

Color and Colorimetry Multidisciplinary Contributions

Vol. XX A

Edited by Filippo Cherubini and Andrea Siniscalco



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Introduction

The Color Conference, organized annually by the Italian Color Association (Gruppo del Colore - Associazione Italiana Colore), reached its Twentieth Edition in 2025.

The international two-day event took place on September 4th and 5th, 2025, at the University of Naples Parthenope in the beautiful city of Naples.

This milestone edition opened with three keynote presentations of exceptional breadth and inspiration. The conference began with Dr. Costanza Miliani from the CNR Institute of Heritage Science, who presented “Writing with Colors: Materials, Techniques, and Cultural Significance in Mesoamerican Codices”. The program continued with Studio Waldemeyer, featuring Farahbod Nazanin and Moritz Waldemeyer, and their evocative talk “Where Light Becomes Emotion”.

The morning session concluded with the Color Award 2025, conferred to Massimo Cantini Parrini in recognition of his extraordinary contribution to the world of costume and creativity.

The following day opened with an outstanding invited lecture by Dr. Massimiliano Guarnieri from ENEA, who presented “Artificial Intelligence and color features detection: some examples and future perspective”.

Sincere thanks go to the Chairs of the Conference, Giuliana Ramella (CNR – Institute for Applied Calculus “Mauro Picone”) Francesca Fragliasso (University of Naples Federico II) and Andrea Siniscalco (Dipartimento di Design, Politecnico di Milano), for their valuable guidance and coordination. A heartfelt appreciation also goes to the University of Naples Parthenope, host of this year’s edition.

We warmly thank Dr. Sofia Ceccarelli (CNR ISPC) for the local organization, the Program Committee, Professors Angelo Ciaramella and Emanuel Di Nardo (University of Naples Parthenope), Professors Laura Bellia and Francesca Diglio (University of Naples Federico II), as well as Dr. Filippo Cherubini, Secretary of the Association, and all the members of the Scientific Committee, for their fundamental contribution to the dissemination, review, and organization of the conference. Special thanks also go to Tectilia, the event sponsor, whose support helped make this conference both culturally enriching and welcoming.

The 2025 program once again confirmed the richness and interdisciplinarity that have always characterized the work of our community, spanning from design to education, and from cultural heritage to psychology.

These diverse perspectives continue to make the Conferenza del Colore a reference point for researchers, professionals, and enthusiasts working on the multifaceted study of color.

Finally, we extend our gratitude to all authors and speakers for the quality of their contributions, and to the institutions and associations that offered their patronage and collaboration, reinforcing the spirit of unity that defines this event.

The following pages collect the proceedings of the Twentieth Color Conference.

We wish you an inspiring read.

Alice Plutino

October 2025

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Considerations about light and colour for human beings in microgravity conditions

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Abstract

The race to long-term space missions beyond Earth's atmosphere requires a deep understanding of how environmental factors, such as light and colour, affect human physiology and psychology in microgravity. While microgravity has been extensively shown to compromise multiple aspects of human health, including the musculoskeletal and ocular systems, its impact on visual perception, specifically colour perception, remains an area of limited investigation. This paper outlines the current state of research, highlighting the need for dedicated studies on the perceptual and physiological responses to light and colour stimuli in microgravity.

Existing studies indicate that microgravity significantly alters the integrity of the human body. Visual stimuli have been proposed and tested as countermeasures against space-induced stress in simulated space station environments. For instance, studies using the Delphi method have investigated how colour schemes can mitigate stress in confined hygiene areas within space habitats. Additionally, short-duration simulated spaces have been used to test multicoloured lighting environments and explore their psychological effects on participants, aiming to enhance well-being and performance.

Other approaches have directly examined visual perception in microgravity through parabolic flight experiments, which simulate weightlessness for brief periods, or through postural techniques that emulate gravitational unloading. These methodologies provide insight into the human visual system's adaptability but are limited in their duration compared to long-term missions.

