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ANVUR Agenzia Nazionale Valutazione sistema Universitario e Ricerca
APeJ Academic Publications eJournal
BASE Bielefeld Academic Search Engine
DBH Database for statistikk om høyere utdanning
DOAJ Directory of Open Access Journals
EZB Elektronische Zeitschriftenbibliothek Regensburg
JURN Search tool for open access content
ROAD Directory of Open Access scholarly Resources

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PEER REVIEW PROCESS

All articles submitted to the Color Culture and Science Journal are peer-reviewed according to the following procedure:

First review level

The Associate Editors evaluate each article to determine if the topic and content are of interest to the journal. Once the article passes the initial review, the Associate Editors select several reviewers from the Editorial Board based on their expertise in a particular subject area or topic.

Second review level

Two or three experts review each article with a blind peer-review process where the reviewers are kept anonymous. Reviewers are asked to evaluate the manuscript based on the following criteria:

- Originality
- Relevance to journal's aims and scope
- Technical merit and/or validity
- Soundness of methodology
- Completeness of the reported work
- Conclusions supported by the data
- Correct acknowledgment of the work of others through reference
- Effectiveness of the manuscript (organization and writing)
- Clarity of tables, graphs, and illustrations
- Importance to color researchers
- Relevance to color practices

If the article is accepted with major revisions, the author(s) are asked to improve the article according to the reviewers' suggestions. The revised article will then be submitted for further review.

After collecting the reviewers' reports, the Associate Editors recommend the acceptability of the article to the Editor-in-Chief.

TOPICS

The CCSJ accept papers on a wide range of topics on color, including and not limited to the following:

1. Color and Measurement/Instrumentation. Colorimetry, photometry and color atlas: method, theory and instrumentation; quality control and food coloring, dyes, organic and sustainable color.
2. Color and Digital. Reproduction, management, digital color correction, image processing, graphics, photography, film and video production, printmaking and 3D print, artificial vision, virtual reality, multispectral imaging, data visualization. Light field imaging. Multi-sensor fusion. Color localization, recognition, HDR imaging, ADAS systems.
3. Color and Lighting. Metamerism, color rendering, adaptation, color constancy, appearance, illusions, color memory and perception, color in extra-atmospheric environments, lighting design, lighting technologies, visual comfort.
4. Color and Physiology. Mechanisms of vision in their experimental and theoretical aspects, color vision and color appearance, deficiencies, abnormalities, clinical and biological aspects, synesthesia, health, well-being.
5. Color and Psychology. Phenomenology of colors, color harmonies, color & form, perceptive, emotional, aesthetic, and diagnostic aspects.
6. Color and Production. Food and beverages, agriculture, textiles, plastic materials, ceramics, paints, gemology, color in the food industry.
7. Color and Restoration. Archaeometry, painting materials, diagnostics, and conservation techniques, restoration, and enhancement of cultural heritage.
8. Color and Environment. Representation and drawing, urban planning, the project of color, architecture, interior design, landscapes & horticulture, color and architectural syntax, territorial identities, biodiversity.
9. Color and Design. Furniture, CMF design, fashion, textiles, textures, cosmetics, food design, museography.
10. Color and Culture. Arts and crafts, history, philosophy, aesthetics, ethno-anthropology, graffiti, geology, sociology, lexicology, semantics, anthropology of vision, food culture and heritage, color naming.
11. Color and Education. Pedagogy, didactics of color, aesthetic education, artistic education.
12. Color and Communication/Marketing. Graphics, communication, packaging, lettering, exposure, advertising.

