Effects of Illuminance Distribution, Color Temperature and Illuminance Level on Positive and Negative Moods

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Abstract
This study investigates how artificial lighting affects people's positive and negative moods, and ascertains the features of lighting environments that more effectively increase positive moods or heal negative moods. The evaluation techniques are subjective evaluation (POMS and VAS). This study discusses 10 lighting environments, which contain different color temperatures, illuminance levels and illuminance distribution types. The findings showed that general lighting can increase people's positive moods to a higher level; however, indirect/ambient lighting is better able to reduce people's negative moods. As to color temperature, 2700K is more advantageous to moods than 6500K in direct/central and indirect/ambient lighting. However, color temperature has very little impact on moods in general lighting. As for illuminance level, moods between 780lx and 1500lx were insignificant. These findings mean that the single factor of lighting may not be influential. The interaction effect of lighting factors plays an important role in moods.

Keywords: color temperature; mood; illumination type; evaluation; stress

1. Introduction
Before the invention of artificial lighting, sunlight was the major light stimulus for people. However, with the growing popularity of artificial lighting and lifestyle changes, the impact of light stimulus of artificial lighting on the physiology and psychology of modern people, who stay indoors for 80-90% of the day, has become a topic of concern.

Due to busy work and the heavy pressures of modern life, various commodities and environments with the healing effect have become more and more attractive to people. In general, healing refers to providing temporary, short and medium term alleviation and soothing effects of mental fatigue caused by excessive pressure, tension, and depression. In fact, many studies found that lighting has some psychological effects.

Among all factors of lighting, illuminance and color temperature are the two factors considered most. For related studies on amenity, the most famous and widely known is the study by Kruithof, regarding the combinations of illuminance and color temperature. Kruithof proposed that the higher the illuminance, the higher the suitable color temperature. High illuminance combined with low color temperature makes people feel sweltering hot and uncomfortable, while low illuminance combined with high color temperature may make people feel gloomy and uncomfortable11. Besides, a study discussed the effects of color temperature in task lighting on subjective evaluations for reading, and found that color temperature has effects on brightness, glare and amenity. 2800K has higher amenity, lower brightness and lower glare than 5200K and 13850K2. The author also discussed the evaluations regarding a combination of illuminance (250lx, 500lx, 750lx) and color temperature (2800K, 4700K, 6700K) in task lighting. The result shows that 750lx and 500lx are better than 250lx, and 2800K is better than 4700K and 6700K for reading3. Shi's study discussed the effect of color temperature (3000K, 5000K, 7000K) in general lighting during exercises on physiological functions and subjective responses, and indicated that 5000K is the best color temperature during exercise for maintaining autonomic stability and psychological balance4. Lee's study indicates that the characteristics of sleep-inducing lighting for the elderly are orange/warm color light, dim light and ambient light5. Although these studies pointed out the effect of illuminance and color temperature, the illumination type discussed is almost limited to general or task lighting.

Regarding the effect of illumination type, Flynn showed that the scales of "bright-dark", "uniform-non uniform" and "central-peripheral" have great impact on impressions of lighting environment6-7. Nakamura employed a 1/15 scale model to study the effect of several combinations of reflectance and
luminance levels on the psychological effect under two illumination types. The results showed that the psychological effect of luminance distribution is closely related to the balance of luminance variations detectable at varying degrees of fineness. Our previous study employed a 1/10-scale model to discuss the effect of illuminance distribution on spatial impressions. The results showed that the effects of illuminance distribution on most of the evaluation items are significant. Among all 20 types, the types with well-balanced illuminance distribution or with a symmetrical arrangement of lighting led to better atmosphere and evaluation, but poor variation.

A literature review suggests that although some studies have explored the impact of the illumination type on mental perceptions, the focus is almost always on "positive moods", such as amenity, while discussions on "negative moods", such as pressure, tension, and depression, as commonly faced by contemporary people, are insufficient. Meanwhile, most of these studies were conducted when the subjects were in a state free from pressure and negative moods; hence, the results could not reflect the level of "relief" of negative moods, such as pressure. Besides, the model experiment cannot reflect the real state in which a person is surrounded by light. So, this study investigates how artificial lighting affects people's positive and negative moods, and ascertains the features of lighting environments that more effectively increase people's positive moods or heal their negative emotions.

2. Method
To facilitate control of the experimental variables, experiments of this study were conducted in the laboratory, where, according to the settings of the manipulated variables, various lighting environments were recreated. Next, the subjects were placed in various lighting environments and given the necessary operations to measure their mental indicators at specific time points. Finally, the data of the measured psychological indicators were analyzed to evaluate the effects of various lighting factors.

