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EFFECTS OF CRI AND GAI ON EMOTION AND WORK PERFORMANCE IN OFFICE LIGHTING

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Abstract

This paper investigated the influence of light colour quality on emotion and work performance, and find suitable value for colour related office environment. Colour rendering index (CRI) and Gamut Area Index (GAI) were selected to describe the colour quality of the light source in this study. GAI was used to assist Ra to evaluate the relationship of light colour quality with emotion and task performance. Chromatic anfimov alphabet test and Farnsworth Munsell 100 Hue Test were carried out for measuring work performance. To access the emotion of participants, we used PANAS (Positive and Negative Affect Schedule) to investigate the emotional states of subjects in different conditions. The experimental results were analysed by (ANOVA) variance analysis. The results showed that colour matching and discrimination has the best performance in GAI = 100, Ra = 100, the participants are most likely to produce positive emotions in GAI = 120, Ra = 80.

Keywords: Colour Rendering Index, Gamut Area Index, Emotions, Work Performance

1 Introduction

The light source colour rendering index (CRI) is a parameter that quantifies the degree of agreement between the object colour appearance under the light source to be measured and the object colour appearance under the reference lighting object (1995). It has been quantified using the CIE colour rendering index Ra to describe the degree the light source expresses the colour appearance of the object, and the full gamut area index GAI can be used to reveal the sensitivity of the hue saturation and the hue sensitivity (Freyssinier & Rea, 2010). Current standards and studies on colour rendering of light sources mainly focus on the research on colour preference and colour fidelity (Khanh & Bodrogi, 2018; Khanh, Bodrogi, Guo, Vinh, & Fischer, 2019; Khanh, Bodrogi, Vinh, Guo, & Anh, 2018). Many scholars have also focused on the influence of colour on human emotions (Ou, Luo, & Cie, 2011). Furthermore, some mathematical models are established based on colour science and psychophysical methods. However, as an indicator to represent the colour quality of light sources, there were few studies related to emotion. At the same time, Consider the performance of workers in colour - related work environments, the colour discrimination performance in the condition of different colour rendering index should be further explored

Newman W P (Newman, Rebman, & leee, 2016) and others explored the relationship between the colour rendering index and the stress levels, the results showed that with the increase of colour rendering index (from Ra= 80-85 to Ra = 96), the stress level decreased significantly. According to this result, the light irradiation with the colour rendering index similar to the natural sunlight could reduce the pressure. In addition, he also obtained the conclusions that reducing stress levels could also be associated with other phenomena, such as improving positive emotions and work performance, reducing employee absences and pain perception.

Li 's study(Li, Yang, & Wang, 2015) explored the relationship between the colour rendering index of light source and the ability of colour match and rapid recognition. They designed an experiment with 20 subjects in four different colour rendering indexes (Ra= 90,80,70,60). The results showed that the colour rendering index Ra of the light source has no obvious influence on the correct proportion of the colour matching operation. However, with the decreases of Ra,

more and more errors appeared in the colour match task. Especially, when the colour rendering index Ra is below 60, the error frequency and error level were obviously higher than other conditions.

In addition, with the wide use of white LED in recent years, Ra can't well describe the feeling of the people for light source colour rendering(He, Sun, & Lin, 2015; S. Jost-Boissard, Avouac, & Fontoynont, 2015), and a scholar considered that the description of the CRI has nothing to do with the human subjective feeling, and it could not accurately describe the colour properties of solid-state lighting (Sophie Jost-Boissard, Fontoynont, & Blanc-Gonnet, 2009).

In view of this situation, JP Freyssinier (Freyssinier & Rea, 2010) and MS Rea(Rea & Freyssinier-Nova, 2008) used GAI to assist CRI in measuring the colour rendering of the light source. Their results suggested that when GAI is used to supplement CRI, two indicators (when CRI≥80, $80 \le GAI \le 100$) seem to ensure positive subjective impressions of nature and activity. Considering the universality of the results, this study chose most widely used CRI and GAI as variables to investigate the impact of light sources colour rendering index on emotion and work performance, in order to find suitable value for office environment.

2 Methods

2.1 Subjects

The participants were randomly recruited between ages of $18 \sim 29$ years old, with total number of 10 including 4 males and 6 females, average age at $22.60 \pm (std)2.73$. All with normal orthoptists and no colour blindness, colour weakness or other eye diseases.

