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*Research Article*

# Space Habitat Astronautics: Multicolour Lighting Psychology in a 7-Day Simulated Habitat

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During space missions, astronauts live in a confined technological environment, completely isolated and deprived of the variety and variation found in the environment on Earth. This circumstance has a strong impact on the psycho-physiological states of the crew. Particularly in light of the plans for long-duration missions, new research needs to be carried out. The goal of this study, conducted at Xiangtan Central Hospital in China, was to test whether multicolour lighting can improve people's psychological state in an isolated and confined environment over a period of seven days. Twenty participants (10 male and 10 female) were randomly divided into two groups: one group that was exposed to multicolour lighting and a control group, which was exposed to a static, monotonous white interior. The participants' psychological state was recorded on the first day, the fourth day, and the seventh day. The results of the control group showed that the participants' negative emotions and anxiety continued to increase over time, whereas the group randomly exposed to multicolour lighting that changed every three hours did not show any significant increase in negative emotions and anxiety. Moreover, the random change of light colour in the isolated environment appeared to help the participants increase their sense of surprise, thereby counteracting monotony. Finally, during this experiment, it was observed that when people who are accustomed to being connected to social networks were deprived of this, they experienced insomnia and unaccustomed reactions, in particular on the first days of deprivation. This article contributes to future space exploration and to social and psychological support of life in isolated and confined environments.

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## 1. Introduction

As missions for deep space exploration and space habitats are put on the agenda, long-duration space travel poses new problems for the psycho-physiological needs of astronauts. These problems are synergistic with environmental factors and human factors regarding behavioural health [1]. In the initial stage of the construction of the International Space Station (ISS), both the former Soviet Space Agency and NASA believed that psychological problems were a key factor in the success of mankind's long-term space exploration. Whether they establish habitats on Mars or explore more distant planets, astronauts need to withstand being tested by multiple stressors in confined and isolated conditions during such long flights [2–7], especially because in deep space exploration, problems such as signal delays make astronauts feel the anxiety of being far away from Earth and the psychological fear of deep space. Therefore, the exploration of how to alleviate psychological problems in a closed and isolated environment is an important mean to ensure long-term space exploration and habitat missions.

A series of experiments have been conducted recently on Earth and during current space missions aboard the

International Space Station (ISS) [8–17]. Tafforin (2019) found in a 180-day controlled environment life support system that sensory interaction is of great help to the crew's mood and that variability and stability of behaviour are adaptive strategies [18, 19]. This was also confirmed by Schlacht (2010 and 2012) at [MDRS] [20–25]. Furthermore, NASA's Extreme Environment Mission Action [NEEMO] conducted psycho-physiological investigations of interplanetary expeditions at the Antarctic Space Simulation Station and found that the ICE environment provides higher fidelity to dangerous environments, reducing sensory stimulation and resulting in a cumulative stress response, and the photoperiod changes experienced during long spaceflights [26]. NASA believes that long-term sensory monotony deepens the extreme conditions of an isolated and confined environment and aggravates the crew's anxiety, irritability, depression, and other psychological problems. In a long-duration isolated and confined environment, monotony of vision, in particular, has a serious impact on human psychology [27–31]. A large number of studies have found that crew members on long-term missions on the Antarctic Space Simulation Station are extremely susceptible to psychological problems caused by visual monotony and monochromatic colours. Crew usually exhibit responses such as unresponsiveness, intermittent mania, and crying. Positive results against the monotony of confinement were already found in an early study on the use of circadian light variation produced by Iguzzini (Sivra) or Philips smart lighting system (Philips, Netherlands), which simulated colour changing in respect to the colour and temperature of the light of a solar day cycle for use as a countermeasure to sleep and circadian disruption in astronauts [32–35].

In an isolated and confined environment, visual perception consists of several elements, including indoor colour, space lighting, and material characteristics; especially from the aesthetic, indicative and symbolic perspectives, environmental colours, and lighting play an important role in forming the user's visual comfort effect [32–34, 36]. A large number of studies have found that colours are not only conducive to improving psychological comfort, work performance, safety, and environmental satisfaction but also help reduce environmental stress, work fatigue as well as physical and mental problems [35, 37–39]. In recent decades, studies have demonstrated that coloured lighting produces effects on the visual system, including visual alertness, visual monotony and visual sensitivity, and other related performances; Burattini (2019) studied the effects of different lighting conditions on attention and found that cool-coloured light has a positive effect on visual alertness [40]. Cavonius (1970) found that visual acuity recovers faster when a person is exposed to orange or red light than when they are exposed to other colours of light [41]. A study of coloured lighting in the hygiene area of the space station found that yellow light can relieve humans' stress response in the hygiene area better while white light can optimise behaviour and operation [42]. In the early phase of the construction of ISS, the Soviet orbital space station Salyut 6 used soft pastel interior colours to provide a more harmonious atmosphere [43, 44]. On Salyut 7, these were replaced by two contrasting colours to help distinguish between left and right walls [45]. Relevant literature of experiments on colour for space has been started on the 70$^{th}$ in USA and Russia [43, 46, 47]. Moreover, light has been shown to exert strong nonvisual effects on a range of biological functions such as the suppression of melatonin levels [34]. Specifically, the colour of lighting can play a significant role in emotional regulation [48] and potentially affects the habitability level of the extreme environment [45]. Furthermore, some studies have also found that lighting affects cognition through emotions. A number of Knez studies have found that lighting alters the positive and negative emotions in participants, thereby impairing or enhancing the cognitive performance in memory and problem-solving tasks, and that lighting conditions that induce the lowest level of negative emotions and the best positive emotions improve long-term memory and cognitive ability in problem-solving tasks [49]. Many studies have explored the effect of colour (of either lighting or wall colour) of rooms on human psychology and physiological responses. For example, in one study, a colourful (red) room with visual complexity put the brain into a more excited state and caused a lowering of the heart rate compared to an achromatic room [48]. In the same study, analysis of brain waves suggested that a blue-painted room had a more drowsy and sleepy effect on participants compared with those in the red-painted room [48]. Good workplace colour combinations can have a positive influence on visual working capacity and increase comfort [50]. Relative to illuminating spacecraft interiors, it is important to be aware that current lighting designs are configured to serve only one function, i.e., to support astronaut vision, not psychological issues. For optimum astronaut health and safety, future coloured lighting also needs to support both circadian regulation and psychological issues.

On the basis of these studies, the goal of the study presented here was to compare two groups of participants in an isolated and confined environment to check whether visual changes of multicolour lighting would alleviate psychological distress in space missions.