Although lighting factors are complex, they can be roughly divided into three categories: light color, brightness, and arrangement. Light color is related to color temperature. Brightness is related to luminance and also illuminance. Arrangement is related to illumination types and illuminance distribution. Previous studies have confirmed that these three factors have a psychological impact. Hence, this study used color temperatures, illuminance, and illumination types as the manipulated variables of lighting environments, while the other non-manipulated factors were fixed in the laboratory. The above three factors were changed to present the different lighting environments.

In order to understand the level of relief and soothing of pressure and tension of subjects under different lighting environments, at the beginning of each experiment, the subjects were provided with assignments to increase mental loading. When the assignments were ended, the researcher observed the changes in the mental indicators at different time points.

3. Experimental Design
3.1 Experimental Space
An existing office space, 428 cm in length, 244 cm in width, and 293 cm in height was used as an experimental room. In order to prevent the effect of natural light on the interior lighting environment in the experimental room, the windows were covered with black curtains. The desk and chairs for the experimental subjects were placed in the middle part of the experimental room. There were two seats. In each experiment two subjects were tested. The desk centers of the two seats were separated by a 70cm high partition, thus, their lines of sight were blocked when the two subjects were seated (Fig.1.). The distribution of illuminance measuring points in the experimental room was as shown in Fig.1. The height of measuring points was 75cm above the floor.

3.2 Lighting Environments
The office exhibited three illumination distribution types (Type A, B and C) and 10 lighting environments. A-a1~A-b3 were six lighting environments that simulate uniformly distributed lighting in ordinary offices (General lighting). The actual light source was T8 fluorescent lamps (18W). Among the above six lighting environments, the average illuminance of A-a1–A-a3 was 780lx (12 fluorescent lamps), and the color temperature was 3000K, 4000K, and 6500K, respectively. The average illuminance of A-b1–A-b3 was 1500lx (24 fluorescent lamps), and the color temperature was 3000K, 4000K, and 6500K, respectively (Table 1.). 780lx was within the illuminance range required for ordinary offices, and...
1500lx was within the range required for a precision operation space.

B-c4, B-c3, C-d4, and C-d3 simulated lighting in living rooms, coffee shops and restaurants. B-c4 and B-c3 were direct lighting, and the light sources were set in the center of the rooms ceiling. The light sources used were three 15W compact fluorescent lamps. The average illuminance of the room was about 150lx, and the illuminance on the desk was about 200lx. The color temperatures were 2700K and 6500K. C-d4 and C-d3 were indirect lighting, and the light sources were around the walls of the room. The light sources used were also compact fluorescent. The illuminance on the desk was about 75lx (Table 1.); the color temperatures were also 2700K and 6500K.

The illuminance distribution patterns of 10 lighting environments are shown in Fig.2.

### Table 1. 10 Lighting Environments

| Lighting environment | Characteristic | Average illuminance level (lx) | Color temperature (K) | Illuminance on the desk (lx) | Maximum illuminance (lx) | Minimum illuminance (lx) | Average illuminance (lx) | Uniformity ratio of illuminance (E_{max}/E_{min}) |
|----------------------|---------------|--------------------------------|-----------------------|-----------------------------|--------------------------|--------------------------|--------------------------|------------------------------------------|
| A-a1                 | Direct/General| 780                            | 3000                  | 785                         | 999                      | 629                      | 784                      | 0.80                                    |
| A-a2                 | Direct/General| 780                            | 4000                  | 758                         | 1001                     | 606                      | 784                      | 0.77                                    |
| A-a3                 | Direct/General| 780                            | 6500                  | 762                         | 988                      | 606                      | 761                      | 0.80                                    |
| A-b1                 | Direct/General| 1500                           | 3000                  | 1538                        | 1875                     | 1271                     | 1514                     | 0.84                                    |
| A-b2                 | Direct/General| 1500                           | 4000                  | 1519                        | 1900                     | 1228                     | 1517                     | 0.81                                    |
| A-b3                 | Direct/General| 1500                           | 6500                  | 1471                        | 1842                     | 1191                     | 1465                     | 0.81                                    |
| B-c4                 | Direct/Central| 150                            | 2700                  | 201                         | 223                      | 81                       | 150                      | 0.54                                    |
| B-c3                 | Direct/Central| 150                            | 6500                  | 190                         | 213                      | 75                       | 141                      | 0.53                                    |
| C-d4                 | Indirect/Ambient| 75                            | 2700                  | 80                          | 91                       | 61                       | 77                       | 0.79                                    |
| C-d3                 | Indirect/Ambient| 75                            | 6500                  | 76                          | 84                       | 56                       | 70                       | 0.80                                    |

3.3 Subjective Evaluation

Two types of subjective questionnaires, the POMS and VAS, were used to follow up the mental state of the subjects in 10 lighting environments. The effects of each lighting factor were judged based on the scores of POMS and VAS.

