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GENDER DIFFERENCE IN COLOUR PREFERENCE OF LIGHTING: A PILOT STUDY

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ABSTRACT

Gender difference has been widely reported in many research fields. However, in the topic of colour preference of lighting, such an issue has not aroused much attention. In this study, therefore, three groups of visual experiments with different illuminance (*E*) levels (50 lx, 200 lx, 600 lx) were conducted which investigated the preferred correlated colour temperature (CCT: 3500 K, 5000 K, 6500 K) for six single-coloured decorative artificial bird-shaped objects (red, green, yellow, blue, white and black). Twenty subjects, ten males and ten females, were invited to respond with their visual colour preference of the experimental objects. The aim of this work was to investigate if gender difference exists when the observers judge objects with different colours under different *E*-CCT conditions. The results indicate that there is significant difference between males and females for the 200 lx and 600 lx conditions, especially for the cases with higher CCTs (5000 K and 6500 K). In addition, it was found that under certain *E*-CCT conditions the preference ratings of males and females for certain colours were obviously different. Similarly, for some scenarios the subjective ratings from observers of the same gender also varied with object colour.

Keywords: gender difference, colour preference, correlated colour temperature, illuminance

1. INTRODUCTION

Colour preference of lighting is currently an intensively examined topic in the field of lighting quality evaluation [1–7]. The aim of those studies was to investigate under which kind of light sources subjects prefer the rendered colours of the illuminated object [1, 8–10] to explore the influencing factors of visual colour preference perception [1, 8, 11–16] and to set up an objective metric which correlates with the subjective responses of the observers obtained from psychophysical experiments [17–21]. According to current literature, the colour preference of lighting is influenced by several factors including lighting application [13–14], regional or cultural difference [6, 16, 22–23], illuminance [24], familiarity with the experimental object [11], colour features of illuminated objects [25] as well as the whiteness of the light sources [1, 8, 26–27].

In our latest work on investigating the optimal lighting for jeans, significant gender difference was found in colour preference and colour discrimination [2]. According to that study, gender difference in colour preference varies with lighting application. Female participants exhibited better colour

Fig. 1. Experimental scene in the light booth with the red bird (an artificial decorative bird-shaped object)

discrimination ability than males. In fact, similar findings have been extensively reported by related research from multiple subjects, including genetics [28], neuroscience [29], ophthalmology [30], biology [31] as well as colour science [32]. For instance, genetically speaking, the spectral sensitivities of many of the photoreceptors in the retina are determined by genes on the X chromosome [33] and it is regarded as one possible explanation for the basis of gender differences in colour perception [34]. Moreover, as reported by Hurlbert *et al*., such differences may also be attributed to the gender specific functional specialisations in the evolutionary division of labour [31].

However, although many studies in related subjects have proved such a difference between men and women, currently for the topic of colour preference of lighting, that issue has not been paid enough attention. In fact, the unbalanced recruitment of male and female observers [13,14, 16, 24, 35–46] in current literature is common and we suspected that such neglect might to some extent lead to a potential bias in the overall conclusions.

In this study, therefore, three groups of psychophysical experiments were implemented with the aim of validating the gender difference in colour preference of lighting. We speculate that such differences might be related to specific lighting conditions as well as to the colour attributes of the experimental objects, so light sources of different illuminance (E) and correlated colour temperature (CCT) levels were adopted, together with the decorative artificial bird-shaped objects of different saturated colours. In addition to this, since the experiments were grouped by E levels (i.e. for each experiment, the observers rated their colour preference for different CCTs with a constant E value), the results of this work should also provide a deeper understanding of the preferred CCT under different illuminance levels.

2. EXPERIMENTAL METHOD

2.1. Experimental Setup

The visual experiments in this work were conducted in a light booth, as shown in Fig. 1. The size of the booth was 50 cm×50 cm×60 cm (W×D×H) and its walls and floor were uniformly painted with medium-grey matt paint (Munsell N7). A chair was placed approximately 40 cm in front of the booth, which resulted in a viewing angle of approximately 30°. In addition, the height of the chair was adjustable such that each observer was unable to see the lighting module in the roof of the booth during the test.

