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The effect of three body positions on colour preference: an exploration of microgravity and lunar gravity simulations

Highlight

- Colour preference during normal sitting, -15° head-down bed rest and 9.6° head-up tilt bed rest was assessed.
- A significant change in colour preference during -15 ° head-down (HD) bed rest was found.
- In the three positions, the participants appeared to prefer lighter colours rather than darker ones.
- No gender differences in colour preference by body position were found in this short-term simulation study.

Abstract

Understanding the colour preference in microgravity environments will enable better design of future spacecraft and extra-terrestrial environments. In this study, a space station's crew cabin was simulated and evaluated in 33 different colours by 55 participants using a standard body position change methodology in controlled conditions. Three body positions were tested, and included normal sitting position (SP), to reflect terrestrial conditions; -15 ° head-down (HD) bed rest, to simulate a microgravity state; and 9.6 ° head-up tilt (HU) bed rest, to simulate a lunar gravity state. VR devices were worn by participants to ensure an immersive environment in which to evaluate the different coloured environments across the three different body positions. The results show that in all colour environments, there was no significant difference in the colour preference between SP and HU, but there was a significant change in the colour preference in HD compared to SP and HU. In the three positions, the participants appeared to prefer lighter colours rather than darker ones, warmer colours in ST and HU, and cool colours in HD. In this short-term simulation study, no evidence of gender differences in colour preference by body position was found, but in each body position, men and women had different preference levels for basic hue and chroma brightness.

Keywords: head inclination, simulated space environment, colour preference

1. Introduction

In long-term manned spaceflight, the isolation and monotony of the crew can be alleviated through the interaction between the crew and the internal environment of the habitat [1-3]. This includes the use of materials, interfaces, colours, lights, sounds and smells to actively support the crew [4]. Among them, the habitat factors related to vision are particularly poignant because vision is closely related to the performance of astronauts in almost all missions [5-6]. In the early stage of the U.S. space program, the Skylab missions considered the internal colour of the space station to support visual perception, and suggested that light blue or green were preferred in the crew module instead of the existing tan and brown. They also underlined the necessity to differentiate the colours of small objects to increase the contrast between them and the background, in order to more easily recognise floating items inside the spacecraft [7-8]. In a Soviet orbital space station – Salyut 6 – the interior colour was manipulated to provide a more homely atmosphere by selecting soft pastel colours [9]. In Salyut 7, the pastels were replaced by a right/left colour distinction – the left wall was painted apple green and the right wall a beige to help the astronauts in space orientation [10]. A systematic review found that colour has an important effect on the physiological and emotional state [11]. Green arouses the most positive subjective responses and is associated with relaxation, calm and happiness [12]. Red is associated with danger, so it will cause avoidance behaviour [13]. A cross-cultural study concluded that a colour environment that matches human preferences may contribute to a positive emotional state and relieve monotony and isolation [14].

Human perception of colours in the terrestrial environment is not necessarily applicable to space. During long-term orbital flights, NASA found that the visual ability of astronauts may change in a microgravity environment [8]. Soviet researchers said that weightless vision is reliable and does not affect space missions [15]. But various studies have shown that the perception of colour by the human eye will be different [16]. Kitayev-Smyk [17] found in a study on "Achromatic and colour comfort during short-term weightlessness" that colour comfort is related to brightness-chroma under microgravity conditions. They also pointed out that microgravity will cause changes in colour intensity, including a decrease in brightness and a decrease in contrast. The study attributed this phenomenon to excessive movement of the retinal image. In early parabolic flight experiments, it was found that the contrast sensitivity of the colour of the human eye will increase under microgravity conditions, and the contrast will be greater when the colour is saturated [18]. A recent expert survey of spatial environments found that colour preference significantly depends on people's applicability and comfort evaluation of colour applications in different scenarios or different tasks [19]. Therefore, colour preference is a direct factor affecting human visual comfort [20-21], but human colour preference in microgravity and lunar gravity has not yet been investigated.

So far, it is thought that related factors including lighting conditions, the surrounding environment of colour stimulation, gender, age, and nationality of the observer, may all affect human colour preferences [22-25]. More and more studies have proven that there are cultural differences in colour preferences [25-26]. For example, Europeans prefer blue, but this colour preference is not found in Brazil, Hong Kong and Canada [27]. In addition to cultural differences, the study also found differences in colour preference between genders. A series of studies have shown that men prefer soft colours such as yellow and green, while women prefer colours such as pink and purple [28-30]. On the other hand, according to the theory of social structure, the difference in colour preference may reflect efforts to improve gender role equality in society [31]. Moreover, there are studies on colour preference and age. Walsh [32] found that children generally prefer red and white more than adults do. Zhang [30] found that with age, preferences for orange and red increase, while preferences for blue, yellow, black, and dark colours decrease. Furthermore, Camgöz [33] believes that when studying colour preference, it is very important to analyse hue, chroma and brightness, which are sufficient to distinguish one colour from another in terms of perception.

The head-down bed rest test is widely used to simulate the physiological effects of microgravity [34-37]. In particular, a large number of studies use -6 ° or -15 ° head-down bed rest to simulate microgravity [34-35,38]. A 9.6 ° head-up tilt (HU) bed rest method has also been developed to simulate the physiological effects of lunar gravity [38-39]. Therefore, this study used three methods to simulate the effects of different human positions on colour preference, including; normal sitting position (SP) to reflect conditions on Earth; -15 ° head-down (HD) bed rest to simulate microgravity state; and 9.6 ° head-up tilt (HU) bed rest to simulate lunar gravity state. Gender differences in colour preference were also considered.

