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Multidisciplinary Contributions

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Edited by Filippo Cherubini and Andrea Siniscalco

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Between the lines: a survey to evaluate how light color gradients affect emotions

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Abstract

This article explores the hypothesis that light, through different color gradients within it, can influence individuals' moods and emotions while doing simple operations like reading a text. This premise is rooted in the theory of color psychology, which suggests that colors can evoke certain emotions and behaviors. Light, being a spectrum of colors, may thus have the potential to influence mood and emotions, particularly during reading when the reader's engagement is high and they are more susceptible to subtle environmental cues. To test this hypothesis, this study employs a series of psychological questionnaires designed to measure participants' emotions, arousal, and anxiety levels. These questionnaires are administered after exposure to different lighting conditions, with varying brightness levels, CCTs, and color gradients. The aim is to establish a correlation between the lighting conditions and the emotional and behavioral responses of the participants. The research builds on previous studies that have demonstrated the influence of light on mood and cognitive performance. Küller (Küller *et al.*, 2006) found that light quality affects employees' mood and well-being in work environments. Knez (Knez, 2001) highlighted how different color temperatures of light can influence cognitive performance and mood. Recent research (Bortolotti *et al.*, 2022) has delved deeper into the influence of perceived color lightness on psychological functions. This research investigates how the perception of color lightness can affect various psychological processes, adding another layer to our understanding of the complex relationship between light, color, and human psychology. The study examines how light, particularly its color and intensity, can influence mood and emotions through its impact on circadian rhythms and the production of hormones such as melatonin and serotonin. Many researches have shown that intrinsically photosensitive retinal ganglion cells (ipRGCs) play a crucial role in this interaction, influencing circadian rhythms and acute behavioral responses to light. As a premise for this research, we have raised the question of whether colour and light affect physiology and psychology in proportional ways. Our research suggests a complex interplay between the physical properties of light and colour and their psychological and physiological effects, highlighting the need for a nuanced understanding of these relationships. The findings of this study could have implications for various fields; optimizing lighting conditions in education and office settings could enhance reading comprehension and productivity. In conclusion, this article presents a comprehensive investigation into the potential influence of light, through its color gradients, on individuals' moods and emotions during text reading. Integrating psychological measures with exploring physiological mechanisms provides a thorough and credible understanding of this phenomenon.

Keywords: Color, Light, Design, Emotion, Behaviour.

Introduction

Human perception of the physical world is predominantly visual. Despite extensive research on the nature of light and vision, the design of lighting for individual well-being is a relatively recent discipline. Historically, lighting design focused on optimal illumination levels for productivity and energy efficiency. However, scientific evidence from the 1990s onwards has highlighted the significant role of light and color in influencing human well-being and performance (Cajochen *et al.*, 2005).

The phenomenon of vision has been studied since the fifth century BC, but it is only in modern times that we have achieved a satisfactory description of the nature of light and how our visual system interprets it. For decades, the primary concern of designers was to ensure optimal lighting levels for workers, passersby, or tourists, with attention to energy savings where possible. The scientific proof that light and color actively contribute to well-being and performance had to wait until the 1990s to be considered at a production level. Laws and standards have traditionally focused on the quantitative aspects of light and only recently have begun to include the psycho-physiological well-being of humans. Recent advancements in human-centric lighting have further emphasized the importance of considering both visual and non-visual effects of light. Human-centric lighting aims to support human health, well-being, and performance by mimicking natural light patterns and adjusting artificial lighting to align with human circadian rhythms (Houser et al., 2021). This approach recognizes that light influences not only vision but also various biological processes, including sleep, mood, and cognitive function (Jalali *et al.*, 2024) among others. The impact of light on human physiology is mediated through specific retinal structures known as Intrinsically Photosensitive Retinal Ganglion Cells (IPRGCs), which contain the photosensitive protein melanopsin. These cells play a crucial role in regulating the circadian rhythm by influencing the production of melatonin, a hormone that governs the sleep-wake cycle (Hattar *et al.*, 2002). The suppression of melatonin by light exposure, particularly blue light, has been well-documented and is a key factor in designing lighting systems that support healthy sleep patterns (Brainard *et al.*, 2001). Moreover, the psychological effects of light and color are equally significant. Studies have shown that different colors can evoke various emotional responses and influence mood and behavior. For instance, warm colors like red and yellow are often associated with feelings of warmth and excitement, while cool colors like blue and green are linked to calmness and relaxation (Boyce, 2014). The integration of these psychological insights into lighting design can enhance the overall well-being and productivity of individuals in various environments, from workplaces to healthcare facilities. The design of lighting systems that consider both the physiological and psychological effects of light and color is essential for promoting human well-being. By understanding the complex interplay between light, color, and human responses, we can develop lighting solutions that not only meet functional requirements but also enhance the quality of life.