Nine light spectra were generated by an LED cube spectral tuneable smart lighting system provided by Changzhou Thouslite Ltd. This device can simulate a wide range of spectral power distributions in a temporally stable manner by blending the 11 LED channels fitted inside the lighting

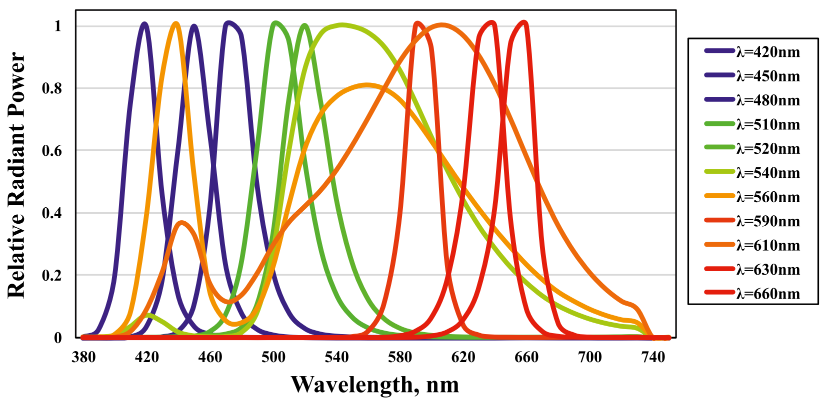

Fig. 2. Relative spectral power distribution of the 11 LED channels fitted in the LED cube system

Table 1. Colorimetric Data of the Experimental Light Sources

ID*	1	2	3	4	5	6	7	8	9
E-level (lx)	50	200	600	50	200	600	50	200	600
CCT-level (K)	3500	3500	3500	5000	5000	5000	6500	6500	6500
Measured *E* (lx)	52	203	603	48	210	600	52	204	602
Measured CCT (K)	3412	3523	3529	4956	5005	5102	6624	6520	6604
Duv	0.0032	0.0036	0.0012	0.0031	0.0011	0.0014	0.0036	0.0011	0.0012
CRI (R_a)	91	92	92	90	90	90	95	93	93
GAI	59	62	65	88	90	90	101	101	102
Q_a (9.0.3)	91	90	91	90	92	92	94	94	93
Q_f (9.0.3)	91	90	91	89	92	92	93	93	92
Q_g (9.0.3)	92	93	94	99	99	99	102	101	101
Q_p (7.4)	90	90	91	91	94	94	96	96	95
CRI2012	92	92	93	91	91	94	97	97	97
MCRI	89	89	89	91	91	91	90	90	90
R_f	87	87	88	86	86	87	94	94	93
R_g	93	93	94	98	97	97	101	101	101
GVI	80	81	81	91	89	89	92	90	90

**Note to Table1:* Duv is the distance from the test chromaticity coordinates at the Planck's locus; CRI is the general Colour Rendering Index [18]; GAI is the Gamut Area Index [19]; CQS (Q_a, Q_f, Q_p, Q_g) is the Colour Quality Scale [20]; CRI2012: An updated version of CRI [47], MCRI is the Memory Colour Rendering Index [48]; R_f and R_g is the IESNA TM-30 metrics [49]; GVI is the Gamut Volume Index[17].