2.2 Light Conditions

The experiments were conducted in a lighting lab and the room size is L3.7m×W3.2m× H3.1m laid out as an office. One side of the room is open and has a neutral grey curtain. The curtains were closed during the experiment. There are desks, sofas, tea tables, chairs, paintings and so on. The layout of the laboratory is shown in figure 1.



Figure 1 – Experimental Environment

In this experiment, six THOUSLITE LED CUBE with a spectral tunable light source were used to create 9 different lighting conditions with different CRI and GAI. The three CRI conditions were 60, 80 and 100, and the three GAI conditions were 80, 100 and 120. which were determined according to table 1. Where Ra=100, GAI=120 cannot be achieved in theory, so the Ra=90, GAI=110 was substituted in the experiment. The spectral power distribution corresponding to the 9 conditions is shown in figure 2.

Parameter Type	Parameter	Value
Variable	CRI(Ra)	60,80,100
	GAI	80,100,120
	Illuminance(Ix)	300
Constant	CCT(K)	4000
Constant	Duv	<0.01
	UGR	<19

Table 1 – Experimental parameter setting



Figure 2 – Spectral power distribution in different experimental conditions

A variety of test methods were adopted in the experiment, including subjective scale and objective test. The specific methods are as follows:

2.3 Chromatic Anfimov Table

Chromatic Anfimov table contains 1200 English letters, letters are A, B, C, E, H, K, N, X, A, with the same probability, each letter randomly shows one of the twelve kinds of colour. These colours were selected evenly from the colour rings of the Wilhelm Ostwald colour system which was shown in figure 3. The observer's task was to select the "B" that matches the specified colour.



Figure 3 – (a) The colour rings of the Wilhelm Ostwald colour system; (b) Excerpts of Chromatic Anfimov Table

Because colour printing on Anfimove table could inevitably produce colour difference. Thus, we compare the printed colour block with the standard colour block and calculate the colour difference using Reilly cube root colour difference formula. The results were within the range allowed (ΔE <1).

2.4 FM-100 Hue Test

In the experiment, the experimenter shuffled each pair of colour chess separately, the subjects were required to arrange these four pairs of colour chess in each group. This process was based on the original working manuscript, written by D Farnsworth (Farnsworth, 1943), which mentioned that to ask the subject to arrange the colour chess at their own pace, if it took more than two minutes, experimenter needed to remind them in a low voice; In addition, it is necessary to record the sequence of colour chess in each arrangement. The experiment process of colour chess is shown in figure 4.





2.5 Positive and Negative Affect Schedule (PANAS)

Positive and Negative Affect Schedule (PANAS)(Watson, Clark, & Tellegen, 1988) has five kinds of state in each part, "1" on behalf of the least, "5" represents the highest degree, which used to investigate the emotional states of subjects in different conditions.

The sequence of experimental conditions in the experiment is random. In addition, the order in which the Amfimov table and the colours selected in different experimental conditions are also random. The experimental process of each part is shown in the following table 2.

NO.	Process	Duration
1	Fill in the basic information, and conduct color blindness test	3min
2	Familiar with the experimental procedures and equipment	10min
3	Dark adaptation	3min
4	Light adaptation (condition 1)	3min
5	Chromatic Anfimov table	8min
6	Farnsworth Munsell 100 Hue Test	10min
7	PANAS	4min
8	Repeat 4-8 to complete the remaining 8 conditions	

3 Results

3.1 Emotion

MANOVA analysis was carried out for lighting appraisal and analyses were made for emotion components both under CRI and GAI. The PANAS scale can be analyzed in the following standard ways: 1, 3, 5, 9, 10, 12, 14, 16,17 and 19 items in the scale are added as positive

effect scores. And the sum of 2, 4, 6, 7, 8, 11, 13, 15, 18 and 20 items in the scale was used as a negative effect score. Then, the results were analyzed by using repeated measurement in SPSS. The results showed that in different GAI conditions, there were significant differences in emotional scores, while in different CRI conditions, there were no significant differences in emotional scores:

(I)GAI	(J)GAI	Mean Difference (I-J)	Sig.
GAI=80	GAI=100	-0.0877	0.19
	GAI=120	-0.1349*	0.045
GAI=100	GAI=80	0.0877	0.19
	GAI=120	-0.0472	0.497
GAI=120	GAI=80	0.1349*	0.045
	GAI=100	0.0472	0.497

As can be seen from the table above, the score of PANAS scale at GAI=80 is significantly different from that at GAI=120, while the score of PANAS scale at different Ra conditions is not significantly different. This indicates that GAI may have a certain influence on positive and negative emotions, while Ra has a small influence. Next, we can analyze and compare the mean of PANAS scale in different experimental conditions.



