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Effects and challenges of operational lighting illuminance in spacecraft on human visual acuity

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Abstract. For large-scale manned spacecraft bound for the Moon and Mars, lighting should be explored that can reduce safety risks while increasing visual capability. The use of ap-propriate lighting in large-scale manned spacecraft can provide astronauts with a comfortable and safe living and working environment while reducing the energy consumption of the lighting equipment. Visual acuity is an important aspect of the quality of the light environment. It directly determines the human eye's ability to discern details and has an important impact on visual ergonomics and the efficiency of receiving visual in-formation. In this study, we investigated changes in the human eye's visual acuity in a simulated spacecraft environment under three illuminances. 18 healthy persons participated in the study and tested binocular vision under three illuminance light environments. The results show that the amount of change in visual acuity decreased as the il-luminance value increased, the rate of decrease gradually slowed down and eventually tended to be flat. We found that with 200 lx as the dividing line, increasing the illuminance value at low illuminance can significantly improve visual acuity.

Keywords: Human Factors · Spacecraft · Illuminance · Visual acuity

1 Introduction

When astronauts perform space missions, there are many operations that require visual observation before making control decisions. For this reason, it is necessary to pro-vide good and adjustable illuminance from the lighting and meet the requirements of human observation through the ergonomic design of lighting. Good lighting can enable astronauts to see the target, move safely and freely in the cabin, and enable them to effectively, accurately, and safely complete visual work without causing undue visual fatigue and other discomfort, thereby ensuring the success of the mission. From the engineering perspective, the lighting in manned missions includes interior lighting and exterior lighting [1]. Inside the cabin, the climatic environment is close to an atmospheric environment with atmospheric pressure, while there is a vacuum environment outside the cabin. Therefore, adjustable lighting should consider

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reliability, redundancy and high-quality standards. These requirements have a great influence on the selection of the lighting systems used during flight [2]. The brightness of the field of view environment has a greater impact than the intensity of the lighting source. If the brightness ratio of the field of view environment is between 3:1 and 5:1, then the human eye can adapt to the environment for a long time. When the brightness ratio increases, the luminous flux of the light source needs to be increased to prevent eye irritation and visual fatigue of the astronauts [3]. In the local environment, the ideal illuminance value matches the requirements in Table 1. In addition, although it is necessary to provide sufficient light on the work platform, in many cases visibility also depends on the illuminance parameters. Therefore, the illumination requirements must be determined for different workplaces and types of operations in the cabin.

Table 1. Recommended value of illuminance level in each area in different cabins.

Area/task	Cabin space				
	Steamship	submarine	freighter	Train compartment	Aircraft cabin
general	75	75	54	215	108
read	301	301	54-301	215-538	269-430
Food preparation	/	183	215	108	215-323
meal	301	301	54	54	215-430
washing up	301	301	54	54	/
Casual	301	301	323	215	/
Medical surgery	/	/	215-538	/	/
Cleanliness	154-484	151-484	54-538	54-538	/
Storage room	75	54-75	54	54	/
Channel area	75	75	54-108	54-108	/

1.1 Lighting requirements for manned spacecraft

To design optimal lighting conditions for manned space flight, it is necessary is to comprehensively consider the visual acuity of the flight crew, the power supply of the spacecraft and the weight limitation. The lighting environment during space flight should be based on visual efficiency, a comfortable lighting environment and available power, striking a balance between consumption and weight distribution [4]. Lighting ergonomics research shows that the lighting system used during flight should consider the monitoring effect of sub-tasks, the type of lighting fixtures, the fixed position and the illumination requirements of the light source [5]. Similar to the design reference basis of ground lighting systems, lighting design during manned space flight should also consider many characteristics of human visual ergonomics, such as visual perception ability and characteristic operating attributes, which determine the quality of the astronauts' visual skills and thus determine their level of work efficiency. In addition, in some cases, improving these influencing factors can improve work efficiency without increasing the overall lighting. For example, to

improve the contrast of the work, the latest visual amplifier can be used to amplify the work and provide a special lighting system with a directional local lighting function [6]. In short, in order to ensure a good work place during space flight, lighting is not only needed to provide good visibility for operations but is also essential for astronauts to feel relaxed and comfortable to complete related operational tasks [7, 8]. Therefore, the lighting must meet the environment's requirements regarding quality and quantity, that is, it needs to ensure:
(1) Visual comfort, so that the astronauts' eyes are not strained during operation.
(2) Visual effects, so that the astronauts can complete visual tasks quickly and accurately even under difficult conditions and during long hours of work.
(3) Visual safety, so that the astronauts can see objects surrounding the operation target inside and outside the cabin, preventing operation mistakes or abnormal conditions.