2. Method

2.1 Participants

Fifty-five Chinese participants with an average age of 23.7± 2.6 years were used in the study. The group was composed of 29 men and 26 women. They were all right-handed and had normal vision (none were near-sighted). All participants passed the Ishihara colour-blindness test, and no one was colour-deficient. All participants had participated in a course on the use of head-mounted displays (HMD) and had an understanding of the functions and definitions of the crew cabin of the space station. All had passed a health screening assessment, had no heart or cerebrovascular disease nor any history of neurological and/or psychiatric disorders, and had undergone a physical examination including a tilt test. During the experiment, all subjects were asked to avoid caffeine, alcohol, prescription drugs and smoking. The experiment was reviewed and approved by the Research Ethics Committee of the University of Leeds (FAHC 19-073).

2.2 Scene setting

Before the study, a preliminary investigation was conducted on the Chinese "Tiangong-2" space laboratory, and the already announced internal environment of the China "Tianhe" core cabin, to simulate a typical crew cabin environment (Fig. 1). The ceiling and floor of the standard laboratory cabinets on both sides of the environment are covered with one main colour, while the handrails, docking hatch and inherent equipment use the original colour of the product as the secondary colour. The Keyshot 9.0 version rendering program was used to simulate the space station cabin scene, and the average illuminance of 400lx and the correlated colour temperature of 4500K were configured in accordance with the lighting requirements of the space station's crew cabin. The Unity (2020.2.0a21) 3D modelling tool was selected as the method for generating realistic internal perspective drawings, and a head-mounted display (HMD) was imported as the experimental scene. This method has been used in previous studies [40-42], and verified for its accuracy in representing actual scenes [43].

Fig. 1. The virtual reality scene of the crew cabin of the space station in 33 colours

2.3 Values of colour scenes

A total of 33 colours were chosen to render the simulated crew cabin environment. This consisted of a white (W) and four chroma-brightness levels of eight different colours (red (R), orange (O), yellow (Y), green (G), cyan (C), blue (B), grey (GR) and purple (P)). The four chroma-brightness levels for each colour were "Dark" (D), with low brightness and low chroma; "muted" (M) with medium brightness and low chroma; "light" (L) with high brightness and low chroma; and "saturated" (S) with a high chroma. The selection of these varying chroma-brightness conditions is a method used in related research also exploring colour preference [30]. Full coverage rendering was performed on the inner wall of the cabin to reduce the interference of other colours. Instead of mimicking more ecologically valid environments to which astronauts may be exposed in a space station, in this study it was important to use full coverage colours to see if there are any preference differences. The colours were converted to a CIE (Commission Internationale de L'Eclairage) L * a * b * space to be generated and calibrated on a computer (Table 1). It is important to note that although the HTC Vive system is widely used in studies of the effect of colour on human behaviour and performance, the colour values in colour studies only describe the colours specified by the colour system and do not indicate the actual amount of light displayed by the HTC Vive HMD [77-78]. However, numerous virtual reality studies consider this to be a minor problem. As the system has a relatively high spatial frequency, chromatic aberrations due to optical techniques are not perceived by the human eye, and are not easily identified in experiments due to the usually smooth luminance transitions used by the system in natural texture stimuli [79-80]. 33 colours were used in this laboratory investigation, so the contrast between the set colour values and the colours displayed by the HMD was relative, i.e. the contrast between the different colours was always relatively consistent.

Table 1. CIE L * a * b * values for each scene colour

No.	Hue	L*	a*	b*	R	G	B
1	Saturated red	56.4	68.8	33.8	244	64	82
2	Light red	88.2	13.9	4.2	250	212	214
3	Muted red	62.8	37.5	15.2	218	124	127
4	Dark red	33.9	41.5	16.0	140	45	57
5	Saturated orange	74.0	31.2	66.4	254	158	53
6	Light orange	89.2	11.2	18.2	255	216	190
7	Muted orange	66.1	22.0	28.8	209	145	110
8	Dark orange	42.4	34.6	53.3	140	86	55
9	Saturated yellow	93.8	-10.2	81.0	251	241	60
10	Light yellow	97.2	-3.3	25.0	255	248	198
11	Muted yellow	76.3	4.4	46.1	216	184	101
12	Dark yellow	50.7	42.0	83.9	143	117	46
13	Saturated green	59.808	-41.659	8.317	34	163	128
14	Light green	92.4	-15.2	5.0	205	242	223
15	Muted green	61.638	-32.597	1.045	71	165	146
16	Dark green	44.561	-29.106	2.921	37	118	99
17	Saturated cyan	65.516	-27.371	-24.404	52	174	202
18	Light cyan	90.9	-13.2	-4.0	198	237	236
19	Muted cyan	63.211	-25.560	-21.361	62	167	190
20	Dark cyan	48.261	-25.641	-11.783	34	127	134
21	Saturated blue	63.810	-16.024	-38.201	64	165	222
22	Light blue	80.668	-2.916	-27.399	171	203	251
23	Muted blue	60.614	-10.401	-33.692	87	153	205
24	Dark blue	43.887	-9.196	-28.182	53	110	150
25	Saturated purple	49.7	58.8	-56.9	174	71	217
26	Light purple	72.4	25.5	-28.3	205	162	230
27	Muted purple	55.145	21.070	-31.672	147	120	187
28	Dark purple	38.951	17.618	-32.732	98	83	145
29	Saturated Grey	53.364	-1.167	-11.300	117	129	147
30	Muted Grey	88.0	-0.4	-0.1	220	221	221