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Editorial

Dear Readers[1],

With volume 15, issue 2, we enter our Journal's tenth year. Since our start, we have published 14 volumes for 17 issues. I wish to remember that since 2019 the CCSJ has been based on OJS for better indexing of the published articles through the OAI-PMH protocol. In 2020 we refined our archiving policy to guarantee long-term access to our issues, making agreements with the Biblioteca Nazionale Centrale di Firenze. Starting in 2015, we applied for the blind peer review, and in 2016 we used the DOI system.
As you can see on our home page, our Journal is indexed and included in the databases of ANVUR, APeJ, BASE, DBH, DOAJ, EZB, and JURN. We are constantly working to improve this in the future. I remember we are a "diamond open access"; the Journal is free for readers and authors. This result is possible thanks to the voluntary support of many people around the world: the reviewers of the editorial committee, the associate editors, the deputy editor Alice Plutino, Andrea Siniscalco, the vice-president of our publisher, Associazione Italiana Colore, for the graphic support and last but not least Clelia Gotti for her work in the editorial office.

As you can also read in this issue, our Journal's peculiarity is to collect papers on color and related areas in a multidisciplinary way. In our complex peer review process, we have articles ranging from the science of colorimetry to the culture of color in art history. These papers have very different styles and ways of writing, as rich and multidisciplinary as the team of peer reviewers on our editorial board.

We have three papers with studies regarding color and lighting indoor.

Ayse Nihan Avci and Saadet Akbay, in their paper *A Review based on OLED Lighting Conditions and Human Circadian System*, present a literature review on how OLED lighting, instead of the more well know LEDs, can influence the human circadian system in terms of different characteristics of lighting in an indoor environment.

In the article *Virtual interior environment: Influence of colour on the sense of immersion*, Firdevs Gökmenoğlu and Saadet Akbay investigate how the sense of immersion in virtual interior environments varies based on hue, saturation, and lightness and examine the extent to which color dimensions influence the sense of immersion in virtual environments. They present interesting findings regarding the effects of lightness variations.

A study on children's color preferences, applied to a classroom environment, in generic terms and a school context, through an experiment in digital simulation with the CAVE and digital color samples, is presented by Camilla Giani and Cristina Boeri in their paper *An experimentation on children's colour preferences in generic terms and applied to a school context*.

[1] Colour (UK) or Color (US)? In our Jurnal, both terms are allowed as long as they are congruent within an article. The exception is given by this editorial in which I use color as on our website. Still, sometimes colour could appear to respect the original title of a paper.

The importance of color in manufacturing and marketing is presented in four articles ranging from the lipstick market to textile and neuromarketing.

In the paper *A comparative study of lipstick shades preferences by geographical areas*, Hélène de Clermont-Gallerande, Emmanuelle Mauger, and Nicolas Rolland present research, based on principal components analysis, regarding the 20 best-selling Chanel lipsticks in France, Italy, the UK, the USA, Asia, and South America. They discovered that Italy and France are the markets most representative of lipstick shades.

Isabel Espinosa-Zaragoza, in the article *“Perpetual plum": Colour naming strategies in Maybelline's lip products*, presents a study dealing with the color terminology for lipstick color names by Maybelline through the word formation processes and the imagery exploited. The analysis revealed the predominance of two nomenclatures: morphosyntactic and semantic, and the paramount importance of color terminology in cosmetic verbal identity.

The article *Colour, texture, and luminance: Textile design methods for printing with electroluminescent inks*, written by Delia Dumitrescu, Marjan Kooroshnia, Erin Lewis, and Kathryn Walters, presents research exploring the properties and potential of three textile print methods for electroluminescent inks as smart colors for textiles, proposing a set of techniques to create various color mixtures and design complex patterns.

We also have a review of scholarly articles focusing on the use of color in marketing, identifying main features and highlighting limitations. Practical implications and future directions are outlined, with a particular interest in neuromarketing, presented in the paper *The promise of color in marketing: use, applications, tips and neuromarketing* by Alessandro Bortolotti, Loreta Cannito, Stefano Anzani, and Riccardo Palumbo.

In the field of colorimetry, Cristian Bonanomi and Kedar Sathaye focus on the optical performance evaluation of a camera monitor system for (Advanced Driver-Assistance Systems (ADAS) in terms of the lighting system, test patterns, imaging colorimeter and software, with measurement according to standard ISO16505:2019, in their article *Imaging colorimeters to evaluate Camera Monitor Systems image quality*.

