A Study on the Emotional and Visual Influence of the CICU Luminous Environment on Patients and Nurses

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Abstract
Cardiovascular diseases loom large in China and studies indicate an appropriate luminous environment helps to boost the emotions of cardiovascular patients. This study discusses emotional and visual influences of the luminous environment of Cardiac Intensive Care Units (CICU) on both patients and medical care personnel. We draw the following conclusions: 1) Illuminance level, color temperature, and lighting method all affect patient and nurse satisfaction. 2) Patients prefer low color temperature, while nurses prefer a higher one; however, factors such as illuminance, lighting method, and luminance distribution outweigh the influence of color temperature. 3) The major factors affecting patient satisfaction consist of the emotional and the visual factors in inverse correlation. 4) Nurse satisfaction correlates to the visual factor score. 5) The visual factor scores of subjects (patients and nurses) correlate positively to illuminance levels and average luminance. 6) In a specific range, the visual factor scores of subjects correlate positively to luminance contrast and UGR. 7) In a scenario characterized by an illuminance of 200 lx or an average luminance of 60 cd/m², the trends of patients’ emotional factor and visual factor intersect, where the emotional factor peaks. 8) For the patients and nurses in CICU, their lighting demands varied due to different purposes. Patients needed to rest while nurses needed to see things clearly at work. In our opinion, the CICU Luminous Environment should be adapted to the needs of different major users (patients or nurses) with controlled parameters to achieve ideal performance. However, when illuminance and average luminance grow beyond the peak, the emotional factor will decrease.

Keywords: CICU; light environment; emotion; vision; satisfaction

1. Introduction
According to the Report on Cardiovascular Diseases in China 2014 issued by the National Center for Cardiovascular Diseases, Ministry of Health P.R. China, 290 million people are suffering from cardiovascular diseases¹. In 2011 the WHO reported that cardiovascular diseases have become the worldwide No. 1 killer that takes a bigger annual toll than any other disease². Chinese medical institutions have established CICUs to address the problem. 

Equipped with complex first aid equipment, a cardiac intensive care unit (CICU) is an enclosed space characterized by an extremely depressing atmosphere possibly intensified by the sudden condition deterioration or deceasing of other patients. In a strange space deprived of family company, patients would be prone to negative emotions such as depression, anxiety, loneliness, and fear, which would be aggravated by their concern over their own diseases³. Negative emotions would excite sympathetic nerves, boost blood pressure, increase heart rate, inhibit peristalsis and add to the workload of the heart⁴-⁶. According to research of the Japan Cardiovascular Research Foundation⁷ and Barbara et al. (2010)⁸, negative emotions correlate to the occurrence of cardiovascular disease. Hoen et al. (2011)⁹ launched a long-term tracking survey of 13,708 patients suffering from coronary artery diseases (without history of the disease) and found a close link between depression and the occurrence of cardiovascular disease. Drawing on the correlation between negative emotions and the occurrence of acute myocardial infarction, Rosengren et al. (2004)¹⁰ performed an international tracking survey of 24,767 subjects from 52 countries and analyzed the proportion of depressed patients and those suffering from

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permanent social negative emotions in 11,119 patients with acute myocardial infarction and in 13,648 healthy people. As a result, the occurrence of acute myocardial infarction among the people with permanent social emotional problems was 1.55-fold of the occurrence among healthy people. The study also revealed that the occurrence of acute myocardial infarction among Asian patients with depression was 2.08-fold the occurrence among non-depressed people. While in Europe, this figure was 1.37-fold. Thus, for Asian patients, negative emotions correlate more closely to the occurrence of cardiovascular diseases.

Tsios and Alichanidou (2008) studied the CICU psychosis syndrome and suggested that CICU calls for a soft light environment with an ideal control mode to reflect circadian rhythms. In their researches on hospital coloring and luminance, Dalke et al. (2006) found that good luminance and coloring enhance patient recovery rate. Novaes et al. (1997) performed a randomized questionnaire survey on 50 ICU patients to conclude that a friendly ICU space would help patients to recover physically and psychologically. Espiritu et al. (1994) indicated that under constant color temperature, subjects' emotions would positively correlate to illuminance. The researches of Daurat (1993) and Partonen et al. (2000) revealed that within a certain illuminance range, the subjects would have a better mood than under higher illuminance. Küller et al. (2006) performed a subjective questionnaire survey on 988 subjects from four countries at different latitudes. According to their results, luminance correlated negatively to emotions when it exceeded a certain (not clarified) threshold value.

