

Neville Stanton *Editor*

Advances in Human Aspects of Transportation

Proceedings of the AHFE 2020 Virtual
Conference on Human Aspects
of Transportation, July 16–20, 2020,
USA

Neville Stanton
Editor

Advances in Human Aspects of Transportation

Proceedings of the AHFE 2020 Virtual
Conference on Human Aspects
of Transportation, July 16–20, 2020, USA

Editor
Neville Stanton
Boldrewood Innovation Campus
University of Southampton
Southampton, UK

ISSN 2194-5357 ISSN 2194-5365 (electronic)
Advances in Intelligent Systems and Computing
ISBN 978-3-030-50942-2 ISBN 978-3-030-50943-9 (eBook)
<https://doi.org/10.1007/978-3-030-50943-9>

© The Editor(s) (if applicable) and The Author(s), under exclusive license
to Springer Nature Switzerland AG 2020

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Traffic Behavior and Driver Performance

Determining Infrastructure- and Traffic Factors that Increase the Perceived Complexity of Driving Situations 3
Anika Boelhouwer, Arie Paul van den Beukel, Mascha C. van der Voort, and Marieke H. Martens

Development of Statistical Models for Predicting Automobile Seat Fit of Drivers 11
Baekhee Lee, Kihyo Jung, and Jangwoon Park

How Personal Identity Influences the Driving Behavior-Correlation Analysis with Naturalistic Driving Data 16
Caecilia von Lienen, Jana-Sophie Effert, Fabian Schwarzenberger, Lars Hannawald, and Guenther Prokop

Assessment of Driver Distraction Caused by Social Networking Activities Using the Smartphone: A Driving Simulator Study 24
Fabrizio D’Amico, Alessandro Calvi, Chiara Ferrante, and Luca Bianchini Ciampoli

Personalized Driver State Profiles: A Naturalistic Data-Driven Study 32
Arash Tavakoli, Mehdi Boukhechba, and Arsalan Heydarian

Human Car-Following Behavior: Parametric, Machine-Learning, and Deep-Learning Perspectives 40
Saeed Vasebi, Yeganeh M. Hayeri, and Jing Jin

Alert! Automated Vehicle (AV) System Failure – Drivers’ Reactions to a Sudden, Total Automation Disengagement 49
Sarah El-Dabaja, Deborah McAvoy, and Bhaven Naik

Traffic Behavior Analysis Using Mobile Base Station Data	56
Juyoung Kim and Dongho Kim	
Driver’s Visual Attention Analysis in Smart Car with FHUD	68
Yanjun Zhang, Tian Yang, Xia Zhang, Yongjin Zhang, and Youchao Sun	
Human Machine Interaction	
How Important is the Plausibility of Test Scenarios Within Usability Studies for AV HMI?	77
Nadja Schömig, Katharina Wiedemann, Frederik Naujoks, Sebastian Hergeth, Andreas Keinath, and Alexandra Neukum	
Employing Natural Finger Positioning Strategy for Improving Blind-Positioning of Steering Wheel Mounted Switches	85
T. K. Philip Hwang, Yao-Tin Huang, and Pin-Chieh Kuo	
Towards a Truly Cooperative Guidance and Control: Generic Architecture for Intuitive Human-Machine Cooperation	92
Marcel Usai, Ronald Meyer, Hiroshi Nagahara, Yusaku Takeda, and Frank Flemisch	
Researchers and Public Views on Electronic Sideview Mirror System (ESMS) in the 21st Century Cars	99
Bankole K. Fasanya, Skandip Anand, and Guna Sreeja Kallepalli	
Future Transportation Service Technology Platform System Based on Internet of Vehicles	107
Jia-xin Liu, Zi-yun Li, and Ying Cao	
Impact of Speedometer Forms on Integration Task Performance for Train Driving	112
Chenchen Gao, Weining Fang, Ke Niu, and Jianxin Wang	
New Technology Implementation in High-Risk Organizations - The Application of HRO Principles in New Technology Implementation in Railroad Industry	120
Yalda Khashe and Najmedin Meshkati	
Eye Movement Analysis of Interactive Interface of CRH High-Speed Train Braking Test	127
Jun Li and Jinyi Zhi	
Research on Optimal Design of Metro Driving Interface Based on Driver’s Operating Characteristics	133
Yang Du, Jin-Yi Zhi, Ze-Rui Xiang, and Jing Kang	
Effect of Intercity Train Vehicle Layout on Boarding and Lighting	139
Chen Wang, Weining Fang, Yueyuan Chen, and Caifeng Li	