Literature Review

Light affects human physiology through mechanisms distinct from vision. Specific retinal structures, Intrinsically Photosensitive Retinal Ganglion Cells (IPRGCs), contain melanopsin, a photosensitive protein that influences the circadian rhythm by suppressing melatonin production (Hattar *et al.*, 2002). This physiological response differs from the psychological perception of color, which is processed in the cerebral cortex (Thapan, Arendt and Skene, 2001). The relationship between light and human physiology has been thoroughly investigated. IPRGCs, which contain melanopsin, perform phototransduction similarly to other photoreceptors like cones and rods. However, the electrical impulse created by these cells follows a different path from vision, being conveyed through the retina-hypothalamus tract to influence the pineal gland and suppress melatonin. This hormone is crucial in regulating the human circadian cycle (Hattar *et al.*, 2002).

These studies highlight a fundamental aspect, light influences humans physiologically through mechanisms that differ significantly from those of vision, except for the initial segment in the eye. In vision, after phototransduction by cones and rods, the electrical signal is sent to the optic nerve towards the cerebral cortex, where the psychological sensation of color is formed. This difference is also evident in human sensitivity to different wavelengths of light (different colors). In the spectral sensitivity curve (which colors we see best), the maximum response coincides with 555 nm (yellow-green), while in the sensitivity curve concerning the circadian cycle, the maximum sensitivity corresponds to 460 nm (blue) (Thapan, Arendt and Skene, 2001). The differences between these two mechanisms are reflected in human color perception. It is not uncommon for an individual to associate the term "activating" with warm and vibrant colors like yellow and red, while physiologically speaking, activating colors are at the opposite end of the spectrum (blue). Is it possible that the psychological interpretation we give to colors is so different from the one that influences our physiology? Considering a holistic approach, a complex organism like ours should find at least some points of convergence between these two mechanisms. Unfortunately, studies on the psychology of colors often lack the methodological and scientific rigor typical of those on physiology, and although there is a vast bibliography, it is challenging to extrapolate assumptions suggesting a proportional relationship between the two mechanisms. Recent research has expanded our understanding of how light affects human physiology beyond the visual system. For instance, studies have shown that exposure to blue light can significantly impact alertness and cognitive performance, which is particularly relevant in designing lighting for work environments (Cajochen *et al.*, 2005). Additionally, the role of light in regulating mood and emotional states has been explored, with findings indicating that light exposure can influence the production of serotonin, a neurotransmitter associated with mood regulation (Lambert *et al.*, 2002). The psychological effects of light and color are equally significant. Studies have shown that different colors can evoke various emotional responses and influence mood and behavior. The integration of these psychological insights into lighting design can enhance the overall well-being and productivity of individuals in various environments, from workplaces to healthcare facilities.

After an extensive research phase (Siniscalco, Bortolotti and Rossi, 2022) and an analysis of the issue typical of psychological research (Siniscalco and Bortolotti, 2023), we designed a test whose primary objective of this study is to evaluate whether colored light has psychological effects that are proportional to all evaluated subjects. Researchers hypothesize that psychological responses to colored light may differ from physiological responses. This finding could lead to new awareness when implementing specific applications of colored light to mitigate psycho-emotional discomfort in Human-Centric lighting designs. By understanding the complex interplay between light, color, and human responses, we can develop lighting solutions that not only meet functional requirements but also enhance the quality of life.