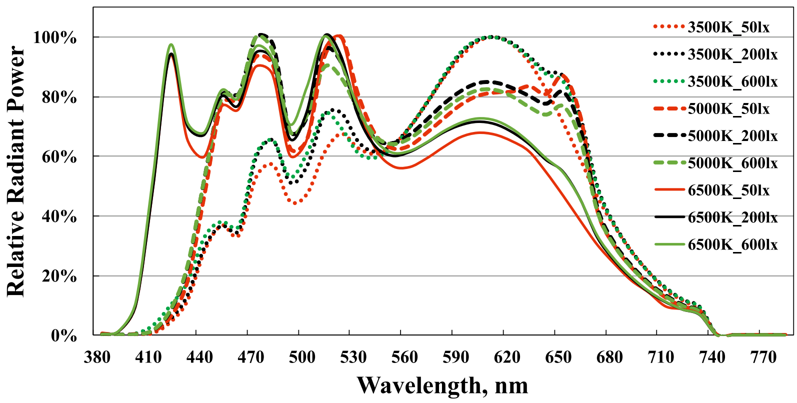

Fig. 3. Relative spectral power distributions of the experimental light sources

unit, as shown in Fig. 2. The chosen experimental light sources had 3 CCT values (3500 K, 5000 K and 6500 K) at 3 *E*-levels (50 lx, 200 lx and 600 lx). An *X-Rite i1 Pro 2* spectrophotometer was used to measure these spectra. The spectral power distributions (SPDs) of the light sources are shown in Fig. 3. The colour parameters of the experimental light sources were calculated, together with several typical colour quality measures, see Table 1.

From Table 1, it is clear that the values of the colour quality metrics of the light sources with a similar CCT are consistent. Therefore, among different *E*-level conditions, the difference of the experimental results could be attributed to *E* levels. Meanwhile, note that the Duv values of the constant-CCT light sources are not completely consistent due to the limitation of the smart lighting device. That is, when we tuning the lights to make the colour quality metrics consistent, those Duv values were the best value our device could achieve. We believe such smaller errors in Duv (~0.002) are negligible when compared to the large variations in CCT (~1500 K). In addition, the CRI values are no less than 90, which indicates that the gamut shapes [14] of those lights are normal and consistent as well.

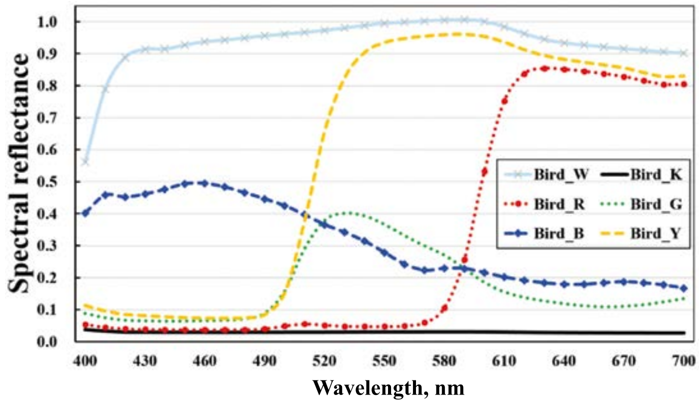

Fig. 4. Spectral reflectance of the experimental objects (artificial bird shapes of different colour). W: white; R: red; B: blue; K: black; G: green; Y: yellow

2.2. Experimental Design

Six decorative artificial bird-shaped objects (see Fig. 1) of similar shape and size (approximately 10 cm×37 cm×28 cm) were adopted as the experimental objects. The birds had the following colours: red, green, blue, yellow, black and white with moderate saturation. Their spectral reflectances were measured using a calibrated spectroradiometer (*X-Rite SpectroEye*). Figs. 4 and 5 show the spectral reflectance of the matt surface objects and their chromaticity coordinates in CAM16-UCS uniform colour space [50] respectively. It is worth mentioning that we did not adopt natural or familiar objects (e.g. fruit and vegetables) in this study since no such objects are of consistent shape and size while of different colours. Moreover, the other reason well-known objects were not used lies in the concern that the ratings of the observers might be influenced by their colour memory [51]. For instance, when rating the colour of an apple, it is possible that a red apple will be preferred while a blue one will not be appreciated.