Vehicle-to-Infrastructure and Human-to-Infrastructure Models for Smart Civil Infrastructure Systems	147
Sara Mostowfi and William Glen Buttlar	
Driving Automation	
Online Feedback Control for Driver-Vehicle Interaction in Automated Driving	159
Khazar Dargahi Nobari, Franz Albers, Katharina Bartsch, and Torsten Bertram	
Automated Driving on the Motorway: A Users' Perspective on Conditional Versus High Automation	166
Johanna Wörle, Barbara Metz, Aaron Lutz, and Marcus Schmitt	
On the Road Again - Explanatory Factors for the Users' Willingness to Replace Private Cars by Autonomous on-Demand Shuttle Services	173
Ralf Philippsen, Teresa Brell, Hannah Biermann, and Martina Ziefle	
How Visual Cues on Steering Wheel Improve Users' Trust, Experience, and Acceptance in Automated Vehicles	186
Arun Muthumani, Frederik Diederichs, Melanie Galle, Sebastian Schmid-Lorch, Christian Forsberg, Harald Widlroither, Alexander Feierle, and Klaus Bengler	
The Impact of a Biological Driver State Monitoring System on Visual Attention During Partially Automated Driving	193
Alice Stephenson, Iveta Eimontaite, Praminda Caleb-Solly, and Chris Alford	
Analysis of Public Transport Ridership During a Heavy Snowfall in Seoul	201
Seonyeong Lee, Minsu Won, and Seunghoon Cheon	
The Role of Attentional Networks in Secondary Task Engagement in the Context of Partially Automated Driving	211
Rui Lin, Yuchen Xu, and Wei Zhang	
Accidents	
Analysis of Human Factors Failures in an Incident of Self-driving Car Accident	221
Ashraf Labib, Yoskue Nagase, and Sara Hadleigh-Dunn	
Assessing the Effectiveness of Augmented Reality Cues in Preventing Rear-End Collisions: A Driving Simulator Study	229
Alessandro Calvi, Fabrizio D'Amico, Chiara Ferrante, and Luca Bianchini Ciampoli	

Operational and Geometrical Conditions of Accident Occurrence and Severity at Signalized Intersections	237
Abdulla Alghafli and Mohamed Shawky	
Effects of a Background Arrangement on Collision-Prediction Accuracy for Approaching Objects	247
Yohsuke Yoshioka and Hinako Tanaka	
Influence of Passive Fatigue and Take-Over Request Lead Time on Drivers' Take-Over Performance	253
Ali Muhammad Hadi, Qingkun Li, Wenjun Wang, Quan Yuan, and Bo Cheng	
Modeling of a Vehicle Accident Prediction System Based on a Correlation of Heterogeneous Sources	260
Pablo Marcillo, Lorena Isabel Barona López, Ángel Leonardo Valdivieso Caraguay, and Myriam Hernández-Álvarez	
Comfort and Posture	
A Theoretical Framework for Occupant Comfort in Future Shared Autonomous Vehicles	269
James Jackson and Davide Salanitri	
Detection and Classification of Unconscious Movements with Body Pressure Distribution Measurement for Ride Comfort Evaluation in Vehicle Seat	276
Junya Tatsuno, Koki Suyama, Hitomi Nakamura, and Setsuo Maeda	
An Ergonomic Analysis on the New E-Traysikel	283
Nouriet Rocel San Juan, Kristiana Louise Abaa, Daniel Jairoh Alto, Enrico Fernando Jr., and Benette Custodio	
Investigation on Driving Posture and Operating Habits of Heavy Truck Drivers	291
Junmin Du, Haoshu Gu, Weiyu Sun, Xin Zhang, Huimin Hu, and Yang Liu	
Research on the Comfortable Joint Angle for Chinese Automobile Drivers	299
Linghua Ran, Yang Gao, Weinan Ju, Chaoyi Zhao, and He Zhao	
Vulnerable Road Users	
Effects on Driver's Yielding Behavior of a Pedestrian Collision Warning System in Different Road Environments	307
Francesco Bella, Chiara Ferrante, Manuel Silvestri, and Maria Rosaria De Blasiis	