Although no direct empirical data currently confirm changes in colour perception during extended space missions, ophthalmological studies have documented physiological alterations due to microgravity, including optic disc oedema, globe flattening, choroidal folds, and hyperopic shifts. These effects suggest possible impacts on retinal and cortical processing, yet astronauts have not self-reported changes in colour perception. This discrepancy raises questions about compensatory mechanisms, such as chromatic constancy and contrast adaptation, which might preserve perceptual stability despite physiological changes.

Furthermore, distinguishing the intent of colour sensitivity assessments is critical. The context in which colour perception is evaluated, such as the observed environment, can trigger compensatory cognitive or physiological mechanisms that play a vital role in interpreting the results.

Given the absence of evidence indicating altered colour sensitivity in space, it is plausible that the physiological mechanisms underlying circadian entrainment via light at specific wavelengths remain functional in microgravity. This hypothesis supports the continued application of light-based interventions for circadian regulation in extraterrestrial settings. However, targeted research is essential to verify this assumption and optimise lighting design for future long-duration missions.

Keywords: Colour, Lighting, Microgravity, Physiology, Psychology.

Introduction

Staying in confined and isolated environments, such as space stations, requires numerous precautions in the design of living spaces. In these places, microgravity and the context - so different from the one in which we evolved - have proven adverse effects on the quality of life of astronauts (from a psychological and social point of view) and on their physiology, introducing a series of deteriorations that put a strain on their bodies. Astronauts are, in fact, faced with factors such as the lack of spatial and temporal references, induced by the removal of the normal cycle of day and night and life in microgravity conditions.

The individuals who participate in these missions are trained for a long time and possess excellent preparation both physically and mentally, however, despite this, microgravity induces a series of changes to their body that lead them to experience a series of systemic problems such as variations in intracranial pressure that can lead to the SANS - Spaceflight-Associated Neuro-Ocular Syndrome (Rodrigues, Russomano and Santos Oliveira, 2025), muscle atrophy, reduces bone density, muscle tone loss; bodily fluids shift, changes in blood volume, cardiovascular issues, DNA damage and disruptions to sleep-wake cycles. All these issues are under constant review (Ray, Parvez and Islam, 2025), with more ambitious missions in mind (such as Moon permanent outposts, tourist space stations or Mars exploration).

In space stations, moreover, numerous variables generate strain, the so-called *stressors*, capable of creating problems for the crew, as much as, if not more, physiological problems. For example, the perception of a decline in care provided by individuals outside the crew (Bell et al., 2025) or numerous other issues related to astronauts' mental health status (Smith, 2022). Mood and time orientation during the day, together with the regulation of the sleep-wake cycle, are very important factors; These are not exclusively psychological factors (they are also physiological), but the relapse of these problems can be significant from a psychological point of view. In this context, the use of light and colour can help improve the psychophysiological conditions of the crew, following design measures commonly called Human-Centric Lighting. All these procedures play a strategic role, as they directly influence alertness, mood, spatial orientation and cognitive performance (Cajochen *et al.*, 2005).

Despite the growing awareness of the relevance of these aspects, the scientific literature typical of these spaces is biased towards the study of critical factors related to operational safety (e.g. effects of CO₂ levels (Garbino *et al.*, 2024), risk of fire (Guibaud *et al.*, 2022), energy storage (Sharma and Santasalo-Aarnio, 2025), shielding from cosmic radiation (Li *et al.*, 2025), ecc.) In other words, there is an obvious focus on immediate and potentially catastrophic hazards with respect to psychophysiological aspects, such as colour perception, light quality, or the overall sensory experience of the habitat.

In 1988, NASA conducted extensive research on human factors in space design (Wise and Wise, 1988), analysing over 200 articles that dealt with colour and man in various aspects of their interaction. This review resulted in a number of interesting considerations related to the design of the spaces, such as:

- The practice of avoiding decisions based on preferences/taste. Because there are too many variables to keep in consideration;
- Allow personal choices on colour for the astronauts, to promote a «sensation of being in control»;
- Use colour always for his readability and meaning (like red/green), but never for aesthetic choice;

- Visual mechanisms (Purkinje shift, colour constancy, and the position of rods and cones on the retina) must be taken into account and, if possible, used to improve the readability of the environment.