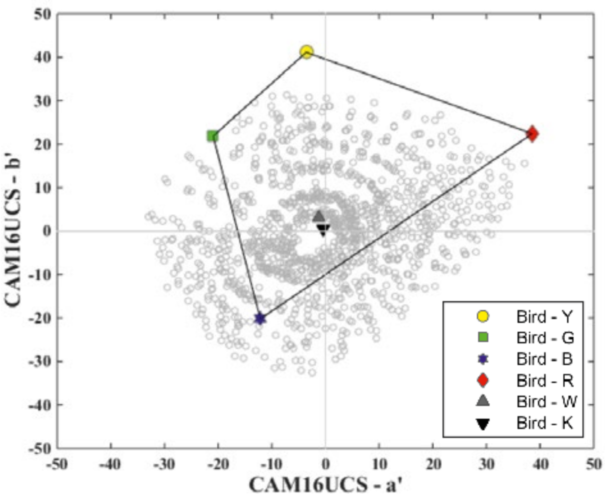

Fig. 5. CAM16-UCS chromaticity coordinates of the experimental objects (artificial bird shapes) at 50 lx and 3500 K. The scattered grey points indicate the location of the Munsell matt colour samples

Twenty observers, ten females and ten males, took part in the visual experiments. These participants were students of Wuhan University. Their age ranged between 17 and 22 years, with a mean of 19.1 years. All the observers passed the Ishihara Colour Vision Test. None knew the research intent before the test.

A 7-point rating scale was used to quantify the colour preference of the observers. Participants were asked to respond with –3, –2, –1, 0, 1, 2, 3, respectively, denoting *strongly dislike, moderately dislike, slightly dislike, neutral, slightly like, moderately like and strongly like*. Within an equi-illuminance level, each observer rated a randomly selected *E*-CCT combination twice; the participants were unaware which equi-illuminance level they were viewing. Such a setting aimed to quantify the intra – observer variability of each participant.

2.3. Experimental Procedure

Upon arrival, the participant was asked to sign a consent form and carry out the Ishihara Test. The experimenter then asked the qualified observer to put on a grey coat so that there would be no coloured light rays reflected from their coloured clothes onto the test object.

After leading the observer to the booth, the experimenter asked him/her to adjust the height of the chair to make sure that the lighting module in the booth could not be seen. Subsequently, the ambient lights were switched off so that the experimental lighting was the only illumination in the otherwise dark room. The experimenter then read the instructions to the observer and asked him/her to respond orally during the test. This protocol was designed in

Table 2. Standard Deviations of the Colour Preference Ratings for Different *E*-CCT Combinations with Different Experimental Objects

Object	50 lx			200 lx			600 lx		
	3500 K	5000 K	6500 K	3500 K	5000 K	6500 K	3500 K	5000 K	6500 K
Bird_K	1.63	1.58	1.51	1.24	0.94	1.06	1.74	0.92	1.19
Bird_W	1.33	1.18	1.12	1.72	0.98	0.97	1.44	1.05	1.41
Bird_R	1.52	1.16	1.20	1.69	1.09	1.44	1.53	1.36	1.79
Bird_Y	1.39	1.11	1.16	1.50	1.09	1.28	1.69	1.23	1.53
Bird_B	1.22	1.37	1.30	1.06	0.80	1.02	1.26	0.99	1.37
Bird_G	1.13	1.19	1.34	1.39	1.03	0.99	1.49	1.10	1.44

order to avoid the influence of reflected light on the observer's visual adaptation condition which might be caused if the observer were to write the answers onto a piece of white paper.

Since it takes a longer time to adapt from a high to a low illuminance level, in this experiment the light sources with low *E* values (50 lx) were evaluated first and then the middle (200 lx) and the high (600 lx) levels. Within a subgroup of constant *E* values, the presentation order of CCTs and experimental objects was randomized and counterbalanced between observers. At the very beginning, each participant was allowed 1 minute to adapt to the initial light which was randomly selected from the candidate lights with an *E* value of 50 lx. Afterwards, with a randomly selected colour bird, a training section was provided to help the observer get used to the evaluation process.