These studies lead to discussions about the relation between luminance stimulation and patient emotions from various aspects. However, there were few studies aimed at CICU spaces and their users. We surveyed the major users (patients and nurses) of the CICU environment and discussed quantitatively how they were visually and emotionally affected by environmental parameters of CICU luminance (illuminance, luminance, color temperature, and lighting methods).

2. Method

2.1 Experimental Set-up

Based on the typical layout of a medical institution in Shanghai, China, our team built a real-size simulated ward. (Fig.1.: plan, Fig.2.: cross-section drawing, Fig.3.: experimental scenario). As a single room (L = 4.2 m, W = 3.6 m, and H = 2.8 m), this simulated ward was equipped with white wall paper, white plaster ceiling, a dark grey carpet, and medical facilities such as a hospital bed, a bed head panel, an ECG, and an infusion bag holder. The bed head panel and the wall below were wooden. A 3.6 m x 3.6 m private space was divided with a white curtain. As shown in Fig.3., the ward had experimental lamps installed at Point A and Point B. Lamp A provided direct luminance, while Lamp B cast indirect light with lighting parameters shown in Table 1. We arranged four monitoring points at "x1 - x4" at four corners of the hospital bed at a height of 1.2 m to automatically record changes in horizontal illuminance, room temperature, and relative humidity. x5, x6 were used to measure vertical illuminance of the infusion bag and ECG screen respectively. The experimental scenario was provided with a room temperature of 26°C, relative humidity of 50%, and wind speed of less than 0.3 m/s. The experiment lasted from June 2014 to December 2014 in Room 114, Wenyuan Building, College of Architecture and Urban Planning Tongji University.
2.2 Experimental Case

In this experiment, we switched from one scenario to another by adjusting the intensity of direct and indirect illumination. To better describe the relation between these two illumination modes, we proposed the concept of "direct illumination contribution rate" as shown in Equations 1 - 4. Equation 1 and 2 defined how to calculate the horizontal illuminance of direct and indirect illumination. The average illuminance of the working surface (E) was the sum of working surface illuminance from direct illuminance (ED) and from indirect illuminance (EI) (Equation 3). As shown in Equation 4, the contribution rate of direct illumination was the ratio of ED and E.

\[
E_D = \frac{1}{4} \sum_{i=1}^{4} E_{D,i} \\
E_I = \frac{1}{4} \sum_{i=1}^{4} E_{I,i} \\
E = E_D + E_I \\
P = \frac{E_D}{E_D+E_I} \times 100\%
\]

Where:
- ED: Horizontal luminance of direct illumination (lx)
- EI: Horizontal luminance of indirect illumination (lx)
- E: Horizontal luminance of the working surface (lx)
- P: Direct illumination contribution rate (%)

Table 2. lists the five direct illumination contribution rates (P1-P5) employed in the experiment. Controlling the three variables: horizontal illuminance of working surface (100 lx, 200 lx, 400 lx), color temperature (3000 K, 4000 K, 5000 K), and direct illumination contribution rate (0%, 30%, 50%, 70%, and 100%) generated 45 experimental scenarios (Table 3.).

2.3 Participants

Each experimental scenario was subject to the subjective evaluations of two subjects (one patient and one nurse), resulting in 14 subjects in this experiment. As shown in Table 4., the average age of the seven patients (all with a history of similar operations) was 43.57 ± 25.15 years, while that of the seven nurses working fulltime in the Division of Cardiovascular Medicine averaged 24.43 ± 2.23. The male/female ratio of patients was 4:3 and that of nurses 1:6. All subjects completed informed consent forms and met the following requirements: 1) Visually and psychologically healthy; 2) No smoking or alcohol during the week before the experiment; 3) No food or drink one hour before the experiment and keeping calm; 4) Throughout the experiment, patients wore typical patient dress and were required to simulate resting in bed calmly, evaluating the illumination environment based on visual comfort. Nurses were required to simulate working in the ward in their uniforms and evaluate the illumination environment based on how it facilitates work.