31	Light Grey	93.0	-0.2	2.1	236	235	231
32	Dark Grey	27.242	-0.992	-1.184	135	133	133
33	White	93.188	0.266	-10.287	254	251	255

2.4 Apparatus and materials

The experiment was carried out in a standard body position change laboratory. The rotating bed controlled by the software program can assume any position from +90 ° to -90 °. The VR scenes were configured using the HTC Vive VR system (HTC) and SteamVR. The resolution of each eye of the head-mounted display (HMD) was 2160×1200 pixels, and the refresh rate was 90 Hz. The field of view was 100 ° horizontally and 100 ° vertically.

2.5 Experimental procedure

The experiment took place between September to October 2022. Participants were taken to the laboratory at 9:00 AM, and rested for 30 minutes after entering, to relax and adjust their surroundings. The experiment was carried out in a room without sunlight. Before the experiment, all participants confirmed that they fully understood the content and precautions of the experiment, and signed an informed consent form.

The experiment included three positions. For the SP position, the participants wore the HMD in a normal sitting position for testing. For the HD position, the participants rested in the −15 ° head-down bed rest position for 3 hours, to induce the microgravity effect, and then wore the HMD to complete the test. For the HU position, the participants rested in a 9.6 ° head-up position for 3 hours, before wearing the HMD to complete the test. The sequence between the three positions was balanced to minimize potential deviations due to the sequence. Each participant had a 48-hour break between each position test to avoid potential carryover effects. The specific test content and timeline are shown in Fig. 2.

Prior to starting the SP test, participants were in the SP position for three hours in a D65 light source environment. Due to ethical approval requirements and participant suggestions, we made this part more user-friendly. Participants were allowed to read, do course homework (paper-based), listen to audio and eat during this time, but were still not allowed to use mobile phones, computers or other devices that would have interfered with the light source. Before the start of the SP position test, each participant was asked to wear an HMD to watch a white screen for three minutes to allow for chromatic adaptation. Subsequently, 33 3D colour environments appeared on the VR HMD in a random order, and stayed for 5 seconds for the participants to experience the environments. After each colour environment experience, a transition to a 3 second dim white environment (dim<6lx) took place to alleviate the legacy effect brought on by the previous colour [44]. After all presentations were completed, the 33 colour environments appeared on the screen in a random sequence. The participants' preference for each colour was evaluated on a 9-point scale, with 1 representing "least favourite" and 9 representing "most favourite". The order of the colour environments experienced by each participant was randomised. In addition, after the participants had experienced all 33 colour environments, the arrangement of all colour environments that appeared on the screen was also randomised to prevent potential repetition effects.

In the HD and HU positions, the participants first had a -15 ° head-down bed rest, and a 9.6 ° head-up tilt bed rest respectively, for three hours under the D65 light source environment. They could chat, listen to music, rest or do other activities during this period, but they were not allowed to use mobile phones, computers and other devices that interfere with light sources. After resting in bed for three hours, they wore the HMD to watch the white screen for three minutes to allow for chromatic adaptation, and then the experiment was the same as for the SP position.