Identified Risk Factors Among Truck Drivers Circulating in France . . .	315
Anabela Simoes, Patricia Delhomme, Blazej Palat, Alexandra Gheorghiu, Jean-Pascal Assailly, Teodora Stefanova, Giulio Bianchi Piccinini, Loic Josseran, Gilles Vallet, and Juan Pérez	
Applying the Systems Theoretic Accident Model and Process to Analyze a Downgrade-Truck Collision Caused by a Brake Failure in Vietnam	322
Do Duy Dinh, Nam Hoai Vu, Rich C. McIlroy, Katherine L. Plant, and Neville A. Stanton	
Transport Planning and Infrastructure Design	
Effect of Perceived Contrast Enhancing Lens Technology on Traffic Signal Detection for Color-Deficient Individuals	333
Cameron Lopez, Jeremy Swan, and Jonas Schmidtlr	
Semi-charmed Life - Willingness to Use and Related Contributing Factors Regarding Semi-public Charging Infrastructure for Electric Cars	340
Ralf Philipsen, Imke Haverkämper, Hannah Biermann, Teresa Brell, and Martina Ziefle	
An Investigation of Traffic Noise Levels Around a Major Hospital in Qatar	354
Khaled Shaaban, Abdelrahman Abouzaid, Ahmad Musleh, and M. Fares Hout	
Analysis of Driving Performance Data Considering the Characteristics of Railway Stations	361
Daisuke Suzuki, Ayako Suzuki, Keiko Shimano, Kazuki Kiyota, and Yutaka Kakizaki	
The Intersection of Spatial Fragmentation and Smart Transport Planning in Gauteng Province, South Africa: Constraints and Opportunities	367
James Chakwizira	
Research on the Bike-Sharing Service from the Users' Perspective and Its Impacts on Their Lifestyles	374
Tianshi Shen	
Route Choice, Navigation and Wayfinding	
An Evaluation Index System for Wayfinding System and Its Research Applications: The Case of Beijing Subway Line 1	387
Chuanyu Zou and Guangxin Wang	

Empirical Study on Evaluation of Railway Wayfinding System: A Case Study of Shandong Province, China	393
Chuanyu Zou, Yongquan Chen, and Ziding Chen	
Empirical Study on Evaluation of Subway Wayfinding System: A Case Study of Shandong Province, China	399
Chuanyu Zou, Yongquan Chen, and Jindong Gao	
Analysis on the Redesigned Metro Safety Signs Based on Eye Tracking	405
Guilei Sun, Yanhua Meng, Qin Li, Zijie Wan, and Yaqi Wang	
TIAMBIENTA Smart Technologies for the Motor-Home Sector	413
Giuseppe Lotti, Marco Marseglia, Elisa Matteucci, Margherita Vacca, Irene Fiesoli, Claudia Morea, Alessio Tanzini, Francesco Cantini, Lu Ji, and Eleonora Trivellin	
Human Factors in Transportation: Maritime	
Preventing Unruly Technologies in Maritime Navigation: A Systems Approach	421
Katie Aylward, Scott N. MacKinnon, and Monica Lundh	
Artificial Intelligence in Maritime Navigation: A Human Factors Perspective	429
Scott N. MacKinnon, Reto Weber, Fredrik Olindersson, and Monica Lundh	
The Anchoring Effect of Technology in Navigation Teams	436
Vitor Conceição, Carlos Teles, and Joakim Dahlman	
Validation of Virtual Command Bridge Training Environment Comparing the VR-Training with Ship Bridge Simulation	444
Jenny Lauronen, Werner Ravyse, Mirva Salokorpi, and Mika Luimula	
Addressing Gaps in Offshore Emergency Egress Training Using Virtual Environments	452
Jennifer Smith, Mashrura Musharraf, and Brian Veitch	
Maritime Resource Management in the Marine Engineering and Nautical Science Education – Attitudes and Implication for Training and Evaluation	461
Gesa Praetorius, Carl Hult, and Jan Snöberg	
Development of a SAGAT Query and Simulator Experiment to Measure Situation Awareness in Maritime Navigation	468
Hui Xue, Bjørn-Morten Batalden, and Johan-Fredrik Røds	