## 2. Materials and Methods

*2.1. Participants and Inclusion Criteria.* This study was approved by the ethics review committee of Xiangtan Central Hospital, China. The 20 healthy participants (10 males and 10 females, all of Chinese nationality and mostly 21 to 27 years old) were from Xiangtan University (Hunan, China). The experiment was conducted as a longitudinal questionnaire survey from April 10 to 18, 2021. The requirements for the participants were good health, passed medical and mental examinations including blind colour test (Ishihara), no addiction to any drug, no mental illnesses, and women could not be pregnant or lactating. Further inclusion criteria were as follows: (a) ≥18 years old; (b) able to give written consent and sign an informed consent form; (c) pass a COVID-19 test. To minimise selection bias, the participants were equally randomly assigned to either the experimental group (multicolour lighting group) or the control group via a random number generator using Microsoft Excel

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(Microsoft Corp., Redmond, Washington, USA). The number of men and women in each group was balanced.

*2.2. Materials and Equipment.* Philips Hue Bluetooth wireless 16 million colour dynamic light bulbs (Philips, Netherlands) were used to project the coloured light in the multicolour lighting rooms. The lighting system could be controlled wirelessly via Bluetooth. Each lighting condition was set to the same luminance of approximately 25 cd/m$^2$ in the coloured lighting system. Five chromatic lighting conditions (red, green, blue, yellow, and purple) were selected, and their chromaticities were specified in the CIE1976 $u'v'$ diagram (Table 1). The multicolour lamp was placed in the middle area between the desk and the bed in the isolated room (this area was the main area of the participants' daily activities) to ensure that the participants were affected by the multicolour lighting in most daily activities.

The PANAS questionnaire is a self-report measure used to assess the specific states that emerge from general dimensions of positive and negative emotional experiences [51]. PANAS has been used to detect fluctuations in mood over a short period [52]. Participants can respond to the questionnaire according to one or more instructions: (a) at this moment, (b) today, (c) in the past few days, and (d) in the past week, depending on the time frame provided by the instructions [51]. PANAS has twenty items concerning affect that are rated on a 5-point Likert-type scale ranging from 1 (very slightly or never) to 5 (extremely). It measures two independent and uncorrelated dimensions, with ten items assessing positive affect (Positive Affect scale) and ten items assessing negative affect (Negative Affect scale) [53, 54]. In our experiment, the order of the items was changed randomly every time. We instructed the participants to assess the extent to which they experienced each affective state during the first, fourth, and seventh day of the experiment.

The GAD-7 is used for screening generalised anxiety disorder (GAD) in primary care settings [55]. The GAD-7 questionnaire is a one-dimensional scale designed to assess the presence of the symptoms of generalised anxiety disorder (GAD) mentioned in the DSM-IV. It is self-administered, and the total score is calculated by simple addition of the answers for each item. The scores of all seven items range from 0 (not at all) to 3 (nearly every day). Therefore, the total score ranges from 0 to 21. According to the original authors [51], the total score can be divided into four severity groups: minimal/no anxiety (0–4), mild (5–9), moderate (10–14), or severe (15–21); the best cutoff for GAD is 10 points.

*2.3. Scene Setting.* The experiment took place on 20 isolation wards of the Xiangtan Central Hospital. The wards were all 3.5 metres long, 3 metres wide, and 2.2 metres high. Each room was furnished with a chair and a table, a bed, and a bedside table, as shown in Figure 1. The walls and the ceiling were painted white and the floor dark grey. These were the two main colours, apart from the door, chair, table, and dresser, which were a light wood colour. Neutral colours such as white and grey reduced any effects of the room on the colours to be used in the experiment. Each isolation room had a separate bathroom for the participants to wash themselves and use the toilet. The bathroom was white and had no windows. Again, neutral colours were used to reduce any effects of the room on the colours to be used in the experiment. The main lighting of the room was set to ceiling light, the illuminance was 150 lx (SD = 18 lx), the colour temperature was 3500 k, and the colour rendering was Ra85. A coloured LED lamp (Philips, The Netherlands) was set up on the table. The size of the LED lamp was 6 cm × 6 cm. The viewing angles were 13° × 10° and 1.9° × 1.9° when the subject viewed them at a distance of 180 cm. The temperature in the ward was constant at 25°C. The room was located on the 3rd floor of an internal multistorey building. The temperature and humidity changes very little throughout the year (Figure 1).

Table 1: $u'v'$ chromaticity coordinates of five lighting conditions.

| | Lighting condition | $u'$ | $v'$ | L (cd/m$^2$) |
|---|---|---|---|---|
| 1 | Red | 0.2433 | 0.4622 | 24.67 |
| 2 | Yellow | 0.1892 | 0.5112 | 24.78 |
| 3 | Green | 0.1525 | 0.4697 | 24.68 |
| 4 | Blue | 0.2049 | 0.4198 | 24.61 |
| 5 | Purple | 0.2700 | 0.2990 | 24.80 |

*2.4. Procedure.* This was a longitudinal observational study. Before starting the experiment, the participants' written consent had to be obtained. All participants were blinded to the study protocol and isolated from each other during the experiment to prevent any intergroup or intragroup dependence. The experimenter explained the content and meaning of the experimental questionnaire to each participant to ensure that each participant could fully understand the questions of each questionnaire.

Each participant entered a separate isolation room. During the isolation, the participants were not allowed to use any carriers such as mobile phones, computers, TVs, or iPads that come into contact with external information. But they could read paper books and do yoga and other activities. They woke up at 8 a.m. and went to sleep at 11 p.m. The mealtimes were 8:30 a.m., 11:30 a.m., and 6 p.m., to ensure regular work and rest times. The hospital provided the participants with three standardised meals a day.

During the seven-day isolation period, three rounds of testing were conducted on the two groups of participants: on the first day, the fourth day, and the seventh day, as shown in Figure 2. In the multicolour lighting group, MATLAB R2020a (The MathWorks, US) was used to set the colour of the bulb to switch randomly. From 8 a.m. to 10 p.m. every day, the colour of the multicolour light was randomly changed every three hours, while the control group did not have the multicolour light bulb. The other scenes and the layout were the same as for the multicolour lighting group. At 4:00-5:00 p.m. on the test day, the experimenters asked the participants to start filling out the paper questionnaire. The questionnaires were filled out in random order to prevent potential interference factors. After the questionnaires were completed, the experimenters conducted semistructured interviews with

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Figure 1: Computer recreation of the simulated isolation environment of the space habitat.

the participants, recording the participants' self-evaluation and subjective feelings. Each interview lasted about 5-10 minutes and was recorded for subsequent transcription and qualitative analysis. This method is widely used in longitudinal isolation surveys [56].