Figure 5 – PANAS Score

Finally, we compared the two mean values and concluded that GAI=100, Ra=100 and GAI=120, Ra=80 were more likely to generate positive emotions.

3.2 Work Performance

We used IMC (Index of Mental Capacity) to represent the work performance score which reflect the work efficiency, as shown in formula.

$$IMC = \frac{M}{T} \times \frac{n-a}{N}$$

The software can automatically calculate the time cost (T), total letter or chess count (M), the number of letters should be deleted or should be arranged (N), the number of letters deleted correctly or chesses arranged correctly (n), the number of letters deleted wrongly and the number of letters missed to delete or chesses arranged wrongly (a). And then we can compute the work performance score (IMC). Then we did the 0-1 data standardization of each subject

under different conditions to eliminate the impact of individual differences on the result contribution.

3.2.1 Chromatic Anfimov Table

The results of data analysis showed that work performance in chromatic Anfimov table were significantly different under different CRI and GAI combination conditions (F=2.49, p=0.018). in general, the higher CRI, the higher performance. And the CRI=100, GAI=100 condition is the best case. The specific data were shown in table 4 and figure 6.

	Ra=60	Ra=80	Ra=100
GAI=80	0.635(0.274)	0.408(0.331)	0.657(0.276)
GAI=100	0.400(0.297)	0.446(0.315)	0.729(0.367)
GAI=120	0.377(0.364)	0.297(0.353)	0.687(0.300)

Tabe 4 – Mean + Standard Error of the Mean (SEM) of Chromatic Anfimov Table



Figure 6 – Work Performance of Chromatic Anfimov Table in Different Conditions

In addition, there were significant differences in the error rates of different colour letters in the chromatic anfimov tests, which put forward higher requirements for the colour selection in the subsequent test.

3.2.2 FM-100 Hue Test

Work performance in 100 hue tests were significantly different under different CRI conditions (F=12.028, p=0.004) and different GAI conditions (F=5.642, p=0.03). The interaction effect between CRI and GAI on work performance was almost significant (F=4.226, p=0.058). The specific data were shown in table 5 and figure 7

	Ra=60	Ra=80	Ra=100
GAI=80	0.375(0.331)	0.379(0.250)	0.641(0.373)
GAI=100	0.364(0.216)	0.598(0.277)	0.672(0.390)
GAI=120	0.257(0.305)	0.293(0.170)	0.405(0.242)

Table 5 - Mean + Standard Error of the Mean (SEM) of FM-100 Hue Test



Figure 7 – Work Performance of FM-100 Hue Test in Different Conditions

As can be seen from the figure above, when GAI=100, Ra=100, the colour chess performance was significantly better than the other conditions. And the work performance in GAI=100 was significantly better than GAI=120 and GAI=80, and Ra=100 was also significantly better than the conditions at Ra=60.

In general, GAI has a more significant impact on FM-100 Hue test and it can be used in combination with CRI as an important indicator in the working environment related to colour discrimination. On the whole, the cumulative error rate of green and the colour chess adjacent to green (no. 27-52) was higher, accounting for 506/928=55% of the total error. Because the human eyes have a poor ability to distinguish green, so this phenomenon is consistent with common sense.

4 Conclusions

In this study, the effect of CRI and GAI on work performance and emotion was investigated experimentally. Experiments have verified that in the range of $80 \le GAI \le 120$ and $60 \le Ra \le 100$, the following conclusions were obtained.

- In terms of emotional influences, GAI have a certain influence on positive and negative emotions, while Ra has a small influence. And GAI = 120, Ra = 80 and GAI = 100, Ra = 100 is the easiest to produce positive emotions.
- Participants have higher work performance with the increase of CRI, and GAI=100 had the best performance among different GAI conditions. The conditions in 80≤GAI≤100 had a better performance than the condition in 100≤GAI≤120. GAI can be used in combination with CRI as an important indicator in the working environment related to colour discrimination ability.

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