" and "contrast" (*r* = 0.88). From these results, it can be considered that "pleasantness and beauty" and "contrast and floridness" are highly similar feelings, respectively, in the context of a two-colour combination of "kimono".

	Evaluation results						
Evaluation results	**Contrast**	**Floridness**	**Warmth**	**Pleasantness**	**Refinement**	**Beauty**	**Lucidity**
Contrast	-	**0.880 ****	0.441 **	-0.388 **	-0.379 **	-0.118	-0.228 *
Floridness	**0.880 ****	-	0.448 **	-0.202	-0.332 **	0.026	-0.112
Warmth	0.441 **	0.448 **	-	-0.231 *	-0.489 **	-0.115	-0.555 **
Pleasantness	-0.388 **	-0.202	-0.231 *	-	0.830 **	**0.882 ****	0.775 **
Refinement	-0.379 **	-0.332 **	-0.489 **	0.830 **	-	0.794 **	**0.869 ****
Beauty	-0.118	0.026	-0.115	**0.882 ****	0.794 **	-	0.780 **
Lucidity	-0.228 *	-0.112	-0.555 **	0.775 **	**0.869 ****	0.780 **	-

	Evaluation results						
Estimation values	**Contrast**	**Floridness**	**Warmth**	**Pleasantness**	**Refinement**	**Beauty**	**Lucidity**
Contrast	0.643 **	0.489 **	0.204	-0.332 **	-0.259 *	-0.189	-0.120
Floridness	**0.697 ****	**0.808 ****	0.493 **	-0.278 *	-0.412 **	-0.091	-0.152
Warmth	0.570 **	0.515 **	**0.868 ****	-0.322 **	-0.467 **	-0.154	-0.480 **
Pleasantness	-0.084	0.039	-0.387 **	**0.544 ****	**0.529 ****	**0.559 ****	**0.644 ****

*Table 2: Correlation matrix for the evaluation and estimation values. * and ** denote significance level of 5% and 1% respectively.*

The comparison of the estimation values obtained by the colour feelings prediction formulas to the mean evaluation values given by the observers in each of "contrast", "floridness", "warmth", and "pleasantness" showed a significant correlation at the 1% level (Table 2). Especially, the correlation coefficient between the estimation and evaluation values of "warmth" was 0.87. Likewise, the correlation coefficient between the estimation and evaluation values of "floridness" was 0.81, resulting in sufficiently high estimation accuracy. However, the evaluation value of "contrast" had the highest correlation coefficient (r = 0.70) with the estimation value of "floridness", followed by the correlation coefficient (r = 0.64) with the estimation value of "contrast". Furthermore, the colour combination feeling that best correlated with the estimation value of "pleasantness" was "lucidity", with a correlation coefficient of 0.64. Besides, the correlation coefficient between the estimation and evaluation values of "floridness" obtained using Formula (4) was 0.72, indicating lower estimation accuracy compared to Formula (3).

Then, after normalising the estimation and evaluation values for the 82 displayed stimuli to mean 0 and variance 1, we calculated the similarities using the multidimensional scaling method [14] and showed the results on a two-dimensional plane (Figure 6). The corresponding estimation and evaluation values were connected with dashed lines, and the correlation coefficients were described in the figure. As in Table 2, Figure 6 also shows that "floridness" and "contrast" are highly similar colour combination feelings and that "pleasantness" and "lucidity" have the lowest similarity among the aesthetic evaluations of "pleasantness", "refinement", "beauty", and "lucidity".

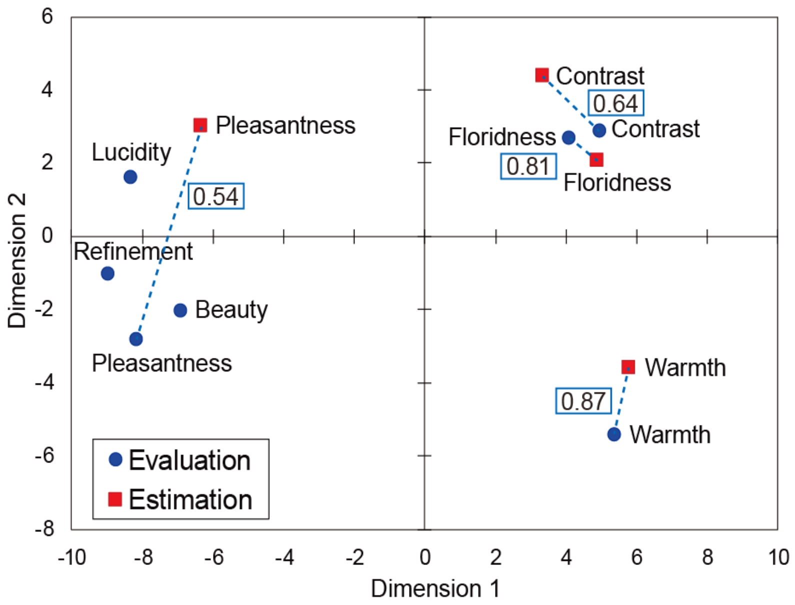

Figure 6: Similarities between the evaluation and estimation values.

From the above, it can be said that the colour feelings prediction formulas are effective in estimating the two-colour combination feelings of "kimono" but also that the estimation accuracy of "contrast" and "pleasantness" is lower than that of other colour emotion factors, leaving room for improvement, and that the estimation value of "pleasantness" corresponds to the evaluation value of "lucidity" rather than that of "pleasantness".

Conclusions

The following conclusions were reached by examining the applicability of the colour feelings prediction formulas to the estimation of colour combination feelings of "kimono".

1. The colour feelings prediction formulas are effective in estimating the colour combination feelings of "kimono". However, the estimation accuracy of "contrast" and "pleasantness" is lower than that of "floridness" and "warmth".
2. "Contrast" and "floridness" are highly similar feelings.
3. "Pleasantness", "refinement", "beauty", and "lucidity" are emotions that are similar to each other. Among these four types of colour combination feelings, "pleasantness" and "beauty" have the highest similarity, and "pleasantness" and "lucidity" have the lowest similarity.
4. The estimation value of "pleasantness" correlates better with the evaluation value of "lucidity" than with the evaluation value of "pleasantness".

As a next step, we plan to improve the colour feelings prediction formulas to estimate the colour combination feelings of "kimono" and verify their performance.

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