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Neville Stanton *Editor*

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Contents

Habitability Study on Space Station Colour Design

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Abstract. Various stressors such as microgravity, vibration, radiation, restriction, and isolation in manned spaceflight environments can cause a variety of negative psycho-physiological effects. At the emotional level, for example, they may provoke anxiety and depression, which affects the astronauts' operational efficiency and overall mission performance. The colour design of a spaceflight environment could positively affect a person's emotional level and thus help to counteract such negative psycho-physiological effects. This paper presents a new model for validating the colour design of spaceflight environments at the psycho-physiological and emotional level in order to increase the quality of emotional habitability and support efficiency and performance. Psycho-physiological experiments were tested on six coloured light in a dedicate physical mockup of a specific spaceflight environment. In particular the sanitary area of the space station was used as a case study. As result the highest quality of emotional habitability was achieved in a yellow coloured light environment, that is very close to the natural solar condition. *Note:* In order to support the confidentiality in this paper is not mentioned the name of the space station.

Keywords: Emotional habitability · Colour design · Human factors · Space station sanitary area

1 Introduction

1.1 Space Colour Design Based on Emotional Habitability

In any space environment, the amount of system design that takes into consideration human factors, i.e., the habitability factor of the environment, is very low. To support the performance of long-term space missions, increasing emotional habitability is a prerequisite [1]. The first step in human factors research based on human-centred design is user analysis, where gathering output from people who will be using the product or service is an important part. In the space environment, the environmental lighting requirements and the colour matching of the visual space in the cabin are important factors affecting emotional habitability. Proper consideration of these factors

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in the design can well improve people's psychological identity and stimulate work efficiency; otherwise, they will feel uncomfortable, their work efficiency will at least be reduced, and in severe cases they will even make operational errors and face safety problems [2]. Especially due to the relatively small space of the passenger cabin and the special environment, the design of the cabin colour will also affect the astronauts' space positioning, information acquisition and judgement, and psychological feelings. Therefore, it can be said that the reasonableness of colour matching design in the cabin layout is related to human ergonomics and safety [3].

1.2 Case Study: Sanitary Area of the Space Station

When mankind envisions building a permanent human habitat in space, it is necessary to consider constructing various functional guarantee systems with stable, reliable and safe performance in each functional section of the habitat. The space sanitary area system is the basic guarantee system for fulfilling the survival needs of astronauts in each functional division. It is closely related to the astronauts' life, functional safety, physical and mental health, as well as to efficient work. According to relevant reports published by NASA [4], the basic needs system for astronauts in future space habitats must be the subject of a reliable, stable and long-term target study. Due to the sanitary area's importance in supporting the basic survival guarantee for astronauts, the high degree of matching with humans, the important features of its complex functions, multiple technical interfaces and strong systemicity, the sanitary area system must have spatial emotional habitability. According to related anecdotal reports published by the Russian (former Soviet) space agency and NASA and relevant interviews with astronauts, the design and usability of the space station sanitary area are not good, as shown in Fig. 1. Complaints include: 1. The space is small and closed; 2. colour and light are unfavourable for astronauts to operate in; 3. the use of hardware is complicated and fault tolerance is low; 4. the location and shape of the fixing device and the handrail device mean that they cannot be used well [5]. These related factors lead to abnormal discharge, causing basic physiological disorders such as constipation, and even serious problems such as psychological and mental depression, insomnia, headaches and worsening interpersonal and social relationships [6].

Fig. 1. Existing U.S. and Russian space station and aerospace laboratory sanitary areas.