After the training session, the formal experiment began with the subgroup of 50 lx light sources. Using a randomly selected CCT, the participant was first asked to rate his/her visual colour preference of the empty booth and then the colour preference of the 6 colour birds (one at a time, with a random order). When the experimenter changed the light source, the observer was asked to keep his/her eyes closed for about 30 seconds to eliminate the short-term memory effect caused by the former lighting condition. Such a wash-up time was determined according to our previous work on evaluating colour preference of different CCTs [9, 11]. Subsequently, the observer was asked to open their eyes and observe the illuminated environment in the empty booth for 1 minute. After this chromatic adaptation step, the experimenter asked the participant to rate their colour preference of the illuminated booth and then the colour preference of the coloured birds. For each judgment, the observer was provided with as much time as they needed.

When the observer announced that they had finished their rating (for the last bird) and confirmed the results, the experimental lighting condition was changed. Meanwhile, when all the trials for a constant illuminance had been completed, the experimenter gave the participant 1 minute for wash-up (with eyes closed) and 2 minutes to fully adapt to the new illuminance level in the empty booth. Afterwards, the visual judgment workflow described above was repeated for every *E*-CCT combination. It took about 100 minutes for an observer to finish the whole experimental session.

3. RESULTS AND DISCUSSION

3.1. Inter – Observer and Intra – Observer Variability

The inter – observer variability of the participants responses was quantified by the standard deviations of their ratings, as summarized in Table 2. It can be seen that these measures are consistent with regard to each experimental object. These results also agree well with those of our previous work, in which similar experimental settings, protocols and the same 7-point rating approach were used [2, 9, 11–12, 52].

For quantifying the intra – observers variability, the absolute-difference method adopted in our previous work [1–2, 9, 11] was followed. As described above, during the test the observers were asked to rate a randomly selected *E*-CCT combination twice (for all the objects) without being informed of this point. If the absolute difference of the two responses was larger than 2 (e.g. –3 for the first time while 0 for the second time), that pair of ratings was classified as abnormal data. Subsequently, the intra – observer variability was represented by the ratio of the number of abnormal data points to the total number of data points. The average value for this experiment was 9 %, which is within the range of average values from previous studies (3–17)%.

It was found that the intra – observer variability for the objects with lower lightness values (i.e. black, blue and green, as shown in Fig. 4) was higher, with values between (15–20)%, while for high-lightness colours (i.e. white, red and yellow) the intra – observer variability values were much lower (0–5)%. This finding prompted us to revisit our latest work on colour preference for jeans, in which the preferred CCT for 7 pairs of jeans with a colour gradient pattern was discussed [1]. Interestingly, it was found in that study that the jeans with lower lightness values also exhibited higher intra – observer variability. This suggests that perhaps the lightness of the experimental object impacts the intra – observer variability. In addition to this, another finding was that the intra – observer variability was also associated with the degree of familiarity. For the objects, which the observers were familiar with, such values were lower (jeans [1–2]: 4.8 % and 6.2 %, fruit and vegetables [1]: 3.3 %, oil painting with a seaside scenery [11]: 5.6 %, black and white object [1]: 6.7 %) while for unfamiliar objects those values were higher (artificial flowers [11]: 16.6 %, reproduction of ancient mural painting [11]: 15 %). For inter-observer variability, the impact of the lightness and similarity of the experimental object was not observed.

3.2. Overall Analysis

The overall result of this study is summarized in Fig. 6. From this figure we can conclude that for some conditions there is indeed a trend for the ratings of men and women to be different. For instance, for the 200 lx and 600 lx scenarios, it is clear that the ratings of female observers are higher than those of male observers while for the 50 lx condition, the results are not so obvious. Meanwhile, when examining the ratings for 5000 K and 6500 K we find that female observers prefer 6500 K no matter under which *E*-level condition, but such a trend is not so significant for male observers. Therefore, it seems that females have stronger demand for higher illuminance and whiter illumination, at least for the condition of this work. In addition, as shown in Table 1, since the light sources of a similar CCT are of consistent colour rendition properties, the data in Fig. 6 also illustrate the impact of illuminance for preferred CCT.