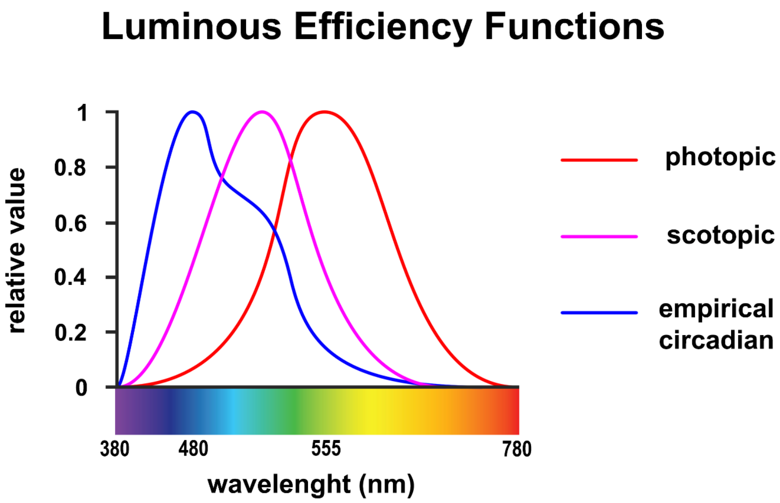

Fig. 1 - The three curves represent the efficiency of light in different aspects. The photopic curve is the human sensibility to color in normal lighting conditions. The scotopic curve is the sensibility to color in very dim light conditions. The empiric circadian curve (derived from the studies of Brainard and Thapan) shows the sensibility to the spectrum of our organism in relation to the physiological reaction to light. While the first two curves are based on vision (thus implying the involvement of the meaning of what the subjects are seeing and interpreting), the last curve is unrelated to vision and describes the efficiency of suppressing Melatonin (sleep hormone) without the involvement of information elaboration by the brain.

Test design

The test aimed to verify the psychological response of the subjects under different conditions of colored lighting. The setup of the experiment involves reading a text that is not related to the test but that requires concentrated reading. The text (an excerpt from a specialized magazine) has been selected so as not to arouse particular emotional reactions. The subjects were in a classroom, and their positions were placed in front of a wall 220 cm away, which served as a secondary light source. The table on which the text to be read was present was illuminated by the direct light of a "tunable white" luminaire (obtained with LEDs converted by phosphors) placed perpendicular to the surface at a distance of 220 cm. This luminaire was able to produce a range of color temperatures from warm (2700 K) to cool (6500 K) and a surface illuminance of 340 lux for warm light and 452 lux for cold light. In addition to the "tunable white" light, the system included a Formalighting Galileo 390 projector, placed behind the subjects, capable of illuminating the wall in front of them with colored light obtained through the mix of RGB LED sources. The positioning of the light sources was designed to provide a predominantly white light on the task and a colored light peripherally in the field of view. The light intensities have been empirically modulated in order to compensate for the different efficiencies of the lighting sources, ensuring natural lighting on the task but an appreciable chromaticity in the peripheral area of the visual field (Figure 2).