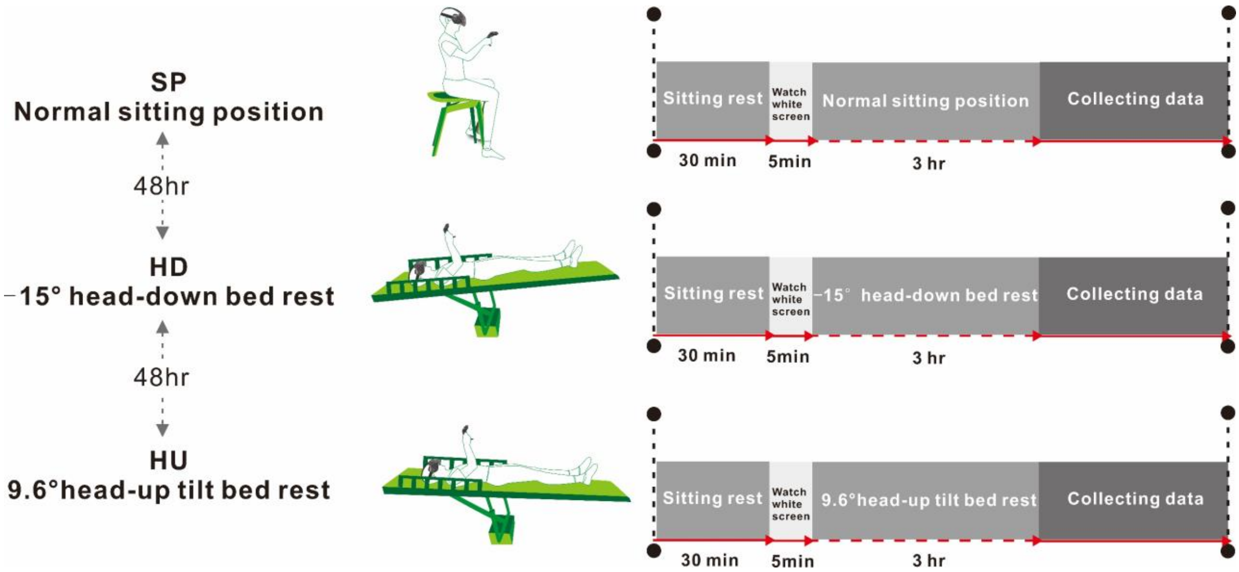

Fig. 2 Experimental design

2.6 Statistical data analysis

A mixed measure design of 3 (position) x [8 (hue) x 4 (chroma brightness level) + one white] x 2 (gender) was used, this method has been used frequently in previous studies [72-73]. The participants experienced each of the 33 colour environments and completed a preference questionnaire while in each body position. The order of body positions completed by different participants were balanced, and the colour environments were randomised for each participant. The dependent variables were the participants' preference ratings for each of the 33 colour environments during the three positions.

Firstly, a repeated measures ANOVA was used to examine differences in hue and chroma brightness levels during the different positions. Secondly, a mixed measures ANOVA was used to examine differences in hue and chroma brightness levels during the different positions and between genders. To find out whether there were any significant differences in colour preference for hue and/or chroma brightness between positions and genders, and to determine statistical significance, $\alpha<0.05$ was considered statistically significant. After any statistical significance ($p<0.05$), an LSD test was performed to follow up on statistical significance, and Bonferroni correction was used. The Statistical Package for Social Sciences (SPSS v25.0) was used for all analyses in this study.

3. Result

3.1 Colour preference in the three positions

The colour preferences of the three positions are summarized in Fig. 3. The results show that among the three positions, the participants had significant differences in preference for the 33 colour environments ($F(2,162)=27.197$, $P=0.0075<0.01$, $\eta_p^2=0.316$). Further post-hoc tests found that the colour preferences of HD differed significantly from those of SP and HU ($P<0.05$), but there was no significant difference in colour preferences between SP and HU (P=0.069>0.05). Specific analysis of the colour preference in each body position found significant differences between the 33 colours in SP (F(32,1782) =14.381,p=0.0052 <0.01, η_p^2=0.314), HD (F(32,1782) = 40.162,p=0.022 <0.05, η_p^2=0.399) and HU (F(32,1782) =16.21 ,p=0.0081 <0.01, η_p^2=0.287). Among them, the participants' most favourite was light yellow in SP and HU ((SP:M=6.41, SD=1.53); (HU:M=6.44, SD=1.69)) while their least favourite colour was dark red ((SP: M=2.89, SD=1.62); (HU:M=2.77, SD=1.71)). In HD, their most favourite colour was light cyan (M=5.78, SD=1.84) and their least favourite colour was dark grey (M=1.62, SD=1.14). A post-hoc test of the colour preference of each body position found that the participants in the three positions had no significant differences in preference between red, orange, yellow, cyan, green, blue, and grey in the light (L) condition (P>0.05), but the preference of red, yellow, orange, green, cyan, blue and grey in the light (L) condition was significantly different from that of the other 27 colours (P <0.05).

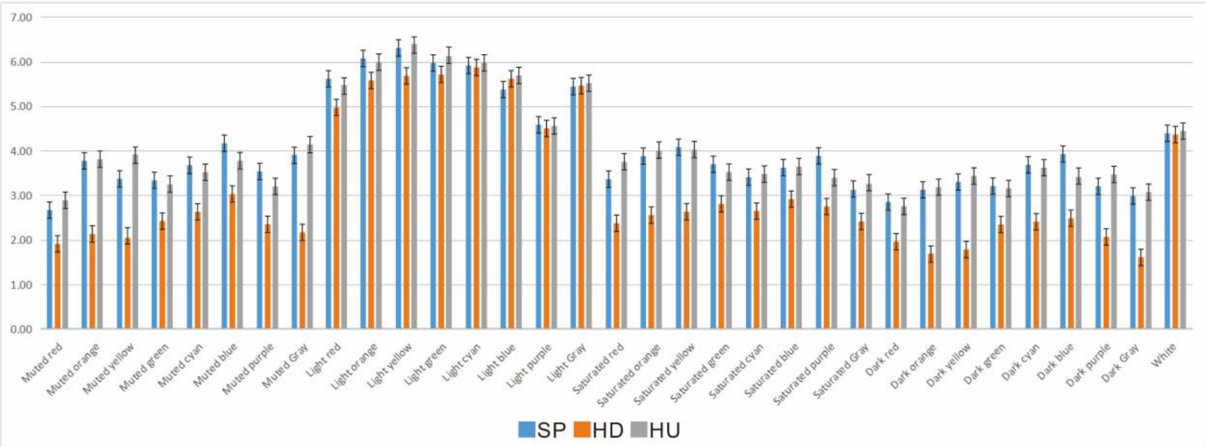

Fig. 3. Participants' mean colour preference for the 33 colours in the three body positions