Assessing Situation Awareness Across Different Submarine Control Room Layouts	475
Kiome A. Pope, Aaron P. J. Roberts, Daniel Fay, and Neville A. Stanton	
Agent-Based Approach to Ship Officer's Navigational Behavior Modeling for Maritime Traffic Analysis	483
Hongtae Kim, Younghoon Yang, and Seung-Kweon Hong	
Exploiting Contemporary Technology in Flight Deck Design to Improve Flight Safety	
Envisioning Mixed Realities on the Flight Deck	493
James Blundell, John Huddleston, Charlotte Collins, Steve Scott, Rodney Sears, and Anastasios Plioutsias	
Supporting Astronaut Autonomous Operations in Future Deep Space Missions	500
M. Natalia Russi-Vigoya, Donna Dempsey, Brandin Munson, Alonso Vera, Bernard Adelstein, Shu-Chieh Wu, and Kritina Holden	
Habitability Study on Space Station Colour Design	507
Ao Jiang, Xiang Yao, Irene Lia Schlacht, Giorgio Musso, Tang Tang, and Stephen Westland	
Human Factors in Transportation: Aviation and Space	
What-if Analysis in Total Airport Management	517
Reiner Suikat, Sebastian Schier-Morgenthal, Nils Carstengerdes, Yves Günther, Sandro Lorenz, and Florian Piekert	
Pilot Tailored Helicopter Systems	524
Christian A. Niermann	
Operational Complexity in Performance-Based Navigation Arrival and Approach Flight Operations	531
Divya Chandra, Andrea Sparko, Andrew Kendra, and Janeen Kochan	
Towards a Glossary of Aviation Communication Factors	539
Simon Cookson	
An Approach to Aerospace Design Integrating Crew Resource Management in Operational Environments	547
Tiziano Bernard, William A. Tuccio, Sebastien Boulnois, Aleksandar Tasic, and Lucas Stephane	
Helicopter Noise Footprint Depiction During Simulated Flight for Training	554
Anna C. Trujillo, Eric Greenwood, and Daniel R. Hill	

Predictive Safety Through Survey Interviewing - Developing a Task-Based Hazard Identification Survey Process in Offshore Helicopter Operations	562
Felipe A. C. Nascimento, Arnab Majumdar, and Washington Y. Ochieng	
Aircraft Accommodation for People Living with Obesity: A Call for a Review of Existing Seating, Safety and Emergency Regulations	570
Kayla Daigle, Dawson Clark, Chantal Trudel, and Shelley Kelsey	
Urban Air Mobility Fleet Manager Gap Analysis and System Design	576
Richard Mogford, Dan Peknik, Jake Zelman, and Cody Evans	
Investigation of Commercial Aircraft's Cargo Luggage Dash Impact on Passenger During Emergency Evacuating	583
Li Wen Wu	
Research on the Comprehensive Evaluation System of Cabin Comfort of Civil Aircraft	590
Jian-Ping Chen, Jin Wang, Jin-Yi Zhi, and Li-Li Zhang	
The Importance of Human Factors When Designing Airport Terminals Integrating Automated Modes of Transit	597
Seth Gatien, John Gales, Ata Khan, and Ariel Yerushalami	
The Flight Scenarios Development Method for Cockpit Design and Evaluation of Civil Aircraft	603
Hongyu Zhu, Hua Meng, Shasha Lu, and Guangyu Bao	
The Effect of Anticipatory Conditions on Pilot Performance in Encountering Stall: A Flight Simulator Study	610
Meilisa Hajriani and Hardianto Iridiastadi	
Criteria Indicators of the Consistency of Air Traffic Controllers' Preferences on a Set of Characteristic Errors	617
Oleksii Reva, Volodimir Kamyshyn, Andrii Nevynitsyn, Valerii Shulgin, and Serhiy Nedbay	
High-Level Review Principles for Human-Machine Interface Design of Civil Aircraft Flight Deck	624
Fei Li and Kaiwen Chen	
Author Index	633



Habitability Study on Space Station Colour Design

Ao Jiang^{1(✉)}, Xiang Yao^{2(✉)}, Irene Lia Schlacht³, Giorgio Musso⁴,
Tang Tang¹, and Stephen Westland¹