These and other considerations have proved helpful in the choices for the construction of extra-atmospheric living spaces. Still, the studies considered almost all referred to the regular interaction between man and colour. Microgravity is not considered, and therefore, a natural question to ask is: In microgravity, does our perception of light and colour vary? And if it does vary, does it affect our choices and habits? Are adaptation strategies applied? The research that addresses these questions is unfortunately not as extensive as that considered by NASA during its colour review; however, some research can provide interesting food for thought.

Simulated and Analog environments

Space stations today are primarily occupied by laboratory facilities, where astronauts conduct numerous tests to evaluate as many study parameters that form the basis of space exploration. In addition to the physical conditions they have at the beginning of the mission, astronauts must maintain excellent psychophysical performance to conduct the numerous tests required at space stations. In addition, they must be able to respond quickly and effectively to adverse and unexpected conditions. The various physical problems we mentioned earlier are partly counteracted by physical exercise.

To predict the perception of space, also from a psychological point of view, an approach often used is that of simulated environments. Realistic mock-ups of space station spaces are created, and subjects are used to evaluate their reactions under certain conditions. Isolation experiments such as the *Mars500* (Basner *et al.*, 2013), in which a group of volunteers lived for 520 days in a complex that simulated a station on Mars, or the *Human Exploration Research Analog (HERA)* of NASA (NASA, 2025), which is intended to pave the way for bases on the Moon and Mars.

Simulated spaces, moreover, are not only isolated mockups in which subjects are locked up for a given period of time, but also places on Earth that, due to their characteristics, are considered *Terrestrial analogue sites*. Places whose unusual conditions (such as the presence of specific microorganisms, extreme thermal conditions, etc.) make them particularly desirable for this type of research. Some mock-ups of space stations or laboratories where these factors are studied are built in places such as the Palmer and McMurdo stations in Antarctica, precisely to simulate portions of the mission, to discover how human health reacts to adverse conditions, to accelerate the development of countermeasures, and to develop new technologies. However, the fundamental problem remains that, even when these mock-ups faithfully simulate the spaces of space stations, microgravity is not taken into account in many cases.

There are mainly three approaches to simulate microgravity:

- *Water immersion* – which, however, requires specific equipment and is not optimal for simulating microgravity in the interiors of space stations;
- *Head Down Bed Rest (HDBR)* – an approach that involves having rest sessions on an inclined plane. A setting that wants the subject's head lower than the rest of the body, in order to have a displacement of fluids that induces the *sensation* of microgravity, as in tests VaPER of 2017 (Clément *et al.*, 2022) and AGBRESA of 2019 (Frett *et al.*, 2020);

- *Parabolic Flight* – a method that allows for remaining in microgravity conditions for a short time, around 20 seconds. A colour perception test using this method will be described in the next section.

With regard to colour perception, we can mention studies conducted in simulated environments, such as virtual reality. In a 2023 study (Jiang *et al.*, 2023), the researchers tested the visual tracking ability on 54 subjects (non-astronauts) using the HDBR method, with an inclination of 12° for short periods of time (three hours) instead of very long periods as those used at NASA (30 days for VaPER and 60 days for AGBRESA) and this was done to reduce the time of the experiment. During the various phases of the test, the subjects observed simulated environments (the International Space Station ISS and the Chinese "Tianhe" station) using a virtual-reality headset. The colours used were very saturated, and what the researchers verified was the visual strain and eye tracking ability of the subjects. The study concluded that HDBR (and possibly microgravity as well) affected the subjects' tracking ability and suggested that cool colours made tracking more effective and less effortful than warm colours. The study, however, presents some points that could be further improved: it was conducted with a very pronounced inclination and in a short time, the subjects, were not astronauts and the environment was virtual; in such a context, only physiological parameters can be considered, while psychological parameters might be too influenced by factors that can compromise the real response of individuals (no EEG or ECG were administered). Moreover, the colours used were highly saturated, and their use in extreme conditions, such as those of a space situation, must be carefully evaluated because saturated colours can affect arousal (Wilms and Oberfeld, 2018). The study does not dwell on changes in colour perception in microgravity states simulated by HDBR.