The POMS (Profile of Mood State), as compiled by McNair, Lorr, and Doppleman, was modified into a simplified version by Grove and Prapavessis. Many studies used the POMS to monitor subjects' mental states under various environments. The POMS covers several positive and negative moods. This study used the scores of "Vigor", "Fatigue", and "Tension" of the POMS as the subjective evaluation indicators.
This study also used the VAS (Visual Analog Scale) to determine the evaluation and mental states of the subjects regarding various lighting environments. The VAS has certain advantages and was conducted in many studies\(^\text{(15-17)}\). The results of the VAS were used for comparison with the results of the POMS in order to verify the differences between different mental indicators. The VAS included two parts, consisting of five items. The first part allowed the subjects to evaluate the interior lighting environment. The evaluation included two items, "Amenity" (Comfortable- Uncomfortable) and "Satisfaction" (Satisfied- Unsatisfied), with the entire environment. The second part allowed the subjects to evaluate their current psychological status. The evaluation included three items, "Anxiety" (Nervous-Not nervous), "Stress" (Stressed-Not stressed), and "Fatigue" (Tired- Energetic). The VAS set two opposite feelings on both ends of the scale, and the scale had no mark. The subjects were asked to place a mark on the scale of the evaluation item to describe their feelings. The scale length was assumed to be 100, and the marked position was converted to a score of 0~100. Without marks, the subjects' answers were not affected by memory or mark.

### 3.4 Tasks

The subjects were asked to perform a 60-minute task in order to create a mental load. The 60-minute task included five kinds, "Mathematical calculations", "Grid check", "Figure recognition", "English typewriting," and "Sudoku". The time periods were 10 minutes, 5 minutes, 10 minutes, 20 minutes, and 15 minutes. Among the five tasks, "Mathematical calculation" was selected from tasks in the previous studies\(^\text{(15-18)}\). "Grid check" and "Figure recognition" were selected from tasks in Takashi's researches\(^\text{(18)}\). "Sudoku" is a puzzle developed by the Japanese Nikoli Co., Ltd., and was used in some studies\(^\text{(19)}\). They selected "Sudoku" as one of the tasks for the subjects because it requires more complicated thinking, compared to simple addition and subtraction. For the same reason, "Sudoku" was listed as one of the tasks in this study, while "English typewriting" was an additional task.

"Mathematical calculation" involved adding three-digit numbers in two groups. "Grid check" required the subjects to draw one oblique line at the intersection between a straight line and a transverse line in a checkerboard table. "Figure recognition" involved finding a specific kind of pattern in thickly dotted and varied geometric figures. "Sudoku" involved filling a 9 x 9 grid with digits 1-9 so that each column, each row, and each of the nine 3 x 3 sub-grids that composed the grid contained all digits from 1 to 9 (Fig.3.). "English typewriting" involved retyping each English word in the English document on a computer without any omissions.

### 3.5 Experimental Flow

The subjects first filled out the POMS and VAS questionnaires before the experiment. After commencement of the tasks, the subjects completed a 60-minute task, which increased their mental load. After the 60-minute task, the subjects completed the second POMS and VAS questionnaires, the contents of which were the same as the first questionnaire. Next, the subjects were allowed to rest and read their favorite books (prepared by themselves). After a 20-minute rest, the subjects completed the third POMS and VAS questionnaires. After a 40-minute rest and read, the subjects filled out the fourth POMS and VAS questionnaires. Finally, they completed one kind of lighting environment experiment, which took two hours to finish. In order to prevent the impact of subjects' fatigue on the experimental results, one subject was tested under one lighting environment per day.

### 3.6 Subjects

The subjects would be under a heavy burden after repeating the experiment under 10 lighting environments; hence, the 10 lighting environments were divided into four groups for experimentation, as per the control variables. Group 1 comprised A-a1–A-a3; Group 2 comprised A-b1–A-b3; Group 3 comprised B-c4 and B-c3; Group 4 comprised C-d4 and C-d3. The subjects in Group 1 only underwent three lighting environmental experiments, and the other groups followed the same pattern. There were 21 subjects in Group 1 (14 males/7 females), 20 subjects in Group 2 (11 males/9 females), 22 subjects in Group 3 (14 males/8 females), and 20 subjects in Group 4 (11 males/9 females). All subjects were aged 18~28, and undergraduate or graduate students. After completion of the experiment, each subject received monetary compensation for the task.