*2.5. Statistical Analysis.* A chi-square test was used to check the variables. The effect of isolation on emotion, anxiety, and self-rated health scores was measured using general linear model repeated measures (GLM-RM). Emotion and anxiety on the test day were included as repeated measure outcome variables. In addition, the least significant difference posttest was used to detect the difference in emotion and anxiety between the multicolour lighting group and the control group. All analyses were conducted in SPSS version 25.0.

## 3. Results

*3.1. Demographic Characteristics of the Multicolour Lighting Group and the Control Group.* The demographics (i.e., age, gender, education level, and marital status) of the participants in the multicolour lighting group ($n = 10$) and the control group ($n = 10$) were not significantly different, as shown in Table 2.

*3.2. Emotion and Anxiety in the Multicolour Lighting Group and the Control Group on the Three Test Days.* Self-reported emotion and anxiety are summarised in Table 2. Both PANAS and GAD-7 show good internal consistency. Cronbach's Alpha calculations show that $\text{positive emotions} = 0.89$, $\text{negative emotions} = 0.82$, and $\text{GAD} - 7 = 0.921$. On the first day, 16 (80%) participants reported at least a little negative emotion, 15 (75%) reported at least a little positive emotion, and 3 (15%) reported at least mild anxiety symptoms, respectively. On the fourth day, all participants (100%) reported at least a little negative emotion, and three participants (15%) had developed quite a bit of negative emotion; 4 (20%) participants reported at least a little positive emotion, and 13 (65%) reported mild anxiety symptoms. On the seventh day, all participants (100%) reported at least a little negative emotion, and one participant (5%) had developed quite a bit of negative emotion; 8 (40%) participants reported at least a little positive emotion, and 19 (95%) reported mild anxiety symptoms. There was no significant difference in negative emotions, positive emotions, and anxiety between the multicolour lighting group and the control group on the first day ($p = 0.83$), but a significant difference was found in negative emotions and anxiety ($p < 0.05$). No significant differences were detected in positive emotions ($p = 0.65$) on the fourth and seventh day (Table 3).

*3.3. Effects of the Two Groups on Emotion and Anxiety Over Time.* Figure 3 summarises the changes over time in PANAS and GAD-7 in the multicolour lighting group and the control group. GLM-RM analysis showed that time had a significant effect on negative emotions ($F = 7.385$, $p < 0.05$, $\eta^2 = 0.74$). The negative emotions on the fourth day had increased significantly compared to the first day ($p < 0.01$). The negative emotions on the seventh day were also significantly higher than on the first day ($p < 0.01$). But there was no significant difference between the negative emotions on the fourth day and those on the seventh day ($p = 0.48$). In contrast, time also had a significant effect on positive emotions ($F = 6.138$, $p < 0.05$, $\eta^2 = 0.83$). The positive emotions on the fourth day decreased significantly compared to the first day ($p < 0.001$). The positive emotions on the seventh day were also significantly lower than on the first day ($p < 0.001$). But there was no significant difference between the positive emotions on the fourth day and on the seventh day ($p = 0.79$). In addition, with the increase of isolation time, there was a significant difference in negative emotions ($F = 4.936$, $p < 0.05$, $\eta^2 = 0.572$), but no significant difference in positive emotions ($F = 1.723$, $p = 0.082$, $\eta^2 = 0.291$) between the multicolour lighting group and the control group. As after multiple comparisons, the difference was found to be significant, a post hoc analysis was also performed. The results showed that compared with the control group, the negative emotions of the multicolour lighting group were significantly lower ($p < 0.05$).

Similarly, GLM-RM analysis identified a significant effect of time on anxiety scores ($F = 7.265$, $p < 0.05$, $\eta^2 = 0.56$), indicating that the anxiety level on the fourth day was significantly higher than that on the first day ($p < 0.05$) in both groups. The anxiety level on the seventh day was also significantly higher than that on the first day ($p < 0.05$). But there was no significant difference between the level of anxiety on the fourth day and on the seventh day ($p = 0.63$). In addition, there was a significant difference between the anxiety level of the multicolour lighting group and that of the control group as isolation time increased ($F = 3.252$, $p < 0.05$, $\eta^2 = 0.41$). In this case, the post hoc analysis showed that the anxiety score of the multicolour lighting group was significantly lower than that of the control group ($p < 0.05$) (see Figure 3).

## 4. Discussion

This was a longitudinal study that examined the psychological effects of multicolour lighting in a short-term isolated and confined environment. The results of the study showed that compared with the participants in the control group, the participants in the multicolour lighting group had significantly lower levels of negative emotions and anxiety. The

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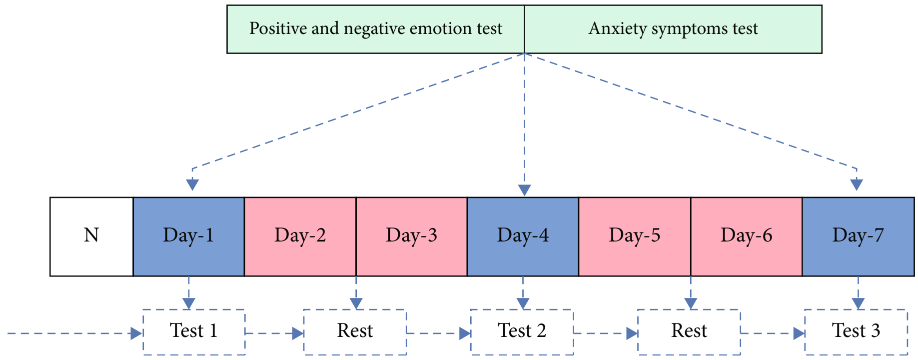


FIGURE 2: Overview of experimental conditions and procedure of the full session.

TABLE 2: Demographic characteristics of the multicolour lighting and the control groups.

| Participant characteristics | Total | Multicolour lighting group | Control group | $Z/t/\chi^2$ | $p$ value |
|---|---|---|---|---|---|
| Age (median, IQR) | 24 (20-30) | 23 (20-26) | 24 (20-28) | 1.091 | 0.32 |
| Gender ($n$, %) | | | | 0.006 | 0.92 |
| Male | 10 (50%) | 5 (50%) | 5 (50%) | | |
| Female | 10 (50%) | 5 (50%) | 5 (50%) | | |
| Marital status ($n$, %) | | | | 0.341 | 0.74 |
| Unmarried or divorce | 16 (80%) | 9 (90%) | 7 (70%) | | |
| Married | 4 (20%) | 2 (20%) | 2 (20%) | | |
| Education ($n$, %) | | | | 3.145 | 0.36 |
| Undergraduate | 9 (45%) | 6 (60%) | 4 (40%) | | |
| Postgraduate | 6 (30%) | 3 (30%) | 3 (30%) | | |
| PhD student | 5 (25%) | 2 (20%) | 3 (30%) | | |

results of this experiment give rise to the hypothesis that multicolour lighting can relieve the psychological stress caused by an increase in isolation time. Considering that long-duration missions start from 15 days [57], this hypothesis will be further investigated with a similar study that will be conducted with an isolation period of 15 days in order to consider how multicolour lighting would affect long-duration isolation missions [57].