Despite the unanalysed aspects, the study by Jiang and colleagues used a fundamental approach in trying to frame the problem, namely the attempt to recreate microgravity. In a previous study (Jiang *et al.*, 2020), the themes of light and colour in the spaces of space stations (sanitary area) were explored, but the microgravity factor was excluded entirely. In this type of work, research is conducted in a simulated space on the choices of subjects (who were also not astronauts) and on the psychological aspects induced by the colour within it. The reconstruction of a mockup, even if it is extremely faithful within a space station, still lacks the microgravity factor. This can introduce an unquantifiable discrepancy between the results obtained and those that astronauts might experience in real-world contexts. It is not difficult to imagine that simulations conducted in Earth-based environments share this crucial point. However, some studies have sought to address this problem by inducing a perception of microgravity with HDBR.

Parabolic Flight

Parabolic flight allows microgravity to be simulated on board an aircraft for short periods (20-25 seconds). The aircraft performs a bell-shaped flight at the peak of which the trajectory cancels out gravity. In this brief period, the perception of microgravity is identical to that experienced permanently on space stations.

There are not many studies in the literature that have addressed light and colour during parabolic flight. *White's* work on the effects of temporary weightlessness on the perception of contrast certainly paved the way (White W. J., 1965), as did *Kitayev-Smik's* on colour perception and saturation (Kitayev-Smik L. A., 1972). Even more recently, attempts have been made to highlight how microgravity can affect colour perception using parabolic flight (Schlacht, Brambillasca and Birke, 2009). Anche il test di *Schlacht* e colleghi sembra confermare l'esistenza di alcune modifiche percettive.

However, some considerations on these results must be made. According to White's results, our visual system appears to reduce the contrast required to discriminate a target, especially at low luminance levels. With regard to colour, *Kitayev-Smik* points out that, while highly saturated yellow and red are perceived with the same brightness, blue tends to appear darker and colours obtained by the sum of tints (yellow-blue), instead of green, tend to be classified as yellow. The test conducted by *Schlacht* and colleagues also reported differences in chromatic perception; the colour results differ from those of *Kitayev-Smik*. In the most recent paper, blue was more distinguishable than red, and an increase in perceived saturation in yellow was observed. The results also seem to confirm a general reduced sensitivity to luminance. The reasons for these results could be sought in the modified blood supply to the retina or in a possible change in the shape of the lens due to the sudden change in gravitational conditions. As early as 1963, *White and Monty* described the visual deficits resulting from large accelerations (White and Monty, 1963).

Parabolic flight tests have a disadvantage due to the very nature of the test, namely, the issue of statistical significance. It is not possible, for practical reasons, to conduct the test on numerous people, as these flights usually have a limited number of passengers. In addition, the cost of the experiment itself limits its repeatability over large numbers. However, the results obtained in these studies are significant, as they show that variations in gravitational conditions lead to changes in chromatic and luminous perception. However, a consideration must be made regarding a factor that *Popov and Boyko* had already expressed in a research on *Parabolic Flight* (Popov, V. and Boyko, N., 1967): our visual system is able to put in place mechanisms to compensate for the effects of unexpected changes, such as, for example, chromatic constancy in simultaneous contrast.

If the information we obtain from these tests is seen in preparation for colour design in environments where microgravity is the normal and permanent condition, we cannot fail to take into account the corrections that are applied automatically and continuously by our brain, effects such as chromatic adaptation over time (Gupta *et al.*, 2020) or even adaptation to extraordinary conditions such as the reversal of the field of vision (Sachse *et al.*, 2017). While the visual system responds to changes in gravity, this does not guarantee that such changes can be felt over a prolonged period.