Finally, an important historical study, *Enquiry into the colours of the MoGao murals at DunHuang from the Sui Dynasty, the Tang Dynasty and the Five Dynasties period*, is presented in the paper by Elza Tantcheva-Burdge, Zhaohua Lei and Vien Cheung. They have done historically enquires on the appearance of colors used in the representative system of the MoGao murals at DunHuang, in three dynasties, to better understand these murals as emblematic of Chinese civilization.

Enjoy the reading.

March 2023
The Editor-in-Chief
Maurizio Rossi
Full professor of Design
Politecnico di Milano

A Review based on OLED Lighting Conditions and Human Circadian System

Ayse Nihan Avci [1] and Saadet Akbay [1]

[1]Department of Interior Architecture, Çankaya University, Ankara, Turkey. nihanavci@cankaya.edu.tr, akbay@cankaya.edu.tr

Corresponding author: Ayse Nihan Avci (nihanavci@cankaya.edu.tr)

ABSTRACT

Light is a form of energy that affects the human sleep cycle, working hours, alertness, productivity, and well-being. As one of the essential environmental factors, lighting requires extensive research to understand the human-environment interaction. Earlier studies reveal that various artificial lighting technologies are utilized to investigate the human circadian system; experiments employing solid-state lighting (SSL) sources are still being conducted to determine how the human circadian system is affected. Due to the advantages of OLED (organic light-emitting diode) lighting, there is a need to enhance this form of artificial lighting in an indoor environment. This paper focuses on a literature review on artificial lighting sources, particularly OLED lighting, used from the past to the present. This article also discusses how OLED lighting can influence the human circadian system in terms of different characteristics of lighting in an indoor environment.

KEYWORDS OLED Lighting, Human Circadian System, Lighting Technologies, Human-Environment Relationship, Lighting in an Indoor Environment

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1. Introduction

Light is radiant energy that ranges from gamma rays to radio waves. The human eye responds to this energy within the limits of the visible spectrum from ultraviolet to infrared. Lighting technologies act as substitutes for natural light. Lighting history might be defined as the evolution of efficient technologies for producing visible light in the required spectral area.

Several lighting fixtures have been produced over the centuries. They have been manufactured to meet the needs by modifying their shape, color, temperature, intensity, and rendering of light. They provide general illumination and are classified into three groups: incandescent, discharge, and solid-state lighting (SSL). Figure 1 shows the evolution of artificial lighting technologies. Incandescent lamps produce light by heating a tungsten filament to incandescence. Discharge lamps have light through an electric discharge in gas and require control gear between the lamp and the power supply.

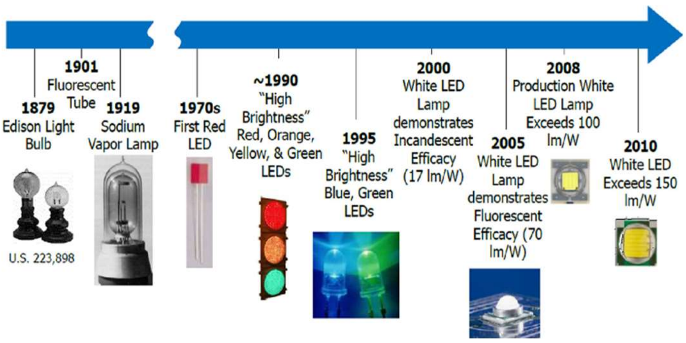

Fig. 1. Evolution of artificial lighting technologies (De Almeida et al. 2014: 32).

The term 'solid-state lighting' is also called 'electroluminescent lighting' since it produces electromagnetic radiation in response to power current; this process does not require heat and electric discharge via gas. As a result, they are cooler and smaller than other lighting sources (Innes, 2012). With the advent of new green SSL technology, the general concepts of artificial lighting sources have been changing (Kar and Kar, 2014). Due to task performances, human comfort, and production of high-quality lighting, researchers have focused on high-tech lighting sources that use more efficient SSL devices, have very long lifetime, resulting in lower maintenance costs, and have good physical robustness and compactness compared to other lighting sources (De Almeida et al., 2014).