### 4. Experimental Results

#### 4.1 POMS

A-a1–A-b3, had the same lighting type and illuminance distribution. Only the combinations of illuminance and color temperatures differed, thus, they could be analyzed together. B-c4–C-d3 had two different illuminance distributions, but could still be regarded as combinations of two illuminance distribution types and two color temperatures. Thus, they could also be analyzed together. For the first six light environments, color temperature and time were regarded as within-subject factors, and illuminance was regarded as a between-subjects factor, as the subjects in A-a1–A-a3 and A-b1–A-b3 were different.

Repeated measures of ANOVA were conducted from three dimensions, "Vigor", "Fatigue", and "Tension", in POMS. The results showed that "Time" has a significant effect on "Vigor" (F(3,114)=19.46, p<0.01), "Fatigue" (F(3,114)=20.58, p<0.01), and "Tension" (F(3,114)=17.56, p<0.01), while the factors of "Illuminance" and "Color Temperature" have an insignificant effect. The subjects had a higher "Vigor" score before the task, and a lower "Vigor" score after the task. The score showed no obvious change after they rested and read for 20 minutes and 40 minutes.
"Fatigue" was exactly the opposite. The subjects had the lowest "Fatigue" score before the task. After the task, the "Fatigue" score reached the highest, slightly decreased after a 20-minute rest, and continued to decrease after a 40-minute rest. The "Tension" score was higher before and after the task, and was lower after a second half-time rest during the experiment (Fig.4.). From the above three indicators, it can be seen that five kinds of task, as anticipated, increased the mental load of the subjects.

Repeated measures of ANOVA were conducted for B-c4~C-d3. The results were consistent with those of A-a1~A-b3. "Time" had a significant effect on "Vigor", "Fatigue", and "Tension", while the "Illuminance distribution" and "Color Temperature" had an insignificant effect.

4.2 VAS

Like the POMS analysis, in A-a1~A-b3, "Color Temperature" and "Time" were regarded as within-subject factors, while "Illuminance" was regarded as between-subject factors. Repeated measures of ANOVA were also conducted from five dimensions, "Amenity", "Satisfaction", "Anxiety", "Stress", and "Fatigue", in VAS. The results showed that, in the main effects, the factor "Time" had a significant effect on the five indicators, while "Color Temperature" and "Illuminance" had no significant effect. From the effect of the factor "Time" of the 60-minute task could increase the mental load of the subjects. After completing a task, rest and reading time could reduce mental load.

The above analysis was also conducted for B-c4~C-d3. The results showed that the factor "Time" had a significant effect on the four indicators of "Amenity", "Anxiety", "Stress", and "Fatigue". The effect was similar to that of POMS, and A-a1~A-b3. The factor "Color temperature" had a significant effect on "Anxiety" (F(1,40)=7.64, p<0.01) and "Stress" (F(1,40)=4.46, p<0.05). Of 6500K and 2700K, the subjects felt more anxious and stressed at 6500K (Fig.5); 2700K had a better healing effect. In addition, regarding interaction effects, "Color temperature*Time" had a significant effect on "Amenity" (F(3,120)=3.07, p<0.05) and "Satisfaction" (F(3,120)=2.87, p<0.05). If 2700K was the control group, "Amenity" and "Satisfaction" at 6500K decreased greatly before and after the 60-minute task. It was clear that "Amenity" and "Satisfaction" were better at 2700K. Even if the mental load was great, people could maintain stable...
"Amenity" and "Satisfaction" at 2700K. In view of this, 2700K was better than 6500K.

4.3 Effects of Illuminance Distribution

If the factor "Time" is ignored, the results of POMS and VAS in different illuminance distribution environments can be compared. One-way ANOVA was conducted to discuss the performance of POMS and VAS in three different illuminance distribution environments. The results showed that, in addition to VAS "Fatigue", "illuminance distribution" had a significant effect on all the indicators of POMS and VAS. The performance of POMS "Vigor" was better in Type A and C, and was the worst in Type B (F(2,813)=5.514, P<0.01). POMS "Fatigue" was better in Type C, and was worse in Type A and B (F(2,813)=4.904, P<0.01). POMS "Tension" was the best in Type C, and was the worst in Type A(F(2,813)=14.490, P<0.01) (Fig.6.). VAS "Amenity" was better in Type A and C, and was worse in Type B (F(2,813)=7.506, P<0.01). VAS "Satisfaction" was better in Type A, and was worse in Type B (F(2,813)=7.450, P<0.01). VAS "Anxiety" was the best in Type C, and was the worst in Type B.
VAS "Stress" was the best in Type C, and was the worst in Type A (F(2,813)=17.681, P<0.01) (Fig.7).