To meet these requirements, the following illuminance parameters related to the light environment must be considered. In a spacecraft, the illuminance level and the illuminance distribution of the operating platform and its surrounding area have a major im-pact on how astronauts can quickly, safely and comfortably understand and perform operations. For the space where the designated area is not known, the area where visual work may occur is considered as the work area. For engineering applications, the illuminance value must be maintained, which is an index that must be considered for the visual safety and visual ergonomics of astronauts during operation [9]. It mainly includes the requirements of visual operation, safety and human psychological and physiological factors [10]. Therefore, subjective experimental methods were used in this study to conduct experiments in a simulated space station crew cabin in order to explore the impact of illuminance parameters on visual acuity.

2 Method

2.1 Participants

There were 18 participants in the experiment, 9 males and 9 females, ranging in age from 20 to 30 years old, with normal visual function; none of them had myopia or hyperopia. The experiment time was from 19:00-21:30 every day. All participants were right-handed and were non-athletes. Prior to the experiment, they received verbal and written explanations of the test protocols before providing written informed consent. They were paid and awarded for their participation.

2.2 Experimental scene and parameter setting

The crew cabin of the International Space Station was simulated to have a full-scale experiment cabin with adjustable lighting as a setting for the experimental scenes. The experiment cabin had a total area of 15 m2, and the free enclosure on the plane was realized by a mobile partition system. A solid-state light source was installed at the top, and each light source could continuously adjust parameters such as luminous flux and spectrum. The space was 6 m in length, 2.5 m in width, and 2.5 m in height. The effect is shown in Figure 2.

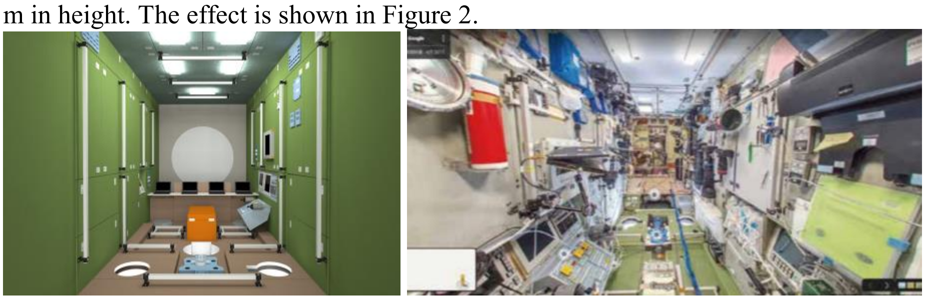

Fig. 1. Space station crew cabin scene construction. On the left is the crew cabin scene, and on the right is the crew cabin of the International Space Station.

The most important indicator of a lighting system is the level of illuminance. Although illuminance depends on the type of lighting, the size and shape of the cabin space and the material properties of the illuminated surface also have a certain relationship, but mainly depend on the total lighting power index. According to the illuminance level requirements of different areas or missions of the International Space Station, the lighting for the astronauts' work and life needs to be suitable for tasks such as working, dining, doing maintenance, reading and night sleep. The illuminance level covers 21 lx ~ 538 lx, so the power of the lighting system in the cabin must have a large dynamic adjustment range.

Therefore, in this project, four lighting scene mode settings were set according to different work tasks and the respective required lighting conditions. The specific illuminance values and colour temperature values are shown in Table 2.

Table 2. Typical lighting scene mode settings.

mode	Illumination level	Colour temperature
Working lighting mode	350 lx	4500 K
Fine operation mode	500 lx	4500K
Dining mode	200 lx	4500K
Night sleep mode	22 lx	4500K

2.3 Procedure

In the experiment, a visual acuity chart was attached to the white wall of the simulated crew cabin. The illuminance values of the four corners of the whiteboard were tested under each working condition, and the average illuminance of the vertical plane was calculated. The participants tested binocular vision in a position 3 m directly in front of the visual acuity chart and the smallest line of optotypes that the subject could recognize was measured. The number of correctly recognized optotypes should exceed half of the total number of optotypes in the line; see Figure 2.

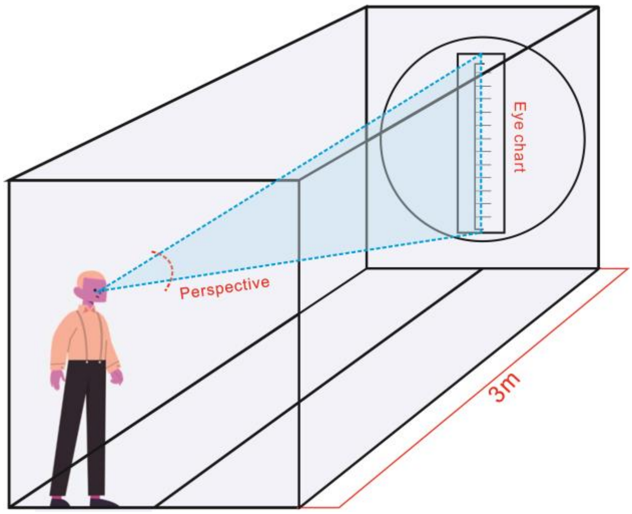

Fig. 2. Experimental scene.