2.4 Measures

In this study, we employed Semantic differential (SD) questionnaires to evaluate subjective feelings in all illumination scenarios and recorded the physiological data of the subjects. We provided 12 optional words for the patients to describe their visual and emotional experience in the questionnaire, as shown in Table 5. The questionnaires for nurses were oriented to evaluate their visual experience during nursing work (e.g. identifying blood vessels for injection, measuring blood pressure, and preparing medical records) and satisfaction concerning light environment, as shown in Table 6.

We used Cronbach's alphas to analyze all recovered questionnaires and identified them. Cronbach's alpha, an index to gauge the credibility of questionnaires, is generally believed to be acceptable when it reaches 0.8 in basic researches and 0.7 in exploratory researches. The Cronbach's alpha of patients' questionnaires was 0.932, while that of nurses' reached 0.942, attesting to the strong reliability of the questionnaire. For the physical measurement, we provided electroencephalography (ECG) next to the hospital bed to automatically record all changes in blood pressure and heart rate. We also recorded the changes in horizontal illumination, temperature, and relative humidity as well as the luminance distribution in patients' visual field using a high-resolution luminance meter. Auxiliary for the experiment, those data were
not directly discussed regarding light stimulation, but only as a reference to help clarify the confusion in later statistical treatment.

2.5 Procedures

Experimental procedures: (1) Patients and nurses entered the lab at 19:00, measured their body temperature and body weight, filled in personal information and adapted themselves to the simulated CICU environment. Subsequently, the experimenter distributed questionnaires and introduced the experiment. (2) Patients then rested in bed while nurses sat beside the bed. All of the participants put on eye shields (below 0.05 lx). The experimenter appointed experimental scenarios at random; (3) Subjects removed their eye shields and adapted themselves to the current scenario for 5 minutes; (4) Patients and nurses evaluated the interior illumination environment and completed the questionnaires, respectively. The experimenter recorded experiment data; (5) We repeated steps 2 - 4 until 15 scenarios were completed. At the end of the experiment, the body temperatures of subjects were measured again and recorded for reference during later statistical treatment if necessary.

3. Statistical Analysis and Validity Checks

3.1 Descriptive Analysis

Figs. 4. and 5. display the average scores of the words for patients and nurses under different lighting environments. As shown in Fig. 4.: For patients, 100 lx scored the lowest among three illuminance levels besides "Harsh". 200 lx and 400 lx scored similarly, but differently from 100 lx. Different direct illumination
contribution rates influenced the word scores: The word scores of Scenario P1 were overall lower than other scenarios and the scores increased from P1 to P5. Color temperature showed no major difference in the word scores of three modes of color temperatures. However, the color temperature of 3000 K had the best performance. Fig.5. showed that for nurses, the word scores increased with increasing illuminance, and this trend was stronger than in patients. The score gap of 100 lx - 200 lx was larger than that of 200 lx - 400 lx. The influence of direct illumination contribution rate on word scores was not significant for patients. Although scenario P1 scored low among patients, it was similar to other scenarios for nurses on scores, even with several words scored higher than those of other scenarios. Color temperature had no obvious influence on word scores. Though 3000 K scored the highest among patients, 5700 K scored higher than the other two color temperature options for nurses.

3.2 Analysis of Variances (ANOVA)

Figs.6., 7., and 8. showed the results of the statistical analysis of overall subject satisfaction. Fig.6. showed the satisfaction of patients and nurses under different illuminance levels: Nurse satisfaction correlated positively with illuminance level, while in patients, the metric peaked at an illuminance level of 200 lx. Satisfaction under different color temperature was shown in Fig.7.: CCT had a minor influence on the satisfaction of both patients and nurses. However, we found by comparison that patient satisfaction was slightly negatively correlated to color temperature. While for nurses, the top color temperature had optimal performance. Fig.8. showed the relation between direct illumination contribution rate and subject satisfaction: P1 (100% direct illumination contribution rate) scored the lowest in satisfaction for both patients and nurses. Subject satisfaction grew as the direct illumination contribution rate fell. This was especially true in patients, whose satisfaction correlated negatively to direct illumination contribution rate and peaked at P5. Nurse satisfaction peaked at P4. We speculated that varied visual demands caused the observed difference in subject groups.