On the first day of isolation in our experiment, an additional unexpected result emerged regarding people accustomed to being connected to social networks with their mobile phones or laptops. According to previous studies on long-term isolation and confined environments, participants who are on their own in a fully enclosed and isolated environment will have serious psychological problems such as negative emotions and anxiety. A large number of studies believe that astronauts who are on their own in a confined and isolated environment will lose resources related to social interaction patterns [57]. This includes isolation from family and friends, as it also means not being able to access social support networks, including not being contacted by letter, email, or phone [58]. This condition can very easily cause anxiety symptoms and other forms of negative emotions, which can increase exponentially [59]. This study also found that when the participants lost Internet carriers such as mobile phones or laptops connected to social networks, anxiety and irritability occurred, in particular on the first day of isolation. The interviews revealed that the participants believed that social interaction is an essential basic need in modern life. On the first day of isolation, participants who were accustomed to being connected to social networks showed unaccustomed reactions when deprived of this, and their capacity for performing other activities such as reading or doing fitness exercises was lower. This problem also strongly impacts the overall circadian cycle, creating insomnia und related effects. This also confirms the viewpoints of some studies that for manned space missions or future deep space explorations, a crew of more than three people must be formed to help stimulate social interaction and support social behaviour [60].

All participants reported in the interviews that the white walls around the room created a strong visual monotony. To alleviate this problem, the subjects from the multicolour lighting group reported that by occasionally looking at the multicolour light bulbs, they could alleviate this problem. This also proves that there will be a higher sense of visual interest in a multicolour lighting environment, which is why some entertainment venues usually use multicolour lighting to render the atmosphere, alleviating visual monotony and feelings of loneliness [61]. Studies have found that in a confined and isolated environment, the isolation of small groups increases loneliness possibly due to the changes

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Table 3: Emotion and anxiety in the multicolour lighting group and the control group on the three test days.

| Participant characteristics | Total | Multicolour lighting group | Control group | $Z/t/\chi^2$ | $p$ value |
|---|---|---|---|---|---|
| PANAS | | | | | |
| *First day* | | | | | |
| Negative emotions (median, IQR) | 18 (14-22) | 17 (14-20) | 18.5 (15-22) | 1.183 | 0.374 |
| Very slightly ($n$, %) | 4 (20%) | 2 (20%) | 2 (20%) | | |
| A little ($n$, %) | 15 (75%) | 8 (80%) | 7 (70%) | | |
| Moderately ($n$, %) | 1 (5%) | 0 (0%) | 1 (10%) | | |
| Quite a bit ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| Extremely ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| Positive emotions (median, IQR) | 28 (25-31) | 28.5 (26-31) | 27 (25-29) | 1.254 | 0.432 |
| Very slightly ($n$, %) | 5 (25%) | 3 (30%) | 2 (20%) | | |
| A little ($n$, %) | 11 (55%) | 5 (50%) | 6 (60%) | | |
| Moderately ($n$, %) | 4 (20%) | 2 (20%) | 2 (20%) | | |
| Quite a bit ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| Extremely ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| *Fourth day* | | | | | |
| Negative emotions (median, IQR) | 30 (25-35) | 27 (25-29) | 32 (29-35) | 2.035 | 0.033 |
| Very slightly ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| A little ($n$, %) | 6 (30%) | 4 (40%) | 2 (20%) | | |
| Moderately ($n$, %) | 11 (55%) | 6 (60%) | 5 (50%) | | |
| Quite a bit ($n$, %) | 3 (15%) | 0 (0%) | 3 (30%) | | |
| Extremely ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| Positive emotions (median, IQR) | 15.5 (12-29) | 14.5 (13-16) | 13 (12-14) | 1.159 | 0.602 |
| Very slightly ($n$, %) | 13 (65%) | 6 (50%) | 7 (70%) | | |
| A little ($n$, %) | 7 (35%) | 4 (50%) | 3 (30%) | | |
| Moderately ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| Quite a bit ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| Extremely ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| *Seventh day* | | | | | |
| Negative emotions (median, IQR) | 29.5 (25-34) | 28 (25-31) | 34 (32-34) | 1.631 | 0.57 |
| Very slightly ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| A little ($n$, %) | 6 (30%) | 5 (50%) | 1 (10%) | | |
| Moderately ($n$, %) | 13 (65%) | 5 (50%) | 8 (80%) | | |
| Quite a bit ($n$, %) | 1 (5%) | 0 (0%) | 1 (10%) | | |
| Extremely ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| Positive emotions (median, IQR) | 12 (10-14) | 12.5 (12-13) | 10.5 (10-11) | 0.724 | 0.055 |
| Very slightly ($n$, %) | 16 (80%) | 7 (70%) | 9 (90%) | | |
| A little ($n$, %) | 4 (20%) | 3 (30%) | 1 (10%) | | |
| Moderately ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| Quite a bit ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| Extremely ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| GAD-7 | | | | | |
| *First day (median, IQR)* | 2 (0–5) | 1 (0–4) | 2 (0–5) | 0.257 | 0.870 |
| Normal ($n$, %) | 17 (85%) | 9 (90%) | 8 (80%) | | |
| Mild ($n$, %) | 3 (15%) | 1 (10%) | 2 (20%) | | |
| Moderate ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| Severe ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| *Fourth day (median, IQR)* | 3 (0–6) | 2 (0–5) | 3 (0–6) | 1.359 | 0.032 |
| Normal ($n$, %) | 7 (35%) | 5 (50%) | 2 (20%) | | |

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Table 3: Continued.

| Participant characteristics | Total | Multicolour lighting group | Control group | $Z/t/\chi^2$ | $p$ value |
|---|---|---|---|---|---|
| Mild ($n$, %) | 12 (60%) | 5 (50%) | 7 (70%) | | |
| Moderate ($n$, %) | 1 (5%) | 0 (0%) | 1 (10%) | | |
| Severe ($n$, %) | 0 (0%) | 0 (0%) | 0 (0%) | | |
| *Seventh day (median, IQR)* | 3 (0–7) | 2 (0–6) | 3 (0–7) | 1.943 | 0.046 |
| Normal ($n$, %) | 1 (5%) | 1 (10%) | 0 (0%) | | |
| Mild ($n$, %) | 13 (65%) | 6 (60%) | 7 (70%) | | |
| Moderate ($n$, %) | 5 (25%) | 3 (30%) | 2 (20%) | | |
| Severe ($n$, %) | 1 (5%) | 0 (0%) | 1 (0%) | | |