¹ University of Leeds, Leeds, UK
sda.j@leeds.ac.uk

² Xiangtan University, Xiangtan, China
31558950@qq.com

³ HMKW University Berlin, ILEWG at ESA ESTEC, Berlin, Germany

⁴ Thales Alenia Space Italy, Turin, Italy

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

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

1 Introduction

1.1 Space Colour Design Based on Emotional Habitability

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

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

1.2 Case Study: Sanitary Area of the Space Station

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



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

2 Method

2.1 Research of the Colour Perception Model Based on Emotional Habitability

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

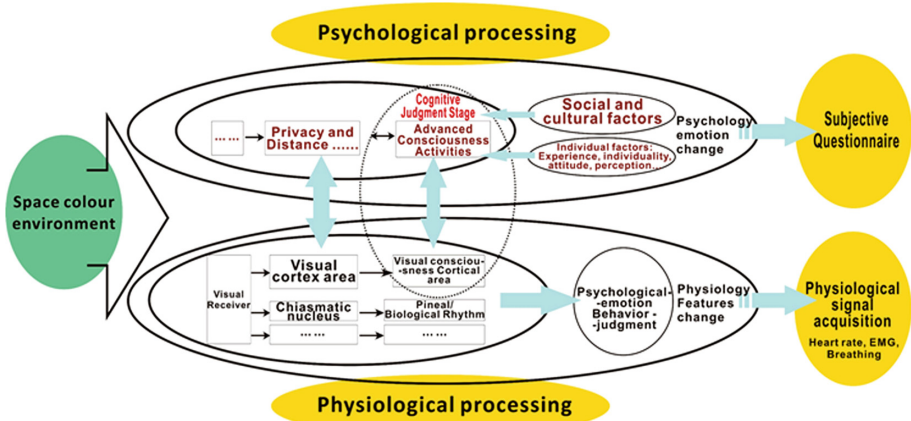


Fig. 2. Colour perception model for spatial emotional habitability

2.2 Development of the Mockup to Test the Sanitary Area

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

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

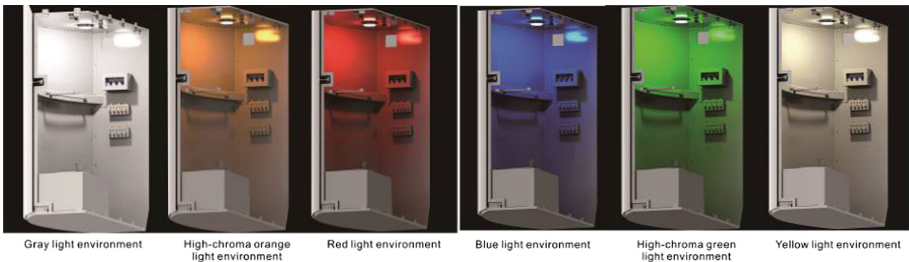


Fig. 3. Colour design study of the space station's sanitary area

2.3 Determination of Colour Specimens Based on Colour Matching Standards

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

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

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

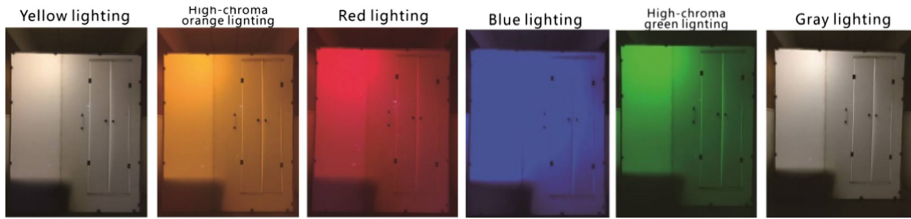


Fig. 4. Colour design test of the entrance of the mockup of the space station's sanitary area (picture of the interior were forbidden for ethical reason)

2.4 Establishment of Test Plan and Countermeasures

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

- A. 40 participants (28 male, 12 female), 30–40 years old, with strong physiques and good physical fitness. They had regular daily routines and did not drink or take drugs.
- B. Six 18 W coloured light bulbs (with six different colours of light: grey, red, high-chroma orange, yellow, high-chroma green and blue; the six colours' RGB values were all within the standard value range used by the International Illumination Commission for colour discrimination). At the same time, this study simulating the system environment of the space station sanitary area used the CAPTIV-L7000 human factor data acquisition system to measure the participants' heart rate, breathing rate and myoelectric signals.

C. The test process comprised the following steps:

C1. The participants needed to be fully rested the day before the experiment, had not performed any bowel movements and maintained a calm and good condition. They were made familiar with the test environment and the operation and use procedures of the sanitary area before the test started in order to eliminate any effects of changes in their psychological state in an unfamiliar environment.

C2. First, experiments were performed in a natural indoor bathroom environment, that is, in a spacious and bright bathroom.