We adopted Multi-way ANOVA to analyze these three factors (illuminance, color temperature, and direct illumination contribution rate) for their effects on satisfaction of patients and nurses.

For patient satisfaction, we concluded that illuminance and direct illumination contribution rate influenced the satisfaction (P-Values < 0.01). P-Values of the main effect (color temperature) were 0.047, and thus smaller than the significance level of 0.05. Therefore, we considered the influence of color temperature on satisfaction as statistically significant.

For the influence of three factors on satisfaction, we observed no significant correlation (P > 0.1) between these three factors, consequently, we analyzed their main effects. The mean differences of illuminance and color temperature were significant (P = 0.001 and P = 0.046, respectively), thus corroborating the influence of illuminance and color temperature on nurse satisfaction. The influence of the direct illumination contribution rate on nurse satisfaction was minor (P = 0.118).

3.3 Factor Analysis

We found that the words of the questionnaire highly correlated, influenced by few independent latent factors. Factor analysis helped us to obtain latent factors, probe the internal connection between those words, and facilitate follow-up analysis and research. The data obtained in this study, including patient Kaiser-Meyer-Olkin (KMO) of 0.886 and nurse KMO of 0.899, were suitable for factor analysis with the purpose to reduce dimensionality. Bartlett's test assumed the correlation coefficient matrix to be a unit matrix. However, as the P-Values of the data of patients and nurses were below 0.05, the original assumption
was rejected, indicating a significant correlation between the words. Therefore, the factor model was appropriate to extract independent principal factors. We used factor analysis to reduce the dimensionality of 12 words (excluding satisfaction) for patients and 6 words for nurses (excluding satisfaction), extracted the independent principal factors, orthogonally rotated them to clarify their meaning and classified the words based on the loadings of the rotated factors. We therefore obtained the Rotated Component Matrix of both patients and nurses as shown in Table 7.

We processed eigenvalues above 1 in a correlation coefficient matrix between variables, as the number of principal factors. We extracted two principal components from patient data with an accumulating contribution rate of 75.96%. The interpretable degree of two principal factors on the original words was 80%. Since the principal factors subsequent to orthogonal rotation was clearer, we only enumerated the rotated component matrix. We extracted one principal factor from nurse data with a contribution rate up to 74.6% and high interpretable degree on the original data.

The loading matrix of patient data with the loadings of Wp4, Wp5, Wp6, Wp7, Wp8, Wp9, and Wp11 were larger on Factor 1 and the loadings of other words were larger on Factor 2. According to their meaning, we defined Factor 1 as an "emotional factor" and Factor 2 as a "visual factor". Resulting from the loading matrix of nurses, loading of every factor on the principal factor was higher than 0.8, indicating a strong interpretable degree of the principal factor on each original factor.

In patient data, we used satisfaction Wp12 as a dependent variable and emotional factors and visual factors as independent variables to probe the influence of emotional and visual factors on satisfaction. A linear regression approach resulted in a model with an R-square of 0.899, indicating excellent goodness of fit. The P-Values of the variance analysis was below 0.01, indicating that the model passed the overall significance test. P-Values of t-tests for parameter coefficients were all less than 0.01, indicating that the coefficients of independent variables were significant. The ultimate equation of the model was as follows:

\[
\text{Satisfaction} = 0.783 + 1.237 \text{ Factor 1} + 0.671 \text{ Factor 2}
\]

where both principal factors had a valid interpretation on satisfaction.

Similarly, we used nurse satisfaction Wn7 as the dependent variable and the extracted principal factor as the independent variable to probe the influence of the principal factor on satisfaction. With this linear regression approach, the model had an R-square of 0.744, indicating excellent goodness of fit. The P-Values of model variance analysis was below 0.01, indicating that the model passed the overall significance test. P-Values of t-tests for parameter coefficients were all less than 0.01, indicating that the coefficient of the independent variable was significant. The ultimate equation of the model was as follows:

\[
\text{Satisfaction} = 0.180 + 1.123 \text{ Factor}
\]

where the principal factor had a valid interpretation on satisfaction. As most of the words selected in this study were relevant to visual functions, only one principal factor was obtained with the factor analysis relevant to satisfaction. We named the principal factor as a "visual factor".