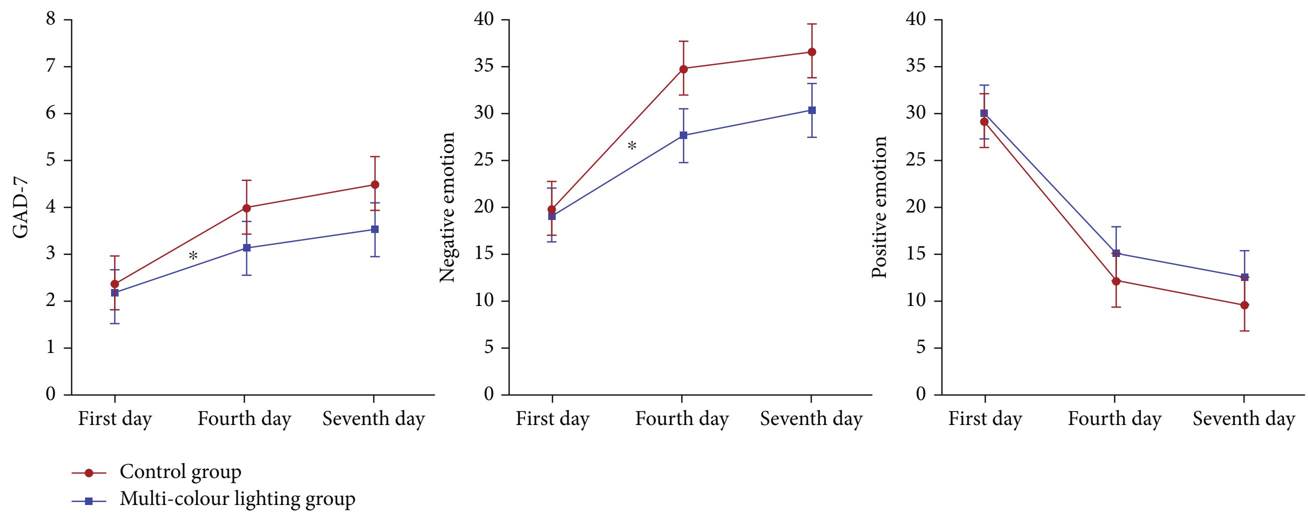


Figure 3: Emotion and anxiety levels of the multicolour lighting group and the control group on the first, fourth, and seventh days (error bars indicate standard errors of the variables). $^*p < 0.05$.

in the personal and/or professional networks and the loss of perceived intimacy and support [10] and that the use of multicolour lighting may be able to alleviate this problem by adjusting the atmosphere. Besides, in some special environments (such as hospitals, libraries, and galleries), the use of appropriate multicolour lighting will produce better visual performance compared to a white lighting environment [62]. The semistructured interviews with participants in this study also revealed that most participants preferred multicoloured lighting, which is similar to earlier anecdotal reports from Skylab indicating that when astronauts are in a confined and isolated environment that lacks a colourful atmosphere for long periods of time, they may be more pleasant only by viewing the main dashboard packed with many colourful lights [63, 64]. Thus, this strongly suggests that shifting attention to a different focus through visual elements can be helpful in alleviating negative emotions. Moreover, the interview results also revealed that when blue lighting was present, some participants reported feeling more engaged in reading books. When yellow lighting was present at night before bedtime, participants reported falling asleep more easily. The majority of the participants said they did not like the red lighting. However, this is only a portion of the participants' verbal accounts, and future quantitative analysis of the effects of colour lighting on people is needed. Furthermore, this study also found that the creation of a multicolour lighting system has a positive effect on psychological responses by randomly changing the coloured light pattern, especially in underearth laboratories without solar cycles, where people cannot see day and night [65], for example, Philips (USA) and Sivra (Italy) smart lighting. It can bring synthetic recreation of light in isolation and extreme environments. Several studies have suggested that light is a powerful regulator of the human circadian system and that the action spectrum for melatonin suppression is important for determining the photopigments of circadian rhythms and related circadian physiology [66]. Short wavelengths of light in the blue part of the visible spectrum are effective in suppressing melatonin, and this wavelength is also effective in suppressing high levels of plasma melatonin at night [67]. Furthermore, due to the random change of the multicolour lighting system, the participants did not know what colour the next light change would be, which aroused the curiosity of the participants, thereby increasing their interest in the isolated environment. Some studies have also found this phenomenon. The random effect of certain changes in the isolated environment seems to help the crew increase their sense of surprise [68]. For example, randomly supplying

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food, drinks, and coloured dress or playing music that the crew likes can significantly alleviate the negative emotions in long-term isolated and confined conditions [50, 69, 70]. In comparison, for a confined and isolated environment, multicolour lighting has the same emotional support function as the "care package" provided to astronauts by NASA and the Russian Space Agency in an isolated and confined environment [10]. Specific types of light can also be used to regulate the synthesis of melatonin and intelligent adjustment of a multicolour lighting system can be used to adapt to different occasions and atmospheres, such as work, rest, and entertainment.

On the seventh day of isolation, the negative emotions and anxiety levels of the participants of both groups increased compared to the fourth day, but the increase was lower than on the fourth day, and there was no significant difference compared with the fourth day. This may be related to the third-quarter phenomenon. A large number of studies have found that when the mission is halfway through, the crew will experience some depressed emotions; then, the depressed emotions will gradually ease, and cheerful emotions will gradually appear because the mission is about to end [66, 71–73]. The participants' reports revealed that some participants' moods stabilised on the sixth and seventh days of the task, and their sleep quality gradually improved as the task was about to end. Furthermore, the results also revealed that the impact of multicolour lighting on the participants was weakened on the seventh day. Through interviews with participants, we found that this may be due to the fact that the participants had been in a multicolour lighting environment for a long time, which leads to visual and cognitive fatigue effects for multicolour lighting. These effects inhibit curiosity and interest. With the task coming to an end, the main effect of the third quarter eased the depressed mood and reduced the role of multicolour lighting in this time period.