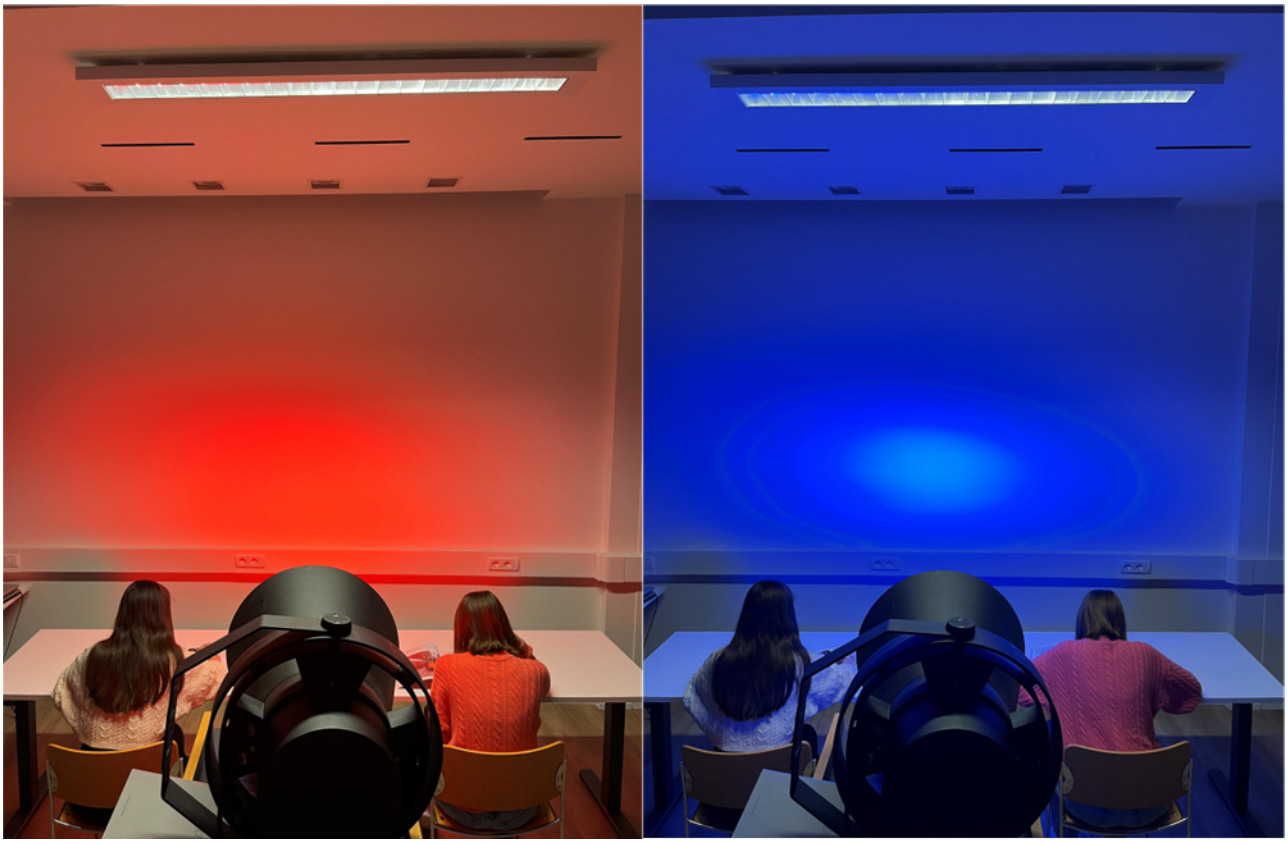

Fig. 2 - Two subjects read the assigned text in two different lighting conditions. On the left, we have a white light at 2700K and a red light, while on the right, we still have the white source at 2700K but combined with a blue light.

The test was administered to groups of two participants at a time, who were engaged in the reading activity for ten minutes. The test was divided into two five-minute sessions, interspersed with a two-minute break during which the subjects were prohibited from using electronic devices. Each session involved exposure to a light scenario for 145 seconds, followed by another scenario of the same duration. The transition between the two lasted 10 seconds. The lighting scenarios included tunable

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white light and colored light, except for one control scenario, which contained only tunable white light. The scenarios are represented in Figure 3.

01A	145s	10s	145s
from	Warm white	to	Cool White
from	Red	to	Blue
on surface	233 lux		204 lux

01B	145s	10s	145s
from	Cool White	to	Warm white
from	Red	to	Blue
on surface	186 lux		201 lux

04A	145s	10s	145s
from	Warm white	to	Cool White
from	Green	to	Magenta
on surface	217 lux		216 lux

04B	145s	10s	145s
from	Cool White	to	Warm white
from	Green	to	Magenta
on surface	213 lux		213 lux

02A	145s	10s	145s
from	Cool White	to	Warm white
from	Blue	to	Red
on surface	204 lux		233 lux

02B	145s	10s	145s
from	Warm white	to	Cool White
from	Blue	to	Red
on surface	201 lux		186 lux

05A	145s	10s	145s
from	Cool White	to	Warm white
from	Magenta	to	Green
on surface	216 lux		217 lux

05B	145s	10s	145s
from	Warm white	to	Cool White
from	Magenta	to	Green
on surface	213 lux		213 lux

03A	145s	10s	145s
from	Cool White	to	Cool White
from	Blue	to	Red
on surface	204 lux		186 lux

03B	145s	10s	145s
from	Warm white	to	Warm white
from	Red	to	Blue
on surface	233 lux		201 lux

CONTROL A	145s	10s	145s
from	Warm white	to	Cool White
on surface	340 lux		452 lux

CONTROL B	145s	10s	145s
from	Cool White	to	Warm white
on surface	452 lux		340 lux

Fig. 3 - Diagram that reproduces the lighting scenarios used during the test. The first three groups were chosen to depict chromatic changes to stimulate the transition from a "warm" to a "cold" environment. Groups 4 and 5, on the other hand, used colors that, on the CIE 1931 chromaticity diagram, have an orientation perpendicular to the one used in the first three groups. Finally, the control group was used to observe whether even the correlated color temperature alone was able to highlight a clear preference in the subjects.