2 Method

2.1 Research of the Colour Perception Model Based on Emotional Habitability

The influence of colour factors on astronauts in terms of emotional habitability mainly originates from physiology and psychology. The channels for transmitting human colour vision information are light sources, coloured objects, eyes and brain [6]. These four elements not only make people feel colours, but also allow them to accurately analyse colours. If one of these four influential factors is inaccurate or biased, the astronaut cannot accurately analyse the effects of light and colour. The radiation effect of light sources and the reflection effect of objects belong to the discipline of opto-electronic physics. Therefore, colour perception is a concentrated reflection of coloured light, the human visual perception system and a person's mental state. Therefore, making use of the physiological and psychological processing involved in colour perception, a colour perception model based on emotional adaptation was constructed, as shown in Fig. 2.

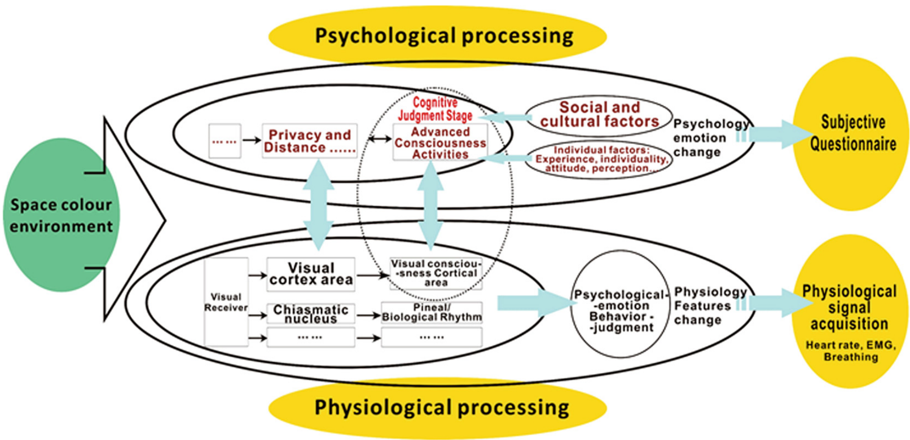

Fig. 2. Colour perception model for spatial emotional habitability

2.2 Development of the Mockup to Test the Sanitary Area

To investigate how to increase the quality of emotional habitability by selecting the best colour design configuration (Fig. 3), a physical mockup of the space station was built (Fig. 4). The mockup included a simulated environmental factor system, a light control system, and a data monitoring and acquisition system. The simulated environmental factor system mainly simulated the temperature and humidity environment of the space station's sanitary area, the noise environment, and the closed environment of the sanitary area to ensure the reliability of the test.

To better understand and simulate the user interaction, interview with specialists, videos and pictures of the ISS's sanitary area operated by the NASA's astronaut Sunita Williams' as well as interaction improvement from NASA and ROSKOSMOS (reported on paragraph 1.2) were analysed and implemented in this study [7].

Fig. 3. Colour design study of the space station's sanitary area

2.3 Determination of Colour Specimens Based on Colour Matching Standards

Table 1. CIE LAB colour attributes of 6 colours using the CIE light source D65/1964 colourimetry observer combination [8]

	Colour centre	L^*	a^*	b^*	C_{ad}	H_{ab}
1	Grey	61.1	−3.2	3.2	4.5	135
2	Red	41.0	33.2	25.5	41.9	38
3	High-chroma orange	60.3	33.0	64.3	72.2	63
4	Yellow	84.1	−6.7	50.4	50.9	98
5	High-chroma green	56.0	−45.7	5.7	46.1	173
6	Blue	37.0	−1.3	−27.9	28.0	267

Six CIE LAB colours were investigated in this study according to the International Space Station (ISS) space colour matching standard SSP 41000 designed to support the best psycho-physiological health conditions in space missions. The colours were distributed inside the mockup as coloured lights. The six colours tested were grey, red, high-chroma orange, yellow, high-chroma green and blue. Table 1 lists the CIE LAB values for the selected colours. Six coloured light bulbs (Fig. 4) were used to illuminate the environment of the simulated space station sanitary area.