## 5. Limitations and Future Work

Several limitations of this study should be mentioned. The present study identified some changes in participants' mental states through a 7-day experiment in isolation in a confined environment and found that multicolour lighting was able to alleviate the negative emotions caused by isolation and confinement. However, short-term simulations of space missions lasting only seven days are limited when it comes to measuring psychological states, especially in terms of obtaining reliable results on depression or anxiety. Although the GAD-7 used in this study revealed some anxiety symptoms, a 2-week period would be required to validate the current results. A number of simulation studies have been conducted in isolated confinement for fifteen days or longer to explore the relationship between psychological states and the course of time [10, 74, 75]. Secondly, this experiment used multicolour lighting to modulate the psychological state of the multicolour lighting group, but this experiment did not specifically investigate the effects of different coloured lighting on people, so the psychological effects of different coloured lighting on people should be reassessed over a longer simulation period in the future. Thirdly, this experiment modulated people's psychological state by affecting their visual system through coloured lighting. There are, however, also studies that suggest that attentional distraction from different senses can alleviate anxiety and depression. Therefore, in the future, it should be examined whether sensory stimuli such as visual, auditory, or olfactory ones can have the same effect, which would provide a new reference for future environmental design.

## 6. Conclusion

When isolated from the solar cycle people has strong psychophysiological effects, artificial circadian light has been developed to face those problem and it uses different colour frequencies throughout the day to reconstruct the circadian cycle. But will there be any benefit if only random colour changes are used in isolation? The results of this study show that indeed there are.

Twenty participants were isolated in the Xiangtan Central Hospital for seven days, the negative emotions and anxiety occurred in all participants within a short time when they had to give up their network carrier and thus lost their social support. The most significant effect was observed on the fourth day, with a significant increase in negative emotions and anxiety in the control group. On the seventh day of the experiment, the psychological state tended to stabilise again. In conclusion, multicolour lighting was found to alleviate the increase in anxiety and negative emotions caused by isolation and confinement. Moreover, the random change of light colour in the isolated environment appeared to help the participants get an increased sense of surprise to counteract the monotony of the isolation, with an effect similar to that of circadian lights [66]. In future space exploration, coloured lighting or other sensory adjustment interventions could be used in addition to teamwork and collective life to reduce negative emotions and anxiety feelings. This experiment should be the starting point for similar studies and that future validation is still needed over a longer period of time and with larger populations.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

## Authors' Contributions

Ao Jiang is responsible for overall coordination, manuscript writing, and data collection. XiangYao, Zhixiong Fang, and Wenhao Yao is responsible for experimental design. Stephen Westland and Caroline Hemingray provided supervisory support. Irene Lia Schlacht and Bernard Foing provided administrative and technical support. Ao Jiang and Xiang Yao are the corresponding authors.

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## References

[1] C. Tafforin, S. Michel, and G. Galet, "Ethological approach of the human factors from space missions to space operations," in *Space Operations: Inspiring Humankind's Future*, pp. 779–794, Springer, Cham, 2019.

[2] V. Gushin, D. Shved, A. Vinokhodova et al., "Some psychophysiological and behavioral aspects of adaptation to simulated autonomous mission to Mars," *Acta Astronautica*, vol. 70, pp. 52–57, 2012.

[3] C. Tafforin, "Behavior, confinement, and isolation," in *Generation and Applications of Extra-Terrestrial Environments on Earth*, D. A. Beysens and J. J. W. A. Loon, Eds., pp. 267–274, River Publishers, 2015.

[4] B. H. Foing, H. Rogers, M. Musilova et al., "Life and research at SouthPole Moonbase: EuroMoonMars campaigns results 2019-2020," in *Lunar and Planetary Science Conference*no. 2548, p. 2502, 2021.

[5] C. Heinicke and B. Foing, "Human habitats: prospects for infrastructure supporting astronomy from the moon," *Philosophical Transactions of the Royal Society A*, vol. 379, no. 2188, p. 20190568, 2021.

[6] B. H. Foing, C. Stoker, and P. Ehrenfreund, "Astrobiology field research in moon/Mars analogue environments," *International Journal of Astrobiology*, vol. 10, no. 3, pp. 137–139, 2011.

[7] P. Ehrenfreund, W. F. M. Röling, C. S. Thiel et al., "Astrobiology and habitability studies in preparation for future Mars missions: trends from investigating minerals, organics and biota," *International Journal of Astrobiology*, vol. 10, no. 3, pp. 239–253, 2011.

[8] C. Tafforin and F. G. Abati, "Interaction and communication abilities in a multicultural crew simulating living and working habits at Mars Desert Research Station," *Antrocom: Online Journal of Anthropology*, vol. 12, 2016.

[9] B. Rai and J. Kaur, "Human factor studies on a Mars analogue during crew 100b international lunar exploration working group EuroMoonMars crew: proposed new approaches for future human space and interplanetary missions," *North American Journal of Medical Sciences*, vol. 4, no. 11, pp. 548–557, 2012.

[10] C. Tafforin, M. Yuan, J. C. Lloret et al., "Behavioral analysis of a Chinese crew's daily activity over the 180-day controlled environmental and life support system (CELSS) experiment," *Acta Astronautica*, vol. 161, pp. 485–491, 2019.

[11] M. Yuan, M.-A. Custaud, Z. Xu et al., "Multi-system adaptation to confinement during the 180-day controlled ecological life support system (CELSS) experiment," *Frontiers in physiology*, vol. 10, p. 575, 2019.

[12] K. Dai, Y. Qingni, Z. Zhang, Y. Wang, and X. Wang, "Aromatic hydrocarbons in a controlled ecological life support system during a 4-person-180-day integrated experiment," *Science of the Total Environment*, vol. 610-611, pp. 905–911, 2018.

[13] N. Inoue, I. Matsuzaki, and H. Ohshima, "Group interactions in SFINCSS-99: lessons for improving behavioral support programs," *Aviation, Space, and Environmental Medicine*, vol. 75, no. 7, pp. C28–C35, 2004.

[14] G. M. Sandal, "Culture and tension during an International Space Station simulation: results from SFINCSS'99," *Aviation, Space, and Environmental Medicine*, vol. 75, no. 7, pp. C44–C51, 2004.

[15] L. A. Palinkas, "Psychosocial issues in long-term space flight: overview," *Gravitational and Space Research*, vol. 14, 2007.

[16] J. I. Pagel and A. Choukèr, "Effects of isolation and confinement on humans-implications for manned space explorations," *Journal of Applied Physiology*, vol. 120, no. 12, pp. 1449–1457, 2016.

[17] Y. Wang, P. Qin, J. Hong, N. Li, Y. Zhang, and Y. Deng, "Deep membrane proteome profiling of rat hippocampus in simulated complex space environment by SWATH," *Space: Science & Technology*, vol. 2021, pp. 1–12, 2021.

[18] E. Öztürk, S. Yılmazer, and S. E. Ural, "The effects of achromatic and chromatic color schemes on participants' task performance in and appraisals of an office environment," *Color Research & Application*, vol. 37, no. 5, pp. 359–366, 2012.