3.2 Basic colour preference in the three body positions (eight colours and white)

Differences in preference between the nine hues during the three positions were examined using a repeated measures ANOVA. The results show that the basic colour preference was significantly different (F (8,486) =16.008, P=0.027<0.05, η_p^2=0.309). For SP and HU, the most favourite colour was yellow ((SP:M=4.85, SD=1.84); (HU:M=4.55, SD=1.67)), followed by orange ((SP:M=4.29, SD=1.39); (HU:M=4.14, SD=1.77)), while red ((SP:M=4.05, SD=2.04); (HU: M=4.27, SD=2.05)) was the least favourite colour, followed by purple ((SP:M=3.89, SD=2.02); (HU: M=3.77, SD=1.74)). The post-hoc test of the nine hues in SP and HU showed that there was no significant difference between yellow and orange (P >0.05), but there were significant differences between (yellow and orange) and the other six colours (P <0.05). But in HD, blue (M=3.67, SD=1.43) and cyan (M=3.59, SD=1.25) were the most favourite colours, while red (M=2.67, SD=1.49) and orange (M= 3.13, SD=1.54) were the least favourite. The post-hoc test found that there was no significant difference between blue and cyan (P >0.05), but there were significant differences between (blue and cyan) and other colours (P <0.05). Besides, the results also show that there was no significant difference in the preference of the nine basic hues of SP and HU (P >0.05), but the preference of the basic hue in the HD was significantly different from that of SP and HU (P <0.05). Particularly significant differences were found in red, orange, cyan and blue (P <0.05).

3.3 Chroma and brightness preference in the three body positions

To examine the effects of the three positions on the preferences of the participants in terms of brightness and chroma, in addition to hue, an ANOVA involving three positions (HU, HD, SP) × eight hues (red, orange, yellow, green, cyan, blue, purple, grey) × four chroma-brightness levels (saturated (S), light (L), muted (M), dark (D)) was performed, The results show that there was no significant difference in the light chroma-brightness level ($F(2,162) = 8.014$, $P = 0.063 > 0.05$, $\eta_p^2 = 0.105$), but the saturated ($F(2, 162) = 12.117$, $P = 0.017 < 0.05$, $\eta_p^2 = 0.216$), muted ($F(2, 162) = 15.251$, $P = 0.032 < 0.05$, $\eta_p^2 = 0.294$) and dark ($F(2, 162) = 19.726$, $P = 0.0092 < 0.01$, $\eta_p^2 = 0.355$) levels showed significant effects.

A further post-hoc test found that during the three body positions, for different chroma-brightness levels, the participants' most favourite were light colours, followed by saturated colours, whereas dark colours were the least favourite (P s <0.05). However, there are some interesting situations. In the three body positions, it was found that for saturated blue, the participants preferred muted blue ($P < 0.05$). In HD and SP, there was no significant difference between muted cyan and saturated cyan ($P > 0.05$). Muted grey was preferred to saturated grey ($P < 0.05$) during HU. The preference order of the other colours was exactly the same for each hue, namely: light>saturated >muted >dark (P s <0.05). In general, the participants preferred light-coloured environments the most, and dark-coloured environments the least in all three body positions (Fig. 4).