The above results showed that the performance of Type A was the best in positive moods (POMS "Vigor", VAS "Amenity" and VAS "Satisfaction"), but was the worst in negative moods (POMS "Fatigue", POMS "Tension", VAS "Anxiety" and VAS "Stress"). Besides, Type C was the best in negative moods.

5. Discussions

Fig.8. shows the relationships between factors, and can be applied to illumination design. General lighting can increase positive moods to a higher level; however, indirect/ambient lighting is better able to reduce negative moods. As for illuminance level, moods were not affected by illuminance level in general lighting. As to color temperature, 2700K is more advantageous to moods than 6500K in direct/central and indirect/ambient lighting. However, color temperature has very little impact on moods in general lighting.

To clarify the overall difference of all evaluation items among 10 lightings, this study took three POMS and five VAS evaluation items as variables for Multidimensional Scaling (MDS) analysis. The result was Stress=0.137, RSQ=0.921, and this indicates that the model is good. The MDS result can be plotted in Fig.9. A closer distance between two points in the graph indicates that the two have more similar performance. Fig.9. shows that the moods were mainly affected by illumination types. The scope of three blue circles has no overlap. Color temperature has a great effect on Type B and C, but has a slight effect on Type A (red dotted lines). The effect of illuminance (blue solid lines) was as slight as the effect of color temperature on Type A. The six points in Type A were relatively close. This result showed the existence of interaction effects between illumination types and color temperature. Besides, illuminance and color temperature have relatively weak influences on moods in general lighting.

Melatonin is a hormone that promotes sleep, and its secretion is inhibited by light stimulation. Therefore, it is thought that higher illuminance level improves people's arousal level, and lower illuminance level promotes relaxation or rest. The finding in this study has similar results. The performance of positive moods is Type A>C>B, and the performance of negative moods is Type C>B>A (Figs.6. and 7.). Type A (780 or 1500lx) is able to promote "Vigor", "Amenity", and "Satisfaction" to a higher level. Type C (75lx) is able to reduce "Fatigue", "Tension", "Anxiety", and "Stress" to a lower level. However, according to the results of 4.1 and 4.2, the difference of the performance of moods between 780lx and 1500lx was insignificant. This means that the single factor of illuminance may not be influential. An interaction effect between illuminance and illumination types exists.

By comparing the findings in this study with the graph of the effect of color temperature and illuminance by Kruithof, two settings fall in the sweltering range (780lx-3000K and 1500lx-3000K), while the other four settings fall into the amenity range, in A-a1~A-b3. The result is not consistent with Kruithof's view. The evaluations at 3000K are as good as 4000K and 6500K. On the other hand, B-c4~C-d3, 75lx-2700K and 150lx-2700K fall into the amenity range, and 75lx-6500K and 150lx-6500K fall into the gloomy range.
is consistent with the finding in this study. Kruithof only discussed the condition of general lighting, and ignored the effect of illuminance distribution on psychological evaluations. This study showed that the illuminance distribution has a strong impact on subjective evaluations. Besides, in everyday life, white light illumination, such as 6500K, is more common in high illuminance general lighting. But according to this study, yellow light, such as 2700K and 3000K, is also suitable for high illuminance general lighting.

Although there are various illumination types in the building environment, this study was limited to three prototypes. Other illumination types should be discussed in future studies. Besides, although this study was conducted in a real office, many factors were ignored, such as luminance distribution within the subject's visual field, furniture, material color, and reflectance of the space. The impact of these factors also needs more follow-up studies in order to be clarified.

6. Conclusions

This study discussed the effects of lighting on positive and negative moods in the 10 lighting environments. The findings showed that the evaluations of POMS and VAS were the same in the six general lighting environments. With direct lighting, and a light source in the central area of the room, people's moods were better at 2700K. 2700K could also mitigate people's pressure and stress. With indirect lighting and the light source diffused around the walls, people's moods were also better at 2700K. 2700K could also mitigate people's pressure and stress. Among three illuminance distribution environments, people felt less anxious, stressed and fatigued (negative moods) in indirect/ambient lighting. However, the performance of vigor, amenity and satisfaction (positive moods) are better in general lighting. Therefore, it can be said that indirect/ambient lighting is advantageous to negative moods, but general lighting is advantageous to positive moods.

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