[19] I. L. Schlacht, A. Ono, S. Bates et al., "Mars habitability project at MDRS sensory experience and creative performance for manned planetary exploration," in *S61th International Astronautical Congress Prague, 2010. 21st SYMPOSIUM ON SPACE ACTIVITY AND SOCIETY (E5.) Future and current space missions: including and expanding all aspects of human life onboard and in other worlds*, vol. 61, pp. 1–13, Prague, Czech, 2010.

[20] A. Ono, I. L. Schlacht, J. Hendrikse, and M. Battler, "Habitability in mars mission simulation: sounds as stress countermeasures," in *Lunar and Planetary Science Conference*, vol. 44, Woodlands, Texas, USA, 2013.

[21] J. Chappuis, C. Pouwels, M. Musilova, and B. Foing, "Personalised dietary plans and health effects on astronauts in extra-terrestrial habitats," in *EGU General Assembly Conference Abstracts*, p. 20628, EGU 2020, 2020.

[22] C. R. Pouwels, G. W. W. Wamelink, M. Musilova, and B. Foing, "Food for extra-terrestrial astronaut missions on native soil," *51st Lunar and Planetary Science Conference*, 2020.

[23] S. Kerber, M. Musilova, and B. Foing, "The human factors of additive manufacturing on human extra-terrestrial missions," *EGU General Assembly Conference Abstracts*, p. 20496, 2020.

[24] S. Kerber, A. Wanske, M. Musilova, and B. Foing, "Semi-privacy and color application as elements of habitability in concept designs for extra-terrestrial habitation," *EGU General Assembly Conference Abstracts*, p. 18245, 2020.

[25] P. Rajkakati, M. V. Heemskerk, K. Edison et al., "EMMIHS-III mission general overview," *Science*, vol. 1633, p. 2, 2019.

[26] Schlacht and I. Lia, *Space habitability. Integrating human factors into the design process to enhance habitability in long duration missions*, Technische Universität Berlin, 2012.

[27] P. Suedfeld, "Extreme and unusual environments: challenges and responses," in *The Oxford Handbook of Environmental*

Downloaded from https://spj.science.org on January 17, 2023

*and Conservation Psychology*, pp. 348–371, Oxford University Press, 2012.

[28] D. Manzey, “Human missions to Mars: new psychological challenges and research issues,” *Acta Astronautica*, vol. 55, no. 3-9, pp. 781–790, 2004.

[29] M. Nicolas, S. L. Bishop, K. Weiss, and M. Gaudino, “Social, occupational, and cultural adaptation during a 12-month wintering in Antarctica,” *Aerospace medicine and human performance*, vol. 87, no. 9, pp. 781–789, 2016.

[30] K. Yu, A. Jiang, X. Zeng, J. Wang, X. Yao, and Y. Chen, Eds., “Colour design method of ship centralized control cabin,” in *International Conference on Applied Human Factors and Ergonomics*, pp. 495–502, Springer, Cham, 2021.

[31] S. Lu, A. Jiang, I. Schlacht, B. Foing, S. Westland, C. Hemingray, X. Yao, and Y. Guo, Eds., “Effects and challenges of operational lighting illuminance in spacecraft on human visual acuity,” in *International Conference on Applied Human Factors and Ergonomics*, pp. 582–588, Springer, Cham, 2021.

[32] S. Lu, A. Jiang, I. Schlacht, A. Ono, B. Foing, X. Yao, S. Westland, and Y. Guo, Eds., “The effect on subjective alertness and fatigue of three colour temperatures in the spacecraft crew cabin,” in *International Conference on Applied Human Factors and Ergonomics*, pp. 632–639, Springer, Cham, 2021.

[33] F. H. Mahnke, *Color, Environment, and Human Response: An Interdisciplinary Understanding of Color and Its Use as a Beneficial Element in the Design of the Architectural Environment*, John Wiley & Sons, 1996.

[34] I. L. Schlacht, M. Rötting, and M. Masali, “Color Design of Extreme Habitats as a Psychological Support for the Reliability (ID: A658026) ESA Proceedings,” in *Tools for Psychological Support during Exploration Missions to Mars and Moon*, ESA, ESTEC, Noordwijik, The Netherlands, 2006.

[35] B. Bluth, “Social and psychological problems of extended space missions,” in *International Meeting and Technical Display on Global Technology*, p. 826, Baltimore, Maryland, USA, 1980.

[36] A. Jiang, X. Yao, C. Hemingray, and S. Westland, “Young people's colour preference and the arousal level of small apartments,” *Color Research & Application*, 2021.

[37] I. L. Schlacht, S. Brambillasca, and H. Birke, “Color perception in microgravity conditions: the results of CROMOS parabolic flight experiment,” *Microgravity Science and Technology*, vol. 21, no. 1-2, pp. 21–30, 2009.

[38] A. Jiang, X. Yao, I. L. Schlacht, G. Musso, T. Tang, and S. Westland, “Habitability study on space station colour design,” in *International Conference on Applied Human Factors and Ergonomics*, pp. 507–514, Springer, Cham, 2020.

[39] B. Konovalov, “New features of Salyut-7 station,” p. 3, 1982, Izv., (USSR).

[40] L. S. Williams, E. J. Brizendine, L. Plue et al., “Performance of the PHQ-9 as a screening tool for depression after stroke,” *Stroke*, vol. 36, no. 3, pp. 635–638, 2005.

[41] A. O. Adewuya, B. A. Ola, and O. O. Afolabi, “Validity of the patient health questionnaire (PHQ-9) as a screening tool for depression amongst Nigerian university students,” *Journal of Affective Disorders*, vol. 96, no. 1-2, pp. 89–93, 2006.

[42] National Aeronautics and Space Administration Space Station Program Office, *International Space Station Flight Crew Integration Standard (NASA-STD-3000/T)*, NASA, 1995.

[43] B. K. Wise and J. A. Wise, *The human factors of color in environmental design: a critical review*, NASA, 1988.

[44] A. Jiang, B. H. Foing, I. L. Schlacht, X. Yao, V. Cheung, and P. A. Rhodes, “Colour schemes to reduce stress response in the hygiene area of a space station: a Delphi study,” *Applied Ergonomics*, vol. 98, article 103573, 2022.

[45] Y. Ju, W. Chen, J. Liu et al., “Effects of centralized isolation vs. home isolation on psychological distress in patients with COVID-19,” *Journal of psychosomatic research*, vol. 143, article 110365, 2021.

[46] R. L. Spitzer, “Validation and utility of a self-report version of PRIME-MD: the PHQ primary care study,” *JAMA*, vol. 282, no. 18, pp. 1737–1744, 1999.