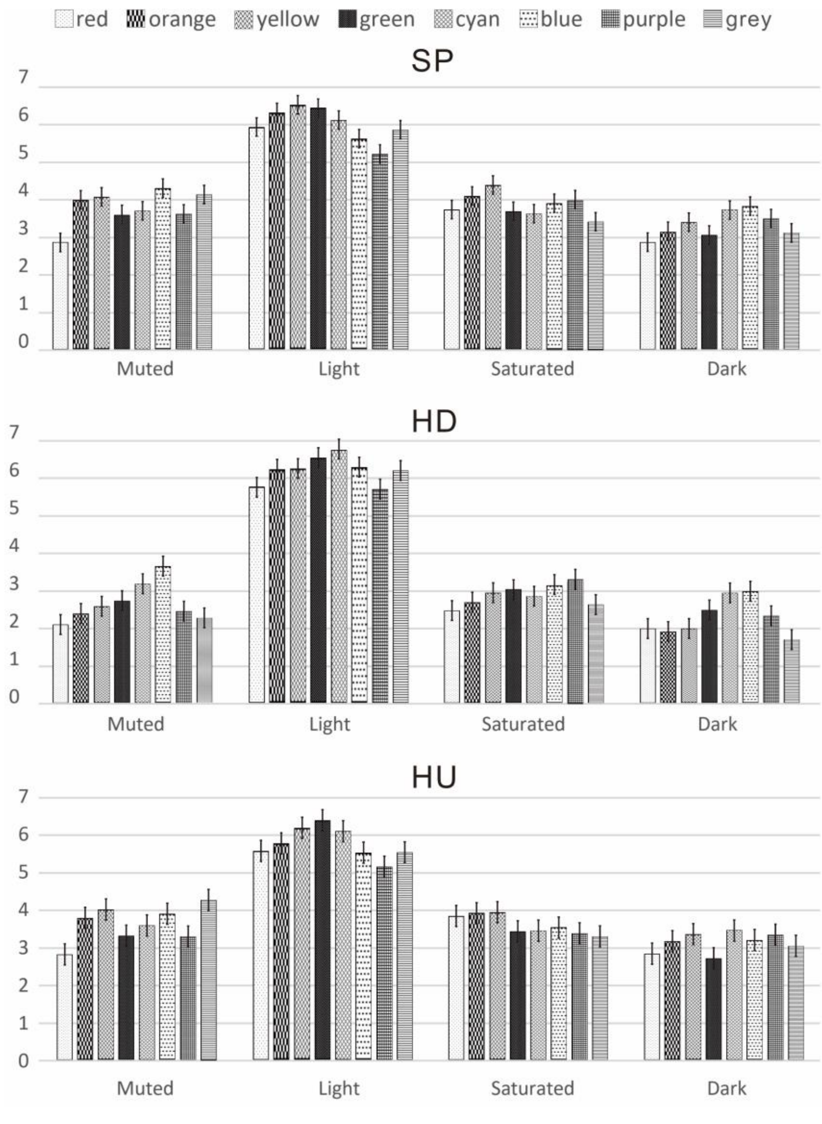

Fig. 4. Chroma and brightness preference in the three body positions

3.4 Gender differences in preference for nine basic colours in the three body positions

We examined male and female preferences of the basic colours in the three positions, and the results show that the body position did not affect the basic colour preferences of men and women ($F(1,1813)=5.17$, $P=0.093>0.05$, $\eta_p^2=0.0109$). Further analysis of the preferences of men and women for basic colours in the three body positions, A9 (hue: red, orange, yellow, green, cyan, blue, purple, grey, white) × 2 (gender) showed that the main effect of hue was significant ($F(8,1476)=62.11$, $P=0.026<0.05$, $\eta_p^2=0.418$), and a significant two-way interaction ($F(8,1476)=6.93$, $P=0.029<0.05$, $\eta_p^2=0.335$) was seen. In the three body positions, men and women had significant differences in preference for the yellow environment ($F(1, 163) = 5.127$, $P=0.037<0.05$, $\eta_p^2=0.194$), the cyan environment ($F[1, 163] = 6.173$, $P=0.028<0.05$, $\eta_p^2=0.156$), the green environment ($F(1, 163)=13.594$, $P=0.049<0.05$, $\eta_p^2=0.113$) and the white environment ($F(1, 163) = 5.93$, $P=0.047<0.05$, $\eta_p^2=0.069$). Men preferred cyan ($P<0.05$) and green ($P<0.05$) more than women did. Women preferred yellow ($P<0.05$) and white ($P<0.05$) compared to men.

3.5 Gender differences in preference for four chroma and brightness levels in the three body positions

We examined male and female preferences of chroma-brightness in the three body positions, and the results show that body position did not affect the chroma-brightness preferences of men and women ($F(1,1758)=5.106$, $P=0.071>0.05$, $\eta_p^2=0.0114$). Further analysis of the preferences of men and women for chroma-brightness in the three body positions, A 8 (hue: red, orange, yellow, green, cyan, blue, purple, grey) × 4 (chroma-brightness level: saturated (S) and light (L), soft (M), dark (D)) ×2 (gender) showed that the main effect of hue was ($F(7,432)=17.152$, $P=0.033<0.05$, $\eta_p^2=0.217$) and of the chroma-brightness level ($F(3,656)=21.015$, $P=0.041<0.05$, $\eta_p^2=0.326$); all interactions were significant ($P\text{s} < 0.05$). Among the three body positions, men preferred muted cyan, muted orange, muted green, saturated orange, muted grey and light grey more than women did ($P<0.05$). Women preferred light orange, light yellow, light red, light purple and white compared to men ($P<0.05$). Basically, men preferred muted colours, while women preferred light colours, as shown in Fig. 5.

