Evaluation on non-visual effects of lighting based on both physiological parameters and subjective ratings

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Abstract: This article explores the influence of different colors of lights on human physiological parameters and at the same time the effects on human emotions, and tries to explore the inner connection of the changes. It helps us to better understand the color of lighting and apply it in daily life or commercial purpose. Then the experience of visual sensation will be enhanced. This article examines the changes in physiological parameters and the subjective emotional ratings triggered by the six lighting conditions such as red, green, blue, warm white, cold white and darkness. From the experiment results, the changes of physiological parameters and subjective emotions can be observed under different lighting conditions, which can be applied to guide lighting design and projects.

1. Introduction

With the improvement life quality, the pursuit of spiritual level is increasing, especially the pursuit of sensory experience. How to provide a better sensory experience has become the key to attract customers. The immersive lighting design has been applied in restaurants, hotels, and shopping mall decorations. The positive reaction of the customers in such lighting conditions will lead to the accomplishment of a deal. The target of this article is to explore the reaction effects of lighting through both the physiological parameters and the subjective emotion ratings.

Color is an important clue for object recognition. In addition, colors can make the observer experience emotions and feelings. Because objects will inevitably show colors, and the emotions caused by colors will affect daily life, the emotional association of colors is inevitable. For example, the influence of color on emotions and preferences is crucial in marketing; the color of a product will have a positive or negative impact on the attitude of the audience, and the color will lead to differentiation of products, brands and corporate images. It is confirmed by modern physics that color is a sensation produced by the transmission of light to the brain's visual center by stimulating the eyes. Different phenomena in nature and society will cause a variety of color changes, so that we have different experience and perception. People have gradually established certain specific meanings, feelings and psychological responses to certain colors in their lives. More often, color is a sensory experience of human beings towards nature and society. For example, red is a color that evokes and stimulates; orange is lively, energetic, and outgoing; yellow represents hope, wisdom and expansion; green represents freshness, Natural; blue is passivity, cleanliness, quietness, etc. Pink can play a good calming effect, and has been successfully used to reduce the offensive behavior of prisoners. Some studies have shown that in an office full of colors, different colors will affect office efficiency. Compared with blue-green offices, red offices can improve office efficiency. The development of
LEDs and lighting control technology provide pure colored lights such as red, blue, and green. Colored light is related to the psychological and physiological effects of color, and attracts people's attention\cite{7}. As reported in recent literature, the impact of lighting goes beyond comfort and safety issues. Illumination level and environmental color seem to have different effects on perception and physiological parameters\cite{8,9}. Therefore, this article is based on these studies by monitoring changes in physiological parameters and subjective emotions under different lights, hoping to play a greater role in lighting design applications.

2. Experiment: the influence of different lights on physiological parameters and subjective emotions

2.1 Experiment Purpose
Explore the physiological responses of the participants. There are six lighting conditions such as the three primary colors (red, green, blue), warm white, cold white, and darkness conditions. The changes in physiological parameters and subjective emotions of the participants are recorded too.

2.2 Participants
Twenty undergraduates and postgraduates (10 males and 10 females), with an average age of 23. All students participating in the test are right-handed, and there is no record of brain, color blindness in the medical files. The subjects are informed with all experimental procedures before the test begins.

3. Materials and Methods
The experiments are in a darkroom. Three primary color light, two white lights and darkness are designed for the tests\cite{10}. The controllable lighting used in the experiment is realized by the intelligent lamp Hue of Philips, and the illuminance at the eyes levels of the participants is fixed 150lx.

The measurement of physiological parameters in this experiment is based on the PM-9000 series multi-parameter monitor. This monitor can be used to monitor ECG, heart rate, body temperature, respiration, blood pressure and blood oxygen saturation. Since the changes in body temperature, blood pressure and blood oxygen saturation are not obvious, the changes in heart rate and respiration will be the key parameters. In this experiment, according to the American standard, the electrode pads were placed in the positions shown in Figure 1 by the five-lead method, and the scanning speed was 12.5mm/s. When the physiological parameters were monitored, continuous waveforms and parameter values were displayed.

![Figure1 Position of five-lead electrode](image)

Before the formal experiment, the participants completed 10 math problems of adding and subtracting mixed operations within 20 in a noise-free environment to adjust their emotions, and monitored the ECG waveform without significant fluctuations up and down. After recording the initial
value of the heart rate and breathing at that time, the first lighting condition can be tested. If the participant makes a calculation error or the ECG waveform has been significantly fluctuating, the experiment will be performed again after a 5-minute rest. The same applies to the last five groups, and the light stimulation sequence is random. This experiment will record the heart rate and respiration value within 60s of light stimulation, and select the maximum value within 60s for analysis and comparison with the initial value. The experiment under light stimulation is shown in Figure 2.