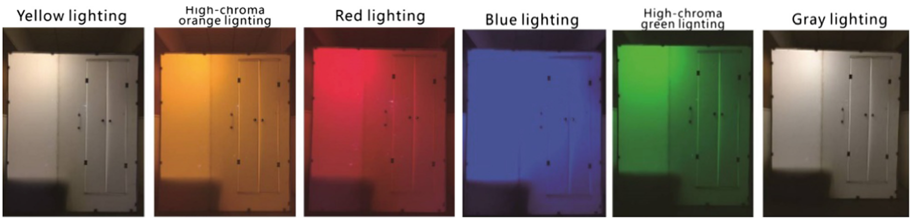

Fig. 4. Colour design test of the entrance of the mockup of the space station's sanitary area (picture of the interior were forbidden for ethical reason)

2.4 Establishment of Test Plan and Countermeasures

During the test the participants were asked to keep their mental state stable, their attention needed to remain focused on the system interaction. The colour changes in the simulated environment were only used for stimulating the physiological state of the participants, which did not affect their test activities. The test set-up was as follows:

A. 40 participants (28 male, 12 female), 30–40 years old, with strong physiques and good physical fitness. They had regular daily routines and did not drink or take drugs.
B. Six 18 W coloured light bulbs (with six different colours of light: grey, red, high-chroma orange, yellow, high-chroma green and blue; the six colours' RGB values were all within the standard value range used by the International Illumination Commission for colour discrimination). At the same time, this study simulating the system environment of the space station sanitary area used the CAPTIV-L7000 human factor data acquisition system to measure the participants' heart rate, breathing rate and myoelectric signals.
C. The test process comprised the following steps:
C1. The participants needed to be fully rested the day before the experiment, had not performed any bowel movements and maintained a calm and good condition. They were made familiar with the test environment and the operation and use procedures of the sanitary area before the test started in order to eliminate any effects of changes in their psychological state in an unfamiliar environment.
C2. First, experiments were performed in a natural indoor bathroom environment, that is, in a spacious and bright bathroom.
C3. After resting for five minutes, the participants entered the simulated test environment to perform the test. Using the sequence of grey, red, high-chroma orange, yellow, high-chroma green and blue, the participants switched the coloured light bulb to a different colour every ten minutes, i.e., the environment colour of the closed simulated sanitary area remained the same for a period of ten minutes each. While switching the colour environment, the participants rested for five minutes. Then they strictly followed the sanitary area operation and use procedures of the "Astronaut Biographies Home Page" published by NASA and the European Aviation Authority. Before entering the environment of the simulated space station, T-Sens breathing frequency sensors and T-Sens heart rate sensors were attached to them. A Sens

surface EMG sensor was also connected to each participant. Once they were ready, this physiological data was collected and stored via the wireless data logger T-log. C4. During the whole experiment, the participants were relaxed, simulated the operation procedures of the space station sanitary area and used the sanitary area normally

3 Result

3.1 Method for Processing Physiological Signal Data

The differences in human physiological states in different environments were compared by analysing the Euclidean distances of the physiological signal data in the different environments. Specifically, the Euclidean distance was calculated for the 40 groups of physiological signals in the simulated experimental environment with grey, red, high-chroma orange, yellow, high-chroma green and blue light, and for the 40 groups of physiological signals in the natural indoor environment. Due to space limitations, only four participants' signal acquisition results are listed in this article, as shown in Figs. 5, 6 and 7.