Earlier studies indicate that various artificial lighting technologies are used to explore the human circadian system; experiments employing solid-state lighting sources (SSL) (i.e., light-emitting diode [LED]) are still being undertaken to understand how the human circadian system is affected. However, due to the advantages of organic light-emitting diode (OLED) lighting, there is a need to use this form of artificial lighting in an indoor environment. Due to the advantages of OLED lighting, it has been a matter of curiosity why it is not used indoors more than other lighting technologies. It aims to expand the indoor-oriented use of OLED lighting technologies and shed light on the studies carried out in different areas by considering the user profile. Specifically, this paper focuses on a literature review of artificial lighting sources, particularly OLED lighting, which also discusses how OLED lighting can be utilized to alter the human circadian system in an indoor environment. Most importantly, it has also the potential to change the design approaches by providing fresh knowledge for architects, interior designers, industrial designers, lighting designers, and lighting companies on how to effectively approach indoor lighting design with newer technologies for all users. Creating optimal surroundings is predicted to reduce stress and enhance visual satisfaction and well-being, having a considerable influence on the human circadian system and greatly boosting the user's quality of life.

2. Organic Light-Emitting Diodes (OLEDs): The Future of Lighting Technologies

Organic light-emitting diodes (OLEDs), one of the most significant advancements in the lighting industry, are unique and revolutionary SSL sources. OLEDs are a type of SSL source; however, they differ from other SSL sources in that they contain electroluminescence in organic compounds (Kunić and Šego, 2012). Following Bernanose and his colleagues' initial innovation, in 1985, Eastman Kodak Company explored many materials to improve this technique, and in 1987, the first OLED devices were introduced. They were later developed by companies including Samsung, LG, Panasonic, and Sony. OLEDs are currently used in various electronic products such as televisions, mobile phones, and automobiles.

OLEDs are composed of multiple organic sandwiched between the cathode and the anode. They are semi-conductive, emit light, and are manufactured on a substrate. The color of the light emitted is determined by the content of the organic layer. Multiple layers (e.g., red, green, and blue) are mixed to produce any color, including white. OLEDs differ in structure, material, and emission type. They are classified into seven classes: passive-matrix OLED (PMOLED), active-matrix OLED (AMOLED), transparent OLED, top-emitting OLED, bottom-emitting OLED, foldable or flexible OLED, and white OLED (WOLED).

OLED lighting offers an entirely new realm of light interaction possibilities. OLED is an SSL technology with numerous advantages over traditional alternatives. Along with its design (i.e., being ultra-thin, featherweight, flexible, cool-to-touch, long-life span, and 90+ color rendering index), health and well-being (no blue light risk, no UV, circadian system friendly, no flicker, naturally diffuse, and glare-free), and sustainability (recyclable, 85% organic and glass materials, does not contain toxic materials, no thermal heat sink, reduced manufacturing footprint, and low power consumption) are among the benefits of OLEDs (Thejokalyani and Dhoble, 2014; Hawes et al., 2012; Why OLED, 2020).

3. Lighting and Human Circadian System

In the 18th century, the term 'circadian' was investigated by French scientist Jean Jacques d'Ortous de Mairan (Rossi, 2019). He notices that the movements of the flowers of plants continue during the day, although they are placed in an indoor environment and not exposed to sunlight. This finding indicates that the movements of the plants are controlled by an internal clock (Vitaterna et al., 2001). Plants, animals, fungi, and cyanobacteria have circadian systems (Edgar et al., 2012). It is a 24-hour cycle internally created and influenced by external factors such as light and temperature. The circadian system has a daily process linked to brain wave activity, hormone production, core body temperature, cell regeneration, and other biological activities. These are all coordinates in the 24-hour cycle of living beings. In addition, the human circadian system influences primary physiological factors such as sleep cycle, changes in body temperature and blood pressure, immune system activities (Rossi, 2019), hormone system, and other psychological factors such as alertness level (Cajochen, 2007), mood, behavior (LeGates et al., 2014), and well-being.