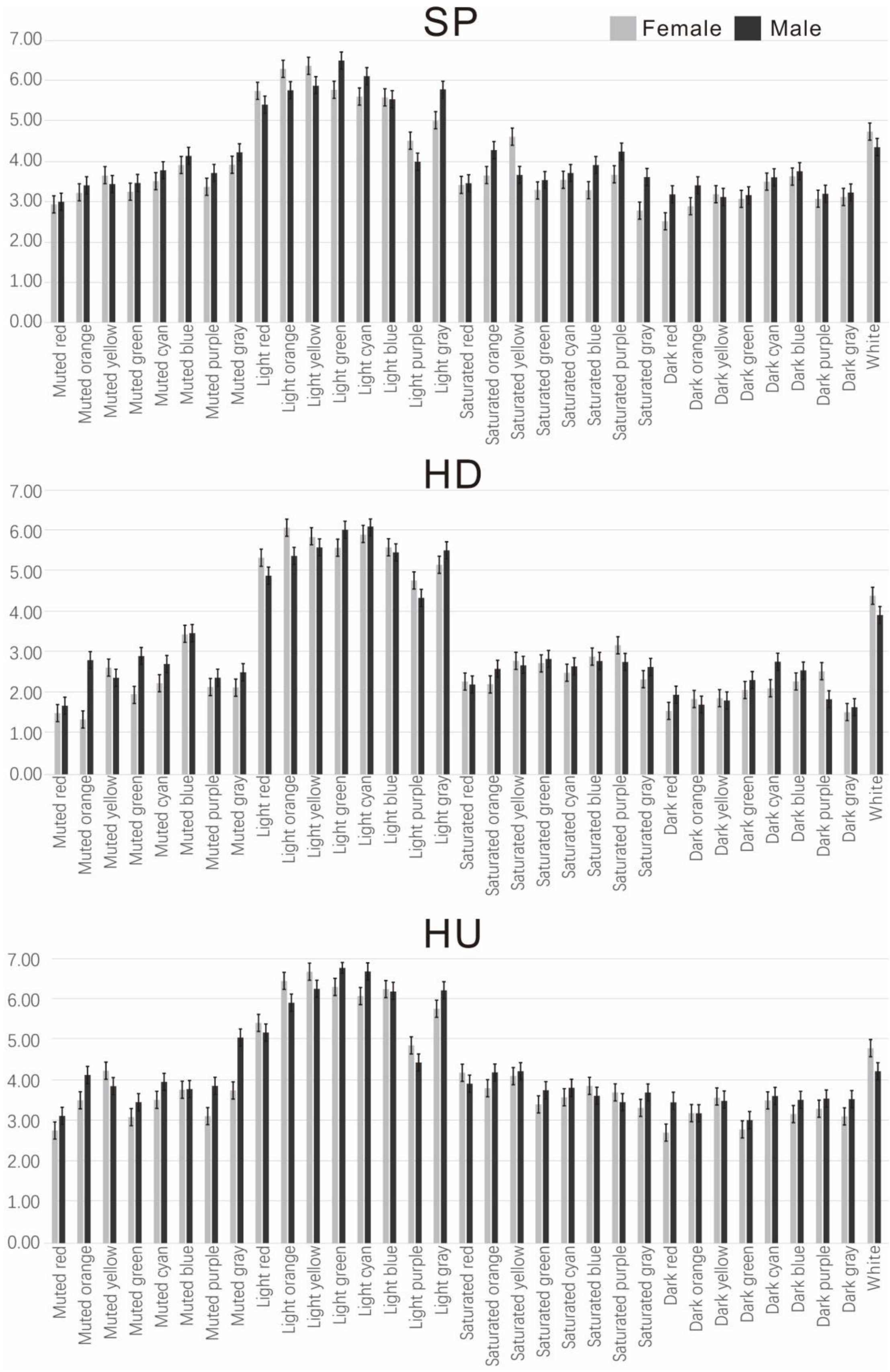

Fig. 5. Preference for the four chroma-brightness levels in the three body positions

4. Discussion

This study evaluated the participants' preferences for 33 colour environments during normal sitting position (SP), -15 ° head-down bed rest (HD), and 9.6 ° head-up tilt bed rest (HU). The results show that in all colour environments, there was no significant difference in the colour preference between SP and HU, but there was a significant change in the colour preference in HD compared to SP and HU. In the three body positions, it seems that the participants preferred lighter colours rather than darker ones, preferred warmer colours in SP and HU, and preferred cool colours in HD. Besides, no evidence of gender differences in colour preference by body position was found, but in each body position, men and women had different preference levels for basic hue and chroma brightness. Men preferred cyan while women preferred yellow, and men preferred muted colours while women preferred light colours.

4.1 Hue and chroma-brightness preference in the three body positions

The results of this study show that the colour preference of the participants in HD was significantly different from that in SP and HU. In HD, the participants preferred light cyan, light green and light blue, compared to the SP and HU positions where they preferred light yellow, followed by light orange and light green. In the preference results of the nine basic hues, it was also found that in the SP and HU positions, yellow and orange were the most popular, while in the HD position, cyan and blue were the most popular. According to theory relating to cool and warm colours [45-46], the results show that participants who were resting in bed with their head down to simulate weightlessness preferred cool-colour environments such as cyan and blue, which is consistent with previous studies which found that cool-colour environments can alleviate the discomfort caused by brain fatigue and brain congestion caused by excessive head pressure, and can also make people feel calm [47-49]. Also, a large number of participants stated that they felt relaxed and relieved in cool-colour environments, and that these could reduce the increase in eye pressure and fatigue caused by resting head down in bed, which is consistent with the findings of Mahnke [50]. Torres believes that red or orange gives people a sense of warning, impulsivity and stress, and can also significantly arouse human physiological activities [51]. Besides, in another long-term head-down bed rest experiment, it was also found that red will increase people's attention resources, which leads to more fatigue, but when it is necessary to engage in highly vigilant work, the performance level of red environment was much higher than that of a blue environment [52]. However, our participants preferred a light yellow or light orange environment in SP and HU, which is consistent with colour studies of some normal environments, which indicate that warm colours in the environment can make people feel warm, and can make the environment appear more spacious and more interesting [53,19]. This also shows that there is no difference between the colour preference of the 9.6 ° head-up tilt bed simulating the gravity effect of the lunar environment and the colour preference in the normal earth environment. However, the significant difference in colour preference between HD, compared to SP and HU, may be caused by the head-ward fluid shift during the microgravity effect. Early in the construction of the International Space Station, in an anecdotal report from NASA, several astronauts reported that a light blue or green crew cabin environment can be more comfortable than a brown or orange colour scheme. They considered it difficult to find small objects like spoons or ballpoint pens in a brown-yellow environment [54]. Vakoch [55] reported that during an 11-day space mission, the astronauts all agreed that they felt heart palpitations in yellow and brown environments, and even some nausea, but blue alleviated this effect to a certain extent. In our study, the participants had the same chroma-brightness preference in all three body positions. They all preferred light-coloured environments, and most did not favour dark-coloured environments, which is consistent with many studies considering normal terrestrial environments, indicating that a light-colour environment makes people feel spacious, bright and comfortable, and can significantly improve work efficiency [47,12,19]. In the study of Stone's [56] reading, performance in dark colour environments was significantly lower than in light-colour environments, and it was easy to produce negative emotions such as irritability and drowsiness. Besides, an interesting finding is that white is not the most preferred colour, although there is a high preference for white in Asian countries, which is related to the purity and cleanliness of the colour [57]. In early studies of some extreme environment, it was found that a white environment will cause visual monotony and fatigue, and strengthen the impact of lighting on the eyes [58-61].