This test presents the first phase of the research's investigation. Therefore, no personal data were collected on the subjects except that they were all males and females between 18 and 25 years old. Normal color vision was required to participate in the test.

Forty-eight subjects took part in the test: ten for each of scenes 1, 2, and 3; six for each of scenes 4 and 5; and six for the control groups.

The first three setups were designed to understand how subjects responded emotionally to light gradients that ranged sharply from a "perception of a warm atmosphere" (warm white and red) to a "perception of a cold atmosphere" (cold white and blue). Then, we tried to cross the various elements (from cold white and red to warm white and blue) to understand if the subjects had a much clearer response to that of the previous scene. Other combinations were also tried, and even two different colors (green and magenta) were used to understand if they were able to bring out clear preferences, such as scenarios with colors more related to the perception of a hypothetical "environmental temperature."

At the end of the exposure to light, each person was subjected to a structured interview that contained general questions about their sleep quality, their routine related to exposure to artificial light, and their awareness of the influence of light on their biology.

Finally, the questionnaire asked about evaluating the light gradient during the tests. The subjects had to indicate whether they perceived an improvement or worsening in the quality of light.

Results

The majority (98%) of respondents stated that they are aware that light can change their mood and their ability to concentrate (96%). To avoid any bias in providing answers to the questionnaire, the subjects were not made aware of the purposes of the test (except through a web page accessible via a QR code at the end of the tests).

Regarding the test, the questions about color preferences that could help to promote concentration did not provide clear results for identifying specific color combinations, covering almost all options in the spectrum.

Other questions related to the ability to discriminate colors and color temperatures (CCTs) during tests. A good ability to distinguish differences related to saturated colors was observed, while variations in color temperature were much more difficult to capture.

The aim was to understand whether the chromatic variation caused an emotional reaction that could be perceived as an improvement or a worsening in the various scenes. The results relating to the various scenarios are represented in Figure 4.