A multivariate analysis of variance (MANOVA) approach was adopted to investigate the influence of CCT, gender and object colour on the colour preference ratings for each group of a constant *E* level. The results show that for the 50 lx condition, only the influence of CCT is significant ($F=29.087$, $p<0.001$) while for the cases of 200 lx and 600 lx, both CCT (200 lx: $F=54.697$, $p<0.001$; 600 lx: $F=31.653$, $p<0.001$) and gender (200 lx, $F=5.276$, $p<0.05$; 600 lx, $F=11.669$, $p<0.05$) impact the preference ratings significantly. In addition to this, the *post hoc* comparison test reveals that for the 50 lx condition significant difference ($p<0.05$) is found between any two of the three CCTs while for 200 lx and 600 lx, only 3500 K is significantly different ($p<0.05$) from 5000 K and 6500 K. Those results agree well with Fig. 6 and strengthen our former statements. Besides, for this analysis the influence of object colour is not significant, regardless of *E* level.

Meanwhile, it must be pointed out that some expressions in this paper like “the preferred CCT” or “CCT influences colour preference” are not theoretically rigorous, since according to colorimetry a CCT corresponds to numerous SPDs and the colour renditions properties of light sources (the metrics shown in Table 1) also impacts colour preference perception. From this point of view, it is not wise to conclude that the finding of this study will be valid for any situations.

However, please note that from the perspective of practical application, it is indeed meaningful to discuss such a topic. The reason is clear: CCT is one of the most fundamental properties of a light source and it is quite common that naive users always have to make choices among light sources of different CCTs with different colour rendition properties. In fact, according to recent studies about “the preferred CCT” [1, 9, 11, 53–55], although the colour quality metrics of the experimental lights in those studies were different, consistent results were found that observers generally prefer CCTs around 4500 K to 5500 K while they dislike the colour rendition of light sources with low CCTs (2500–3500) K, or high CCTs (higher than 6000 K). Such consistency indeed validates the research manner of this work and, as far as we are concerned, it should be ascribed to the correlation between CCT and colour rendition properties. That is, although CCT

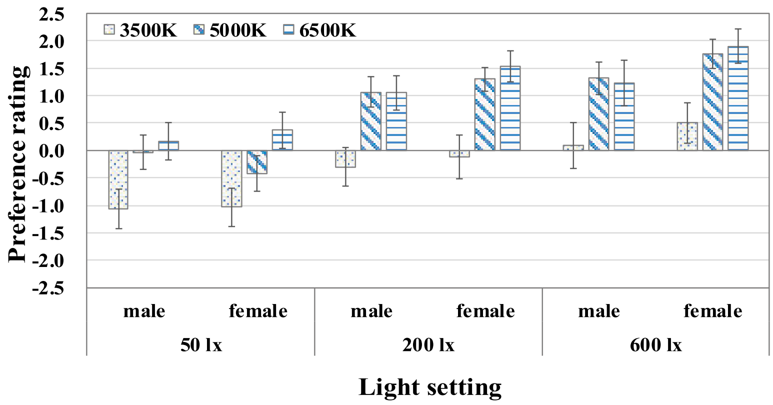

Fig. 6. Average colour preference ratings of the six experimental objects (artificial bird shapes of different colour) with regard to different gender and *E*-CCT combinations. The error bars are 95 % confidence intervals

does not influence colour perception directly, it is highly correlated with many colour rendition metrics [56] so that it has certain, or even significant "impact" on colour perception.