4.2 Differences in colour preference between men and women in the three body positions

We found that the effects induced by different short-term body positions did not affect men's and women's preferences for hue and chroma-brightness levels. However, in the three body positions, two colours showed significant gender differences. Men preferred cyan, while women preferred yellow. Although no relevant differences in colour preference between men and women have been found in other space studies, this is similar to some conclusions in the normal environment. Zhang [30] tested 1,290 participants and found that men preferred cyan and blue, while women preferred yellow and white. In addition, for the chroma-brightness level, we found that men preferred muted colours such as muted cyan, muted blue and muted yellow, while women preferred light colours such as light yellow, light yellow and light cyan. Some studies believe that this difference may be due to the association of different specific objects between the two genders, which is developed from childhood and gradually forms the specific gender roles in adulthood [62,30-31]. However, according to some studies, a more complete and evidence-based model is needed to fully explain the gender differences in colour preference, including culture, customs, region etc. [63-64].

4.3 Potential benefits of colour preference for space missions

Based on the results of this study, the overall layout and atmosphere of the interior of an orbiting spacecraft or deep-space manned spacecraft in microgravity conditions could be designed in lighter, cooler colours for future space missions, which could mitigate the potential stress response due to microgravity effects. In the case of lunar or Mars habitat interiors, lighter, warmer colours could be used to optimise long-term habitability. In addition, this study also found that male and female colour preferences exist regardless of body position. This means that colour could be customised in the design of future spacecraft or habitats for different male and female areas such as sleeping areas, hygiene areas, or use of equipment in order to help counterbalance any negative emotions of the crew during long periods away from Earth.

All of the experiments in this study were conducted during the day, and although the participants completed the experiments in a laboratory without daylight, some studies have shown that people's environmental colour preferences differ between day and night. This may be due to changes in the state of life (mood, lifestyle rhythm, etc.) brought about by differences in the nature of human work and life during the day and at night [74-75]. During the daytime, people may prefer colours to activate their working state, to awaken motivation and to optimise productivity. At night, people prefer colours that are relaxing, warm and soothing [76]. It is also worth considering whether this influences people's colour preferences. This aspect is important for space missions because in space, the external environment does not have the same sunrise and sunset as on Earth. This is true for present-day space stations in orbit, future deep space probes or lunar or Mars habitats. Circadian rhythms and the simulation of day and night must be taken into account in habitat design to aid the normal functioning of the crew. Therefore, designing the most beneficial colour environment or lighting to help regulate the crew's routine, and thus optimise the habitability of the mission environment, offers potential benefits to the success of space missions.

4.4 Limitations and future directions

Regarding possible limitations, this study used a short-term, 3-hour -15 ° head-down bed rest and a 9.6 ° head-up tilt bed rest experiment to induce different physical effects in order to evaluate differences in colour preference. This study is the first part of a series of simulated gravity experiments designed to explore potential colour effects using short-term simulations. In contrast, many previous studies carried out experiments with long-term head-low bed rest (15 days and longer) to explore the simulation of human performance in different microgravity environments [65]. Therefore, in future, bed rest time should be extended to explore the colour preferences of different time periods during head-down and head-up tilt bed rest. Besides, some literature suggests that simulating the sensory-motor effects of microgravity would yield more rigorous data. This includes parabolic flight [68], prolonged dry immersion [69] and the use of weight support systems or devices to eliminate the effects of gravity on individual limbs, either systemically or partially [70-71], to help simulate different gravities. This approach not only allows the participants to simulate microgravity under static tasks, but also helps them experience movement or manipulation more realistically. Also, for studies comparing different gravity effects using different body positions, it would be more rigorous to use specialist rotational tilt sitting devices to allow participants to sit in fixed positions at different tilt angles to simulate different gravity effects. Therefore, these experimental paradigms or devices should be used in the future to simulate the sensory-motor effects of microgravity in order to further validate the current data.

55 Chinese people participated in this study to examine the effect of different body positions on colour preference, but this study did not consider the influence of culture, region, and other factors on colour preference. The sample size should therefore be expanded in the future and include samples from different cultures and regions to ensure more comprehensive results. Besides, our participants were all Chinese undergraduate or graduate students, while the age of astronauts is generally between 40 and 55 years. In the future, consideration should be given to selecting potential astronaut populations, such as pilots and soldiers, to conduct experiments in order to obtain more realistic results regarding the colour preferences of astronauts. We propose to follow on these investigations with future simulation campaigns in the frame of ILEWG EMMESI EuroMoonMars Earth Space Innovation and other relevant programmes [66-67,83-84].

5. Conclusion

This article investigated differences in preference in hue, chroma, and brightness levels between normal sitting position, -15 ° head-down bed rest and 9.6 ° head-up tilt bed rest. We found that the colour preference changed in the HD position, with participants favouring the cyan and blue environments the most. In terms of chroma-brightness preference, light colours were the most favoured among the three body positions, while dark colours were the least favoured. Women liked yellow, orange, cyan, white and light colours, while men liked cyan, blue, yellow, green and muted colours. Therefore, this study provides new empirical evidence for the influence of physical effects induced by different body positions on colour preference, and provides some enlightenment for future research on the colour design of spacecraft environments or lunar or Mars habitat environments.

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