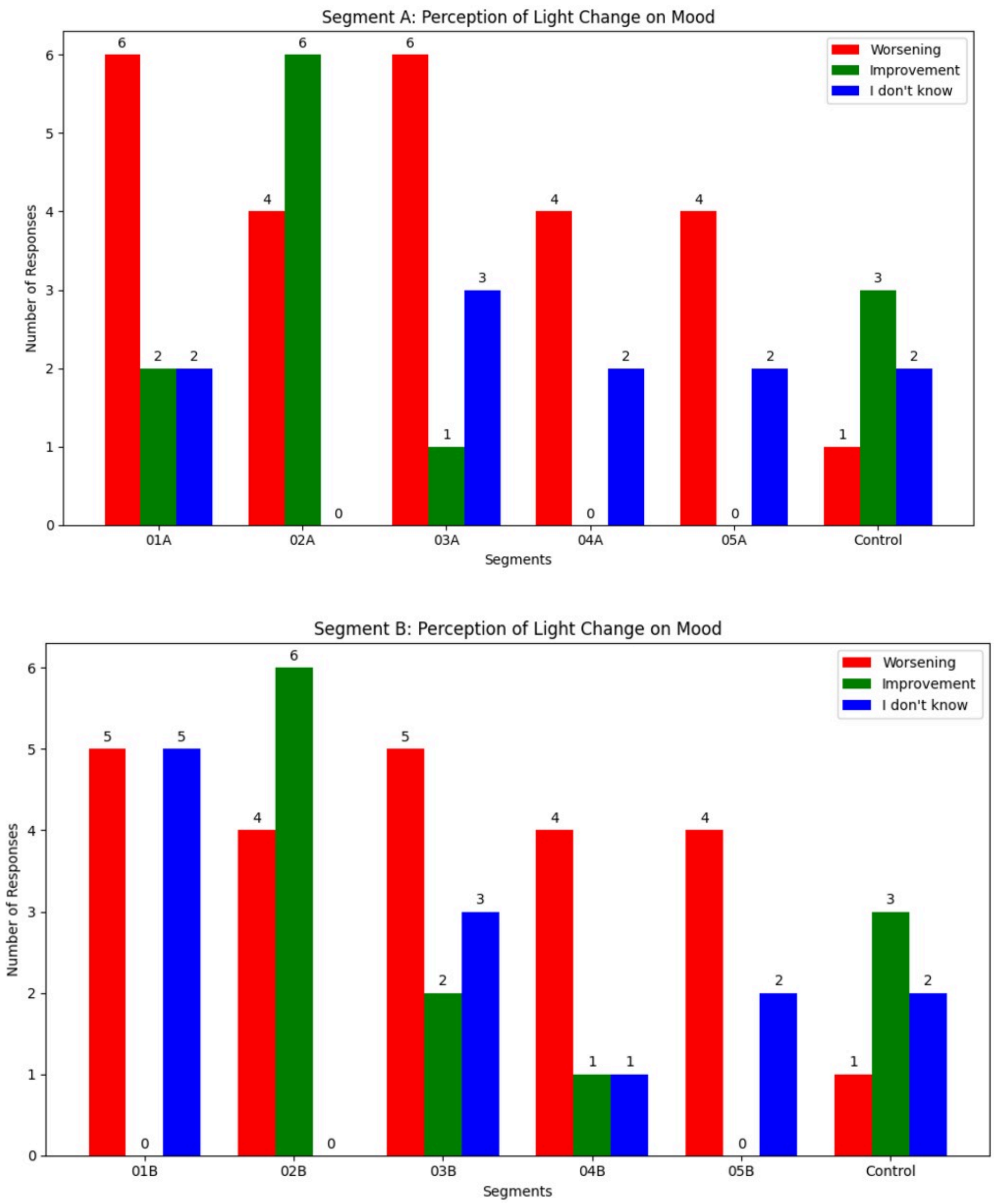

Fig. 4 - Diagram showing the results extrapolated by the questionnaires. The results refer to the color scenarios described in Figure 3.

Conclusions

The test results do not allow for a clear direction regarding emotional reactions to the colors presented. Numerous factors may have influenced this outcome. After reworking the questionnaires, it was clear that the participants were all aware of the influence of light on the well-being of individuals. Having participated in a test on light and color with such awareness plausibly constitutes an early form of bias that could have been instilled in the subjects. In fact, from the questions asked for the Q&A section of the test, it is clear that some of the subjects are aware of the mechanisms of influence of light on human physiology. This may have led to reacting to the colors presented in a way that is not entirely neutral.

The only scenes that showed a significant preference for a gradient were those ranging from a color context clearly identifiable as "cold" to one identifiable as "warm." This preference, however, may have been influenced by the season (the test took place in mid-November) and the temperature of the space where the test took place (around 19°C). Furthermore, the immobility of the subjects may have contributed to creating thermal discomfort, which in the end may have led them to prefer the transition from "cold" to "warm." The colors that could not be traced back to the "climatic" aspects of space, in fact, did not give precise results in terms of preferences. Even in the control groups, where saturated colors were excluded, exposure to a light gradient between "warm white" and "cool white" did not show appreciable preferences.

The conditions of the test themselves may have affected the psychological component of the subjects. The space was a classroom. However, there were only two people present, and the lighting used did not correspond to what the subjects (university students) were used to. This may have created an alienating effect that may have affected the emotional state. The fact that there were two subjects at a time may also have played a role; the couples who arrived independently and were not selected could have been friends, classmates, fiancés, or strangers. Being seated next to each other in an unusual setting may have influenced the emotional state. Single tests and a less characterized space (perhaps a mock-up of a residential space) would probably have had a less impactful effect on the subjects.

The choice to use the wall in front of the subjects as a secondary light source, which reflected the colored radiation, made the shade of white used for reading less identifiable. Although slight, this color pollution made it very difficult for the subjects to discriminate the CCTs used in the test.

Finally, the number of subjects was not enough to cover such a large number of scenes. To have a statistically more relevant number of samples, it would have been better to focus only on one type of scene (e.g., hot/cold scenes).

In conclusion, although we have not obtained results that allow us to work on universal guidelines on the emotional well-being of human beings through light and color, the results have shown that there is undoubtedly a correlation between these factors. The test design phase should be reviewed, and the tests should be repeated on a larger sample of subjects.

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