3.3. Gender Difference for a Certain *E*-CCT condition

In Fig. 6, it is quite clear that the gender difference in ratings varies with *E*-CCT settings. Thus, the same MANOVA approach was applied for the data of each *E*-CCT scenario. The result shows that for 200 lx at the 6500 K, 600 lx at the 5000 K and 600 lx at the 6500 K significant gender difference ($p<0.05$) could be observed while for other *E*-CCT scenarios there is no such significant difference. In addition, only in the scenario of 200 lx at the 6500 K we can observe significant influence ($p<0.05$) of object colour on preference rating and the *post hoc* comparison test demonstrates that in this condition the ratings of the blue bird are significantly different ($p<0.05$) from those of the black, red and green birds while the ratings of the white and the red birds are also significantly different ($p<0.05$). What is more, although for the 50 lx at the 6500 K scenario the influence of object is not remarkable according to MANOVA, by *post hoc* significant difference ($p<0.05$) is found between the ratings of the black and blue birds, as well as between the red and blue birds. Despite of the findings noted above, there are no other significant factors that influence the colour preference ratings for each *E*-CCT scenario.

Fig. 7 illustrates the above findings intuitively, where gender difference in preference ratings of different *E*-CCT combinations and different object colours is shown. First of all, it is clear that for every group of scenarios with a constant *E* value, the preference ratings for multiple objects seen under different CCTs show a similar trend (3500 K is not preferred while 5000 K and 6500 K are relatively appreciated). Such a result strengthens our former conclusion that light dominates colour preference when CCT differs [11].

As can be seen from Fig. 7, for the 200 lx at the 6500 K, 600 lx at the 5000 K, and 600 lx at the 6500 K conditions the average ratings of male observers of different coloured birds are relatively scattered while for female observers the average ratings are relatively concentrated. This explains why significant gender difference is found according to MANOVA as described previously. Similarly, although it has not been validated by MANOVA ($p>0.05$), from Fig. 7 it can also be observed that for the scenarios of the low CCT (3500 K), the average ratings of female observers are relatively scattered while for male observers the average ratings are relatively concentrated. Inspired by the work of Hurlbert [31] and Palmer [57], we suspect that such a finding might be ascribed to the biological long-term adaptations of the human visual system during evolution. That is, according to the hunter-gatherer theory, the vision system of males is more adapted to outdoor behaviour under daylight conditions with high CCTs, while females are more adapted to the indoor behaviour with lighting of lower CCTs (e.g. firelight). Thus, under the higher CCT conditions males are more biologically adapted in vision so that they could response diversely upon different colours while females are more adapted to lower CCT conditions and, thus, more sensitive in judging colours in those situations.

3.4. The Influence of Object Colour

As noted above, for the 50 lx at the 6500 K condition the ratings of the blue bird are significantly different from those of the black and the red birds. For the 200 lx at the 6500 K condition, similar re-