![Figure 2 Test under light stimulation](image)

The recording of subjective emotions is separately from the physiological parameter test. In order to match the color of the light with the subjective emotions, a five-dimensional emotional space based on popular music was adopted, including sadness (loneliness), comfort (warmth), happiness (relaxation), excitement and heroism (excitement)\[^{[11]}\], among which Mainstream music will not cause excessively exaggerated emotions, such as fear (tension), but in order to trigger the completeness of emotions by light, we change the excitement option to fear (tension), and the fear score is recorded as 1 point and 2 points for sadness, 3 points for comfort, 4 points for happiness, and 5 points for bravery. The emotional value changes from negative to stable to positive, as shown in Table 1. The emotional value (mean/standard deviation) marked for each episode (lighting) is recorded as emotional valence.

|          | fear | sadness | comfort | happiness | heroism |
|----------|------|---------|---------|-----------|---------|
| Red      | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 |
| Green    | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 |
| Blue     | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 |
| Warm-White| 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 |
| Cold-White| 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 |
| Dark     | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 | 1-2-3-4-5 |

4. Results & Discussion

The normal distribution test is performed on the recorded initial value of the heart rate and the peak value of the heart rate in 60s. The Q-Q diagram basically meets the normal distribution, so the paired T test can be used for analysis. Data as shown in Table 1. The analysis shows that the heart rate change is more obvious when there is light stimulation than in the dark. Among the three primary colors, green light, \(P \leq 0.001\), has more influence on heart rate than red light and blue light. This may be related to green representing freshness and a symbol of nature. Chinese people prefer to clean, fresh or modern colors\[^{[11]}\]. Under other light conditions, warm white light, \(P \leq 0.001\), has a greater impact on heart rate than cool white light, which proves that more restaurants and hotels choose warm light lighting in
order to create an atmosphere.

Table 2 Paired sample T test of heart rate changes under light stimulation

|       | Red | Green | Blue | Warm White | Cool White | Dark |
|-------|-----|-------|------|------------|------------|------|
| initial M1 | 75.55 | 74.3 | 74.65 | 74.9 | 76.7 | 75.5 |
| Max M2 | 82.1 | 79.9 | 82.95 | 82.1 | 82.1 | 82.8 |
| SD    | 8.727 | 4.418 | 12.938 | 5.435 | 8.485 | 12.239 |
| t     | -3.357 | -5.669 | -2.869 | -5.925 | -3.637 | -2.667 |
| df    | 19 | 19 | 19 | 19 | 19 | 19 |
| sig   | 0.003** | 0.000*** | 0.010** | 0.000*** | 0.002** | 0.015* |

Note: *P≤0.05, **P≤0.01, ***P≤0.001, the following tables are all this note

The respiration changes under light stimulation were also tested with paired T-samples (Table 3). Among them, green light, P>0.05, had no significant effect. This may be related to the lower energy of green light than red light and blue light. The effect is as significant as the effect on heart rate, especially under the light stimulation than in the dark.

Table 3 Paired-sample T test of respiratory changes under light stimulation

|       | Red | Green | Blue | Warm White | Cool White | Dark |
|-------|-----|-------|------|------------|------------|------|
| initial M1 | 20.3 | 20.35 | 19.4 | 20.8 | 20.65 | 19.55 |
| Max M2 | 25.45 | 22.65 | 23.15 | 25.8 | 23.5 | 25.1 |
| SD    | 5.678 | 5.630 | 5.457 | 5.458 | 4.522 | 8.858 |
| t     | -4.056 | -1.827 | -3.073 | -4.097 | -2.818 | -2.802 |
| df    | 19 | 19 | 19 | 19 | 19 | 19 |
| sig   | 0.001*** | 0.083 | 0.006** | 0.001*** | 0.011** | 0.011*** |

The emotional valence and arousal degree values corresponding to each light are inputted into the emotional valence-arousal coordinates. As shown in Figure 3, the emotions of red light and dark tend to be sadness, and the emotions of green light and blue light tend to comfort, the emotion of warm white light approaches heroism, and the emotion of cold white light approaches happiness. In terms of arousal, green light is the strongest, and the warm white light, darkness, cold white light, blue light, red light follow in sequence.

Figure 3 Lighting Emotional valence-arousal
Through the analysis of the subjective emotions triggered by different lights and the rate of change of physiological parameters, it can be seen that in the colored light, the heart rate changes of red and green light are significantly greater than that of blue light. This is in contrast to the blue light in the previous study that increased participants’ feelings of relaxation and calm are consistent\textsuperscript{12}. The heart rate change rate of warm white light is greater than that of cold white and dark conditions. Although the tester’s main evaluation of warm white tends to be happiness, warm, relaxed, and calm words, the arousal rate is the highest among all lights. This is of great help to us when we apply warm white light to actual shopping scenes, which can better improve consumers' desire to buy. In terms of the rate of respiratory change, red light and warm white light are similar. If red light is a kind of arousal, warm white light also has the effect of arousing; blue light and cold white light are similar. In other studies, blue light has a calming effect on tension, fatigue and confusion. Effect\textsuperscript{14}, we guess that cold white light has the same effect as it; green light has the smallest respiration change rate, which may be related to the lower energy value of green light that we mentioned earlier than other colored lights. In terms of arousal, green light and warm white light are the same as their results on heart rate changes, and blue light and cold white light are the same as their results on heart rate changes, which confirm the accuracy of our data. Data show as shown in Figure 4.

![Figure 4: Comparison of lighting data](image)

5. Conclusion
This article explores the mechanism behind how the light affects the physiological parameters and subjective emotion rating. By monitoring the heart rate and breathing and recording the subjective emotion ratings, it is proved that the effects of different colorful lights on people's emotions are significantly compared with the value in darkness. Among the colored lights, green light leads to the most effective results. Both red light and warm white light have the effects of arousing emotions. Blue light and cold white light also have a calming function\textsuperscript{13}. At the same time, the difference in arousal of different lights may have more important application value in medical psychotherapy, but this requires further experiments and verification. More physiological techniques will be introduced into the experiment such as EEG and MRI to get detailed information.

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