[47] K. Yu, A. Jiang, J. Wang, X. Zeng, X. Yao, and Y. Chen, “Construction of crew visual behaviour mechanism in ship centralized control cabin,” in *International Conference on Applied Human Factors and Ergonomics*, pp. 503–510, Springer, Cham, 2021.

[48] R. Küller, B. Mikellides, and J. Janssens, “Color, arousal, and performance—a comparison of three experiments,” *Color Research & Application*, vol. 34, no. 2, pp. 141–152, 2009.

[49] I. Knez, “Effects of indoor lighting on mood and cognition,” *Journal of Environmental Psychology*, vol. 15, no. 1, pp. 39–51, 1995.

[50] K. Dijkstra, M. E. Pieterse, A. Th, and H. Pruyn, “Individual differences in reactions towards color in simulated healthcare environments: the role of stimulus screening ability,” *Journal of Environmental Psychology*, vol. 28, no. 3, pp. 268–277, 2008.

[51] D. Watson, L. A. Clark, and A. Tellegen, “Development and validation of brief measures of positive and negative affect: the PANAS scales,” *Journal of Personality and Social Psychology*, vol. 54, no. 6, pp. 1063–1070, 1988.

[52] L. Qiu, X. Zheng, and Y. F. Wang, “Revision of the positive affect and negative affect scale,” *Chinese Journal of Applied Psychology*, vol. 14, no. 3, pp. 249–254, 2008.

[53] J. R. Crawford and J. D. Henry, “The positive and negative affect schedule (PANAS): construct validity, measurement properties and normative data in a large non-clinical sample,” *British Journal of Clinical Psychology*, vol. 43, no. 3, pp. 245–265, 2004.

[54] E. R. Thompson, “Development and validation of an internationally reliable short-form of the positive and negative affect schedule (PANAS),” *Journal of Cross-Cultural Psychology*, vol. 38, no. 2, pp. 227–242, 2007.

[55] M. Nicolas, P. Suedfeld, K. Weiss, and M. Gaudino, “Affective, social, and cognitive outcomes during a 1-year wintering in Concordia,” *Environment and Behavior*, vol. 48, no. 8, pp. 1073–1091, 2016.

[56] N. Kanas, G. Sandal, J. E. Boyd et al., “Psychology and culture during long-duration space missions,” *Acta Astronautica*, vol. 64, no. 7-8, pp. 659–677, 2009.

[57] N. Kanas, V. Salnitskiy, D. S. Weiss et al., “Human interactions during Shuttle/Mir space missions,” *Aviation, Space, and Environmental Medicine*, vol. 48, no. 5-12, pp. 777–784, 2001.

[58] G. M. Sandal, R. Vaernes, and H. Ursin, “Interpersonal relations during simulated space missions,” *Aviation, Space, and Environmental Medicine*, vol. 66, no. 7, pp. 617–624, 1995.

[59] M. Basner, D. F. Dinges, D. J. Mollicone et al., “Psychological and behavioral changes during confinement in a 520-day simulated interplanetary mission to mars,” *PloS one*, vol. 9, no. 3, article e93298, 2014.

[60] S. Geuna, F. Brunelli, and M. A. Perino, “Stressors, stress and stress consequences during long-duration manned space

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missions: a descriptive model," *Acta Astronautica*, vol. 36, no. 6, pp. 347–356, 1995.

[61] C. Gardner, "The use and misuse of coloured light in the urban environment," *Optics & Laser Technology*, vol. 38, no. 4-6, pp. 366–376, 2006.

[62] Z. Huang, Q. Liu, S. Westland, M. R. Pointer, M. R. Luo, and K. Xiao, "Light dominates colour preference when correlated colour temperature differs," *Lighting Research & Technology*, vol. 50, no. 7, pp. 995–1012, 2018.

[63] G. Edward, "Skylab 4 crew observations," *Biomedical results from Skylab*, vol. 377, p. 22, 1977.

[64] N. Frank, "Mutiny aboard Skylab 4—the stress of living in space," *Humanities*, vol. 85, no. 10, 2022.

[65] J. Stuster, C. Bachelard, and P. Suedfeld, "The relative importance of behavioral issues during long-duration ICE missions," *Aviation, Space, and Environmental Medicine*, vol. 71, no. 9, pp. A17–A25, 2000.

[66] R. L. Fucci, J. Gardner, J. P. Hanifin et al., "Toward optimizing lighting as a countermeasure to sleep and circadian disruption in space flight," *Acta Astronautica*, vol. 56, no. 9-12, pp. 1017–1024, 2005.

[67] G. C. Brainard, W. Coyle, M. Ayers et al., "Solid-state lighting for the International Space Station: tests of visual performance and melatonin regulation," *Acta Astronautica*, vol. 92, no. 1, pp. 21–28, 2013.

[68] R. B. Bechtel and A. Berning, "The third-quarter phenomenon: do people experience discomfort after stress has passed?," in *From Antarctica to Outer Space*, pp. 261–265, Springer, New York, NY, 1991.

[69] W. E. Sipes and S. T. Vander Ark, "Operational behavioral health and performance resources for International Space Station crews and families," *Aviation, Space, and Environmental Medicine*, vol. 76, no. 6, pp. B36–B41, 2005.

[70] N. Kanas and D. Manzey, *Space Psychology and Psychiatry*, 2008.

[71] M. Musilova, B. Foing, A. Beniest, and H. Rogers, "EuroMoon-Mars IMA at HI-SEAS campaigns in 2019: an overview of the analog missions, upgrades to the mission operations and protocols," in *51st Lunar and Planetary Science Conference*, Harvard Press, 2020.

[72] A. P. C. P. Nunes, M. Musilova, A. Cox, J. Agelini, and B. Foing, "Emmihs-2, the second Euromoonmars IMA Hi-Seas 2019 campaign: simulated Moonbase outlook and outcomes-an engineering perspective," in *Lunar and Planetary Science Conference*, no. 2326p. 2405, Harvard Press, 2020.

[73] B. H. Foing, A. Lillo, P. Evellin et al., "ILEWG EuroMoonMars research, technology, and field simulation campaigns," in *2017 Annual Meeting of the Lunar Exploration Analysis Group*, vol. 2041, p. 5073, Columbia, Maryland, USA, 2017.

[74] C. Connaboy, A. M. Sinnott, A. D. LaGoy et al., "Cognitive performance during prolonged periods in isolated, confined, and extreme environments," *Acta Astronautica*, vol. 177, pp. 545–551, 2020.

[75] R. Wu and Y. Wang, "Psychosocial interaction during a 105-day isolated mission in lunar palace 1," *Acta Astronautica*, vol. 113, pp. 1–7, 2015.

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