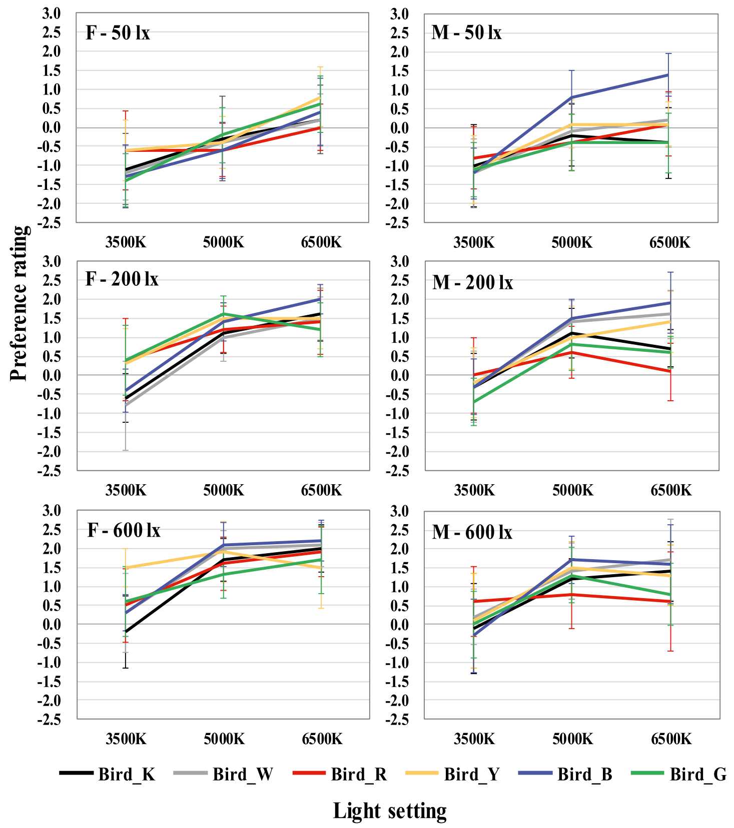

Fig. 7. Gender difference in colour preference ratings of different *E*-CCT combinations and different object colours (F: females, M: males, Error bars: 95 % confidence intervals)

sults are also obtained between the blue bird and the black, red and green birds, as well as between the white and red birds. From Fig. 7 we can conclude that those results are largely due to the ratings from male observers. Such a finding reminds us to consider the impact of object colour when investigating the gender difference in this study.

When investigating the gender difference for ratings of a certain coloured bird under a certain *E*-CCT condition Student t-test approach was adopted. It was found that for the 50 lx at the 5000 K condition, the ratings between males and females on the blue bird differed significantly (p<0.05) and it can be seen in Fig. 7 that the ratings of males is obviously higher. Similar result could be found for the 50 lx at the 6500 K condition (for the blue bird), although it has not been statistically validated by the t-test (p=0.094). Meanwhile, it was found that under the 200 lx at the 6500 K condition, there is still significant gender difference (p<0.05) when judging the red bird but for this case the ratings of female observers are higher. In fact, as for 600 lx at the 6500 K, such a difference could also be observed in Fig. 7, but was not significant at the 10 % level (p=0.115). Despite the above noted findings we suspect that there might be a gender difference for other cases as well (e.g. 200 lx at the 6500 K – black, p=0.063; 600 lx at the 3500 K – yellow, p=0.070; 200 lx at the 3500 K – green, p=0.086, 200 lx at the 5000 K – green, p=0.090), which could be observed in Fig. 7 but denied by the t-test (0.05<p<0.1). Those assumptions need further validation in future work with a larger number of observers.

In addition, the rating difference for multiple colours from a single gender is also discussed. According to Fig. 7 and the t-test a very interesting result was found. That is under the 600 lx at the 3500 K condition the females' ratings on the yellow birds are significantly higher (p<0.01) than those of the blue and black birds while, symmetrically, under the 50 lx at the 6500 K condition, the ratings of males on the blue bird are significantly higher (p<0.05) than those of all the other birds. Moreover, male observers also significantly prefer the blue bird under the 50 lx at the 5000 K condition (compared to the red and green birds, p<0.05) and for the 200 lx at the 6500 K condition, their ratings on the blue and white birds are significant higher (compared to the black, red and green birds, p<0.05) as well. Obviously, such results demonstrate the impact of the object colour upon the gender difference in a preferred *E*-CCT combination. When discussing relevant topics, such a factor should also be considered.

4. CONCLUSION

In this study, three groups of visual experiments with different illuminance levels were conducted, which tested the preferred correlated colour temperature for six single-coloured decorative artificial bird-shaped objects. The main finding of this work lies in the validation of gender difference for defined *E*-CCT conditions. Based on the above findings, we recommend that in future studies the number of female and male observers invited for a visual test should be equal or at least similar, since an unbalanced recruitment of male and female observers may lead to a potential bias in the overall conclusions, especially for some extreme conditions.

Meanwhile, with the aim of drawing safe conclusions, it must be acknowledged that this pilot study only represents a small set of variations in a big, multi-dimensional world. In future work, many influencing factors should be taken into account in order to further investigate this topic. These include the colour rendition properties of light sources, cultural or regional difference, the illuminance range, and other possible variations among the objects.

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