Light is a fundamental human need, providing both vision and non-visual impacts, including regulating the circadian system. It is essential to the human circadian system, accomplished through vision. One of the most complicated senses, vision, is the primary mechanism by which humans perceive their surroundings. The first thing to understand about the visual system is that it comprises more than just the eye. The interaction between the eye and the brain results in vision, in which humans experience lights in their environment. Understanding this process leads to the establishment of such an environment. Understanding the biological context that led to vision requires considering the eye and brain as a unit. The eye governs the physiological effects of light in humans. When light enters the eye, it activates retinal photoreceptors, which convert photic information into neural impulses transmitted to various parts of the brain via ganglion cells. For many years, it was considered that the human retina included just two types of photoreceptors: rods and cones; nevertheless, roughly two decades ago, another distinct photoreceptor type was discovered in the mammalian eye. These retinal photoreceptors are specialized ganglion cells that contain the photopigment melanopsin and are inherently photosensitive, hence being dubbed intrinsically photosensitive retinal ganglion cells (ipRGCs) (Berson et al., 2002; Hattar et al., 2002; Provencio et al., 1998, 2000). When light falls on the retina, photoreceptors and cells transfer the light to the brain's suprachiasmatic nucleus (SCN), which regulates our daily circadian systems. SCN is an organizer for the recurrence of our daily physiological functions and psychological states like hormone secretion, body temperature, mood, well-being, and alertness (Tähkämö et al., 2019). Figure 2 shows the schematic illustration of the neuroanatomical underpinnings of the physiological effects of light.

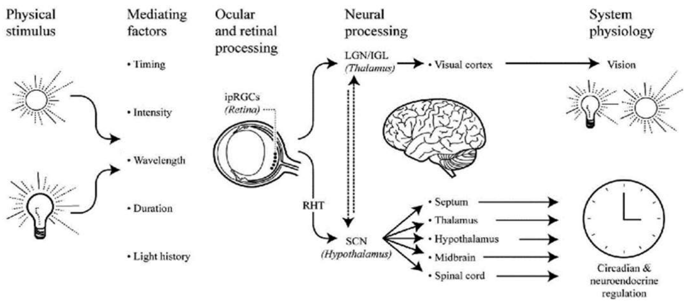

Fig. 2. Schematic illustration of the neuroanatomical underpinnings of physiological effects of light (Vetter et al. 2021: 2).

4. Relationship Between Lighting and Human Circadian System in an Indoor Environment

Most people moved from an outdoor environment to an indoor environment. This has been shown to have a negative impact on our health, productivity, visual comfort, mood, and happiness. However, with the recent discovery of a new photoreceptor in the eye and a better understanding of the process underlying non-visual biological impacts, we may be able to define lighting scenarios that ensure healthy individuals remain healthy even when working in indoor environments. Aside from the benefits to individuals' health and well-being, good lighting contributes to improved job performance (speed), fewer mistakes and rejections, increased safety, fewer accidents, and decreased absenteeism. This all adds up to increased productivity.

Indoor lighting design differs significantly from that of lighting for the circadian system. In general, the latter approach has placed an emphasis on visibility and related issues such as glare and shadow reduction, color rendering, safety, and space appearance. Designing for non-visual impacts of light, such as the circadian system, requires distinct lighting design objectives and, as a result, metrics and parameters related to the physical and psychological effects of light that lighting designers do not currently use.

In the literature, various studies have been carried out within the scope of human-centric lighting by considering the different characteristics of light. Although the studies do not directly address the effect of indoor lighting systems on the circadian system, the topics investigated are related to this field. Kuller and Wetterberg (1993) researched the brain-wave patterns (EEG) of people in a lab set up