C3. After resting for five minutes, the participants entered the simulated test environment to perform the test. Using the sequence of grey, red, high-chroma orange, yellow, high-chroma green and blue, the participants switched the coloured light bulb to a different colour every ten minutes, i.e., the environment colour of the closed simulated sanitary area remained the same for a period of ten minutes each. While switching the colour environment, the participants rested for five minutes. Then they strictly followed the sanitary area operation and use procedures of the "Astronaut Biographies Home Page" published by NASA and the European Aviation Authority. Before entering the environment of the simulated space station, T-Sens breathing frequency sensors and T-Sens heart rate sensors were attached to them. A Sens

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

3 Result

3.1 Method for Processing Physiological Signal Data

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

3.2 Data Processing Results and Analysis

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

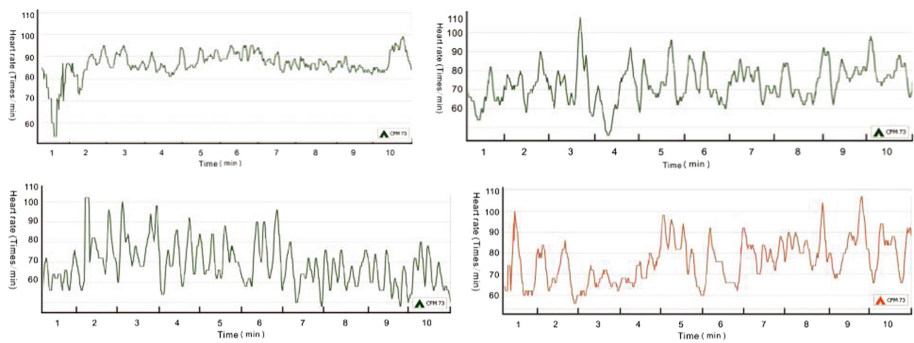


Fig. 5. Heart rate test frequency data

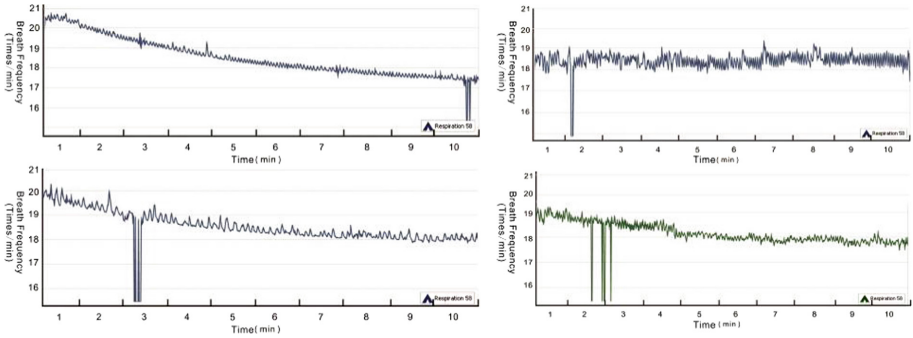


Fig. 6. Breath test frequency data

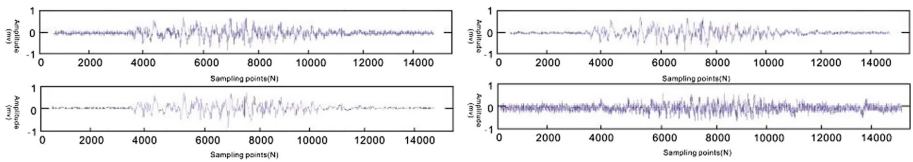


Fig. 7. EMG test frequency data

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

4 Conclusion

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

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

Acknowledgements. This work is supported by a scholarship from the China Scholarship Council and the University of Leeds (No. 201908430166), a scientific research project of the Hunan Provincial Department of Education (No. 19B568), as well as a research project of the China Astronaut Research and Training Centre (No. 2018111400419).

References

1. Stuster, J.W.: Space station habitability recommendations based on a systematic comparative analysis of analogous conditions (1986)
2. Schlacht, I.L.: SPACE HABITABILITY: integrating human factors into the design process to enhance habitability in long duration mission. TU-Berlin. Berlin (2012)
3. Durao, M., Favata, P.: Color considerations for the design of space habitats. In: AIAA Space 2003 Conference & Exposition, p. 6350 (2003)
4. Link Jr., D.E., Broyan Jr., J.L., Philistine, C., Balistreri Jr., S.F.: International space station USOS waste and hygiene compartment development. SAE Trans. **116**, 119–124 (2007)
5. Kitmacher, G.H.: Reference Guide to the International Space Station. CreateSpace Independent Publishing Platform, Scotts Valley (2006)
6. Mahnke, F.H.: Color, Environment, and Human Response: An Inter-Disciplinary Understanding of Color and Its Use as a Beneficial Element in the Design of the Architectural Environment. Wiley, New York (1996)
7. NASA. Space Potty (2013). www.youtube.com/watch?v=5WSiGRBTfNI
8. Robertson, A.: CIE guidelines for coordinated research on color-difference evaluation. Color Res. Appl. **3**(3), 149–151 (1978)