3.2 Data Processing Results and Analysis

The experimental results show that in the simulation experiment environments where blue, high-chroma orange, red and high-chroma green light was used, the participants' physiological signals were farther away from their physiological signals in the natural bathroom; that is, the difference was greater. In the grey light simulation experiment environment, their physiological signals were close to the Euclidean distance of their physiological signals in the natural bathroom; that is, the difference was small. In the yellow light simulation experiment environment, the Euclidean distance between their physiological signals and those in the natural bathroom was the closest; that is, the difference was the smallest. This shows that in a closed and narrow simulation

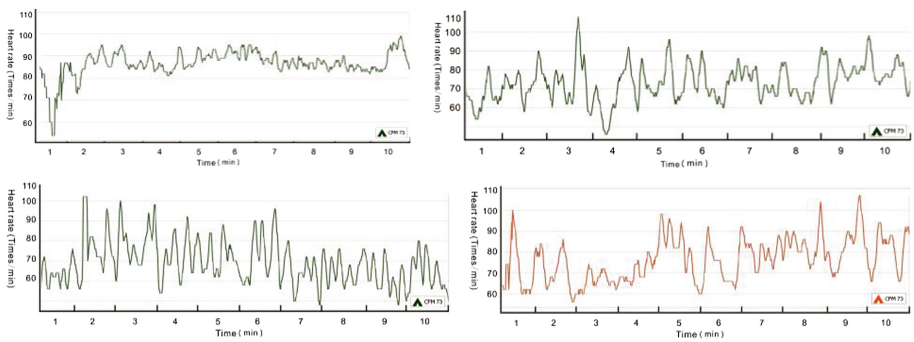

Fig. 5. Heart rate test frequency data

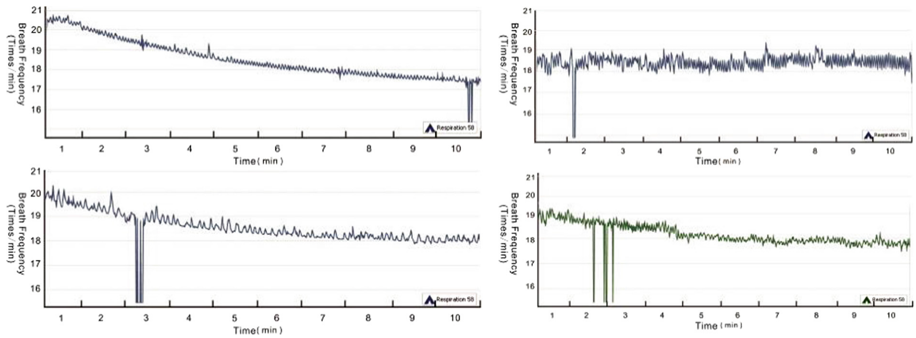

Fig. 6. Breath test frequency data

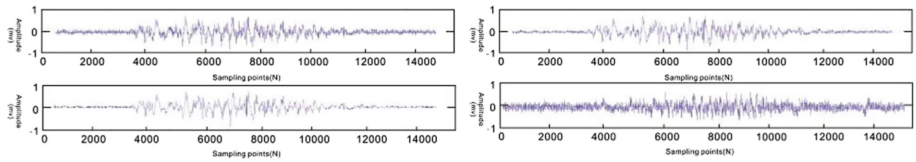

Fig. 7. EMG test frequency data

experiment environment, choosing a yellow environment would be of great help to the mental state of the crew when using the sanitary area. Moreover, yellow is the light colour that resembles the natural environmental solar light the closest.

4 Conclusion

This project involves the study of colour perception models based on emotional habitability applied to space station design. Through the application of a model to the study and evaluation of physiological data and subjective feelings, six different referential light colours were tested in a physically simulated environment based on the space station. In particular, considering the key relevance for supporting the basic survival needs, the environment of the sanitary area was selected as a case study. The results show that the highest quality of emotional habitability was achieved in a yellow coloured light environment, which is the light colour that resembles the natural environmental solar light the closest.

A more profound future study could pay particular attention to three factors: 1. the selection of the participants and the size of the sample to enable a better match of the physical quality and psychological characteristics of the participants with those of astronauts. 2. the influence of microgravity on astronauts' use of sanitary areas and the surrounding environment, could be tested in the future on ISS and parabolic flight as this could impact the physiological signals and subjective feelings. 3. Finally the colour sample variety could be implemented to increase the quality of the results.

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