4. Discussion

The multiple comparisons on satisfaction, emotional factor and visual factors of patients performed with LSD and Bonferroni indicated that 1) satisfaction correlated profoundly to emotional factor and visual factor (LSD: P-Values = 0.004; Bonferroni: P-Values = 0.011); 2) emotional factor had nothing to do with visual factor (LSD: P-Values = 1; Bonferroni: P-Values = 1).

Table 7. Loading Matrix of Factor Analysis Model

| Rotated Component Matrix of Patients | Rotated Component Matrix of Doctors |
|-------------------------------------|----------------------------------|
| Wp4  | .767  | .344  | Wn1  | .851  |
| Wp5  | .746  | .405  | Wn2  | .902  |
| Wp6  | .856  | .283  | Wn3  | .832  |
| Wp7  | .853  | .234  | Wn4  | .876  |
| Wp8  | .825  | .124  | Wn5  | .869  |
| Wp9  | .693  | .551  | Wn6  | .848  |
| Wp11 | .801  | .423  |
| Wp1  | .076  | .927  |
| Wp2  | .497  | .593  |
| Wp3  | .080  | .919  |
| Wp10 | .543  | .651  |
4.1 Relation between Illuminance Level, Satisfaction and Visual and Emotional Factors

Fig. 9 showed how subject satisfaction, visual factor, and emotional factors changed along with illuminance levels. On one hand, within the illuminance level range set of the experiment, the patients' emotional factor showed no linear correlation to the rising illuminance level: it peaked at 200 lx, but its score at 400 lx fell even lower than that at 100 lx. We thus concluded that excessive illumination in a ward contributed to negative emotions in patients. On the other hand, the visual factor was positively correlated to illuminance. Visual efficacy enhanced the visual satisfaction by increasing the contribution rate in an apparent upward trend of illuminance level, even though the patients had to rest in bed. Under the combined effects of emotional factor and visual factor, satisfaction reached the maximum score of 200 lx, indicating a significant influence of changing illuminance levels on a subject's emotions. For nurses, due to their work demands, the score of visual factor was highly correlated to satisfaction and clearly, positively correlated to illuminance level.

4.2 Relation between Color Temperature, Satisfaction and Visual and Emotional Factors

Fig. 10 showed that color temperature had a smaller influence on the emotional and visual factors of patients compared to the illuminance level. The scores of both emotional and visual factors were correlated negatively to color temperature. Such a negative correlation was more obvious in a satisfaction score. Differently, nurses preferred 5700 K color temperature among the three color temperature options provided in this experiment. This echoed the conclusions of previous research, indicating that high color temperature enhanced alertness and work efficiency.

4.3 Relation between Light Method, Satisfaction and Visual and Emotional Factors

As shown in Fig. 11, the direct illumination contribution rate and the score of patients' emotional factors featured a negative correlation, suggesting that rather than direct illumination, increasing indirect illumination was also an effective approach to boost the emotions of subjects. Different lighting methods have no significant visual influence for both patients and nurses on visual factor. Emotional and visual satisfaction was clearly correlated negatively to the contribution rate of direct illumination. In a certain range, nurse satisfaction shared such a trend. However, the values dropped in scenario P5 (direct illumination contribution rate = 0%). Therefore we concluded that a completely indirectly illuminated space was not the ideal light environment for nurses.