Pre- and post-mission clinical analysis

Another interesting approach to evaluating microgravity on light and colour is the one presented by Mader and colleagues (Mader *et al.*, 2011), in which clinical tests were conducted on seven astronauts at departure and after six months of the mission on the space station. The test clearly highlighted the adverse effects of microgravity on the subjects' bodies. Clear signs of damage to the eye appeared: optic disc oedema, globe flattening, choroidal folds, cotton wool spots (CWS), nerve fibre layer thickening, decreased near vision and hyperopic shifts. In addition, the authors administered a questionnaire to 300 astronauts returning from missions (long or short), after which 29% reported losing visual acuity at a distance and 69% at near. In many cases, the damage has been proven to be irreversible. Of the seven astronauts who underwent a medical examination, none complained of any noticeable decrease in the ability to perceive colours.

These results could be consistent with the brain's correction of visual perception described in the previous paragraph. It is difficult to prove that astronauts did not, in fact, undergo any change in colour perception; however, within six months, even if there was one, it could have been dulled by the cognitive mechanisms of our visual system.

Anonym expert consensus

In a 2022 study, *Jiang's* group of researchers reanalysed the health area of space stations (*Jiang et al.*, 2022), which is rightly recognised as one of the areas that can induce the most stress in the astronaut crew. In this case, microgravity was not simulated using HDBR or a reconstruction of space; instead, a Delphi study approach was used. This type of method is significant when the material on the subject is scarce, or not in agreement, or the organisation of meetings or tests is not favourable or practicable. After a careful initial selection phase, the authors identified a pool of 30 experts with over 10 years of experience, including colour designers, colour-measuring experts, space engineers, and astronaut trainers. The experts were called upon to evaluate the colour palette for the design of the stool and urine disposal area, the negative-pressure machine, and the control interface (waste and decompression machine). The primary stressors recognised for this area were: confined space, odours, time of use, operational complexity, and, of course, environmental colour.

The experts, independently and over ten weeks, without confronting each other, formulated hypotheses and chose colour palettes based on the most pertinent observations from their experience. The authors collected the responses, qualitatively and statistically analysed them, identified convergences and outliers, and produced a summary report that was sent to the experts. The latter can see the results (anonymous) and decide whether to revise or modify their proposals based on them. This iterative process, managed by the authors, leads ideas to converge naturally, and anonymity allows experts to maintain independent judgment, avoiding biases arising from authority or the recognition of dominant hypotheses due to expert hierarchy.

This process led to the identification of a valid solution for the chromatic aspects of the health area of the space station, specifically, for the environments with hygienic devices, a palette of light colors (blues, greens and grays) with low saturation was chosen, while for the operational interfaces, the choice fell on bright and high saturation colors (red, yellow, green and blue) used only locally to increase the readability of the instructions without causing visual overload.

Conclusions

In this article, we observed some of the procedures used by researchers to evaluate the interaction between light, colour, environment, and human beings in the context of research on microgravity for the design of future possibilities in space exploration.

Obviously, the best choice for conducting this type of research would be to execute the tests directly on the space stations, assessing individuals' psychological and clinical conditions at the beginning, during, and at the end of the mission. However, the evaluation of the psychological impact of colour (which can be distorted by its reduced perception) is not commonly taken into account in the tests described in the literature.

The use of various shades of white light (Correlated Colour Temperature) is already employed in an extra-atmospheric environment; the principles of Human-Centric Lighting (HCL) are nevertheless proving valid. However, it should be emphasised that the channel that leads to physiological regulation (used by HCL) is non-image forming and does not imply vision (and consequently, the meaning of what is observed that leads to psychological response), which instead follows a different path in our body (*Sinisalco, Bortolotti and Rossi, 2022*).

A test to evaluate the perception of light and colour in the context of microgravity should therefore be scalable, depending on the available resources. Simulated spaces (where, possibly, techniques such as HDBR are used) should allow for as quantitative an assessment of discrepancies as possible, using

tests on validated samples, such as the *Farnsworth-Munsell* (Farnsworth, 1943), or tools such as the anomaloscope, to determine whether it is possible to detect changes in perception.

Another essential precaution would be not to limit the evaluation of feedback to the questionnaires administered to the subjects, but to involve a group of experts, who, similarly to what was described in the Delphi study, can interpret the results and suggest solutions to any critical issues. Multiple considerations by experts from various fields of the gathered data might allow the researchers to evaluate many aspects that a single specialised team might not notice easily.

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