When a person is standing, the visual zone of the left and right directions of the eyes is 20 °, the visual field limit is 65 °, the natural line of sight of both eyes is 12 ° below the horizontal line and the visual zone of the two eyes is 32 ° downward and 14 ° up-ward. In the experiment, due to space limitations regarding placement of the participants and the visual acuity chart, the left and right recognition viewing area of the natural line of sight in the simulated crew cabin was 20 °, and the visual zone was 16.23 ° down-ward and 11.85 ° upward.

3 Result

In this experiment, bubble graphs were used to represent the changes in visual acuity and the illuminance values measured in the four lighting environments. Straight lines were then used to connect the points sequentially to obtain a line, as shown in Figure 3.

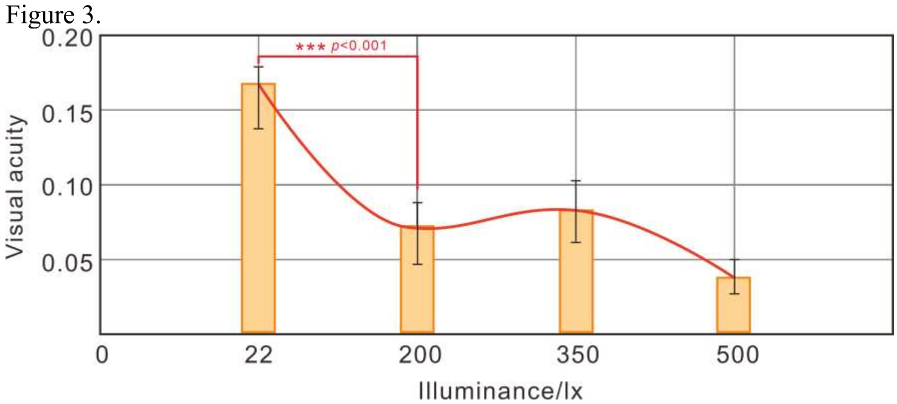

Fig. 3. Visual acuity changes under four kinds of illumination

It can be seen from Figure 4 that under the four lighting conditions, the amount of change in visual acuity decreased as the illuminance value increased; the rate of decrease gradually slowed down and eventually tended to be flat. We found that with 200 lx as the dividing line, increasing the illuminance value at low illuminance could significantly improve visual acuity. The statistical results show that the main effect of illumination on visual acuity is significant (F (4, 48) = 3.534, p = 0.001). Illumination did affect the visual behaviour of the subjects. Compared with 22 lx, subjects tested with 200 lx, 300 lx and 500 lx had a slower visual response to contrast. With 300 lx, their response was slightly higher than at 200 lx and 500 lx (M = 0.08, SD = 0.12). This is consistent with previous work, which showed that illuminance can help the vision system to process tasks faster for about 50-100 ms [22], [23].

We also found that there was no significant difference in visual acuity between males and females in the four illuminance environments (P >0. 05), as shown in Figure 4.

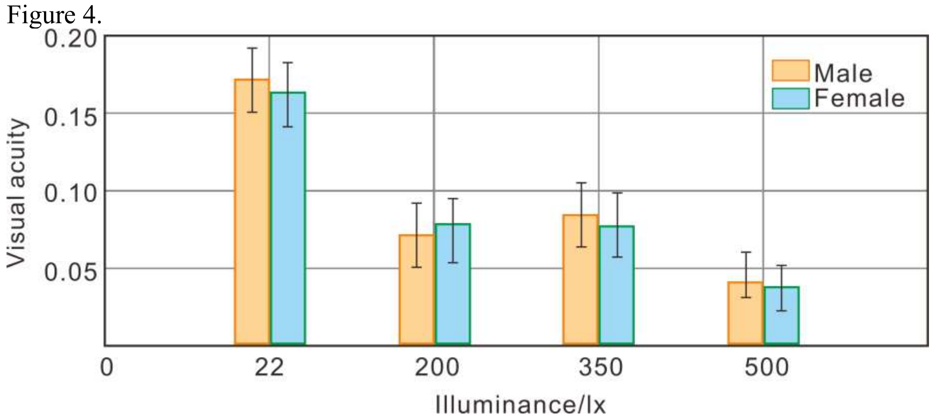

Fig. 4. Visual acuity of male and female under four types of lighting

4 Conclusion

Our experimental results show that the illuminance value has a significant impact on visual acuity, and that low illuminance has the greatest impact on visual acuity. Taking 200 lx as the dividing line, visual acuity significantly increased, but no significant difference could be observed between 200 lx, 350 lx and 500 lx in terms of visual significance. Therefore, in the normal mode of the space station, illuminance can be adjusted to more than 200 lx, thus ensuring that energy is saved on the spacecraft and losses are reduced. This also verifies that the illuminance level of the lighting device in manned space missions should not exceed the illuminance value of the ship or commercial cabin underground conditions. Lighting devices in the spacecraft that are designed according to ergonomic requirements can ensure that the astronauts have an optimal lighting environment during work or life, that is, they have good visual acuity, the reflection coefficient of illuminated target surfaces is reasonable, the light source scattering the light is appropriate and its power consumption and weight meet the specified requirements.

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