4.4 Relationship between Illumination and Scores of Subjects

Even with equal illumination levels, different lighting methods would lead to different luminance distributions over the visual fields of subjects, which likely deeply influenced the subjects' scores. Therefore, we believe that it failed to reflect all the facts to interpret the subjects' scores based only on illuminance levels. For a holistic grasp of the experimental data, we regarded illumination as the independent variable to interpret the influence of illumination parameters on subjects' scores. Figs. 12-14 displayed the relationships between average luminance, luminance contrast, and various factors.
Subjective Rating

Stressors in ICU:

1) For patients' emotional scores, higher illuminance led to a lower emotional satisfaction. In Fig.13., emotional factor scores correlated negatively to satisfaction. The measured illuminance (Fig.14.) correlated negatively to satisfaction. The measured UGR (Fig.17.) correlates negatively to satisfaction. The visual factor scores of the subjects were in positive correlation to average luminance. 6) In a certain range, the visual factor scores of the subjects were in apparent positive correlation to illuminance. The visual factor scores of the subjects were in positive correlation to illuminance and average luminance. 5) The visual factor scores of the subjects were in positive correlation to illuminance and UGR. 7) In a scenario characterized by illuminance of 200 lx or average luminance of 60 cd/m², the trends of patients' emotional factor and visual factor intersected, where emotional factor peaked. 8) For the patients and nurses in CICU, their lighting demands varied due to different purposes. Patients needed to rest while nurses needed to see things clearly at work. In our opinion, the CICU Luminous Environment should be adapted to the needs of different major users (patients or nurses) with controlled parameters to achieve ideal performance. However, when the illuminance and average luminance grew further, the emotional factor score decreased.

References

1) Report on Cardiovascular Diseases in China 2012, National Center for Cardiovascular Diseases, China, Ministry of Health P.R. China, 2013.
2) World Health Organization, Global Status Report on Non-Communicable Diseases 2010, Geneva, 2011.
3) Shan Liang, Psychoanalysis and Nursing Measures for CCU Patients [J]. China Practical Medicine, 2010, 10(10): 220-221.
4) Brian C. Sirois, Matthew M. Burg. Negative Emotion and Coronary Heart Disease A Review [J]. Behavior Modification. 2003, 27(1): 83-102.
5) Kong Cui, Xu Li, Chen Yuqin, Sun Ruizhi. 283 Cases of CCU Psychoanalysis and Nursing [J]. Journal of Qilu Nursing. 2012, 18(7): 101-102.
6) Dai Qian. Staged Psychological Nursing for CCU Patients [J]. Contemporary Medicine. 2010, 16(24): 109.
7) Japanese Cardiovascular Research Foundation, Stress and heart, Circulatory disease, Vol. 95, 2012.11.1.
8) Barbara L. Fredrickson, Robert W. Levenson. Positive Emotions Speed Recovery from the Cardiovascular Sequelae of Negative Emotions [J]. Cognition & Emotion. 1998, 12(2): 191-220.
9) Hoen et al., J. Am. Coll. Cadiol. 2011, 56: 838-841.
10) Rosengren A et al., Lancet. 2004, 364: 953-962.
11) Tsios A, Alichanidou E. Coronary Care Unit (CCU) Psychosis Syndrome [J]. Hospital Chronicles, 2009, 4(3): 32-34.
12) Dalke H, Little J, Niemann E, et al. Colour and lighting in hospital design [J]. Optics & Laser Technology, 2006, 38(4): 343-365.
13) Novaes M, Aronovich A, Ferraz M B, et al. Stressors in ICU: patients' evaluation [J]. Intensive Care Medicine, 1997, 23(12): 1282-1285.
14) Espiritu R C, Kripke D F, Ancoli-Israel S, et al. Low illumination experienced by San Diego adults: association with atypical depressive symptoms[J]. Biological psychiatry, 1994, 35(6): 403-407.
15) Daurat A, Aguirre A, Foret J, et al. Bright light affects alertness and performance rhythms during a 24-h constant routine[J]. Physiology & behavior, 1993, 53(5): 929-936.
16) Partonen T. Bright light as an inhibitor of adenosine transport [J]. Medical hypotheses, 2000, 54(3): 343-344.
17) Rikard Kuller, Seifeddin Babi, Thorbjorn Laike, et al. The impact of light and colour on psychological mood: a cross-cultural study of indoor work environments [J]. Ergonomics, 2006, 49(14): 1496-1507.
18) Lin Yandan, Ju Jiaqi, Chen Wencheng, et al. Subjective Rating on Indoor Luminous Environment and Its Effect on Reading Task Performance. CIE 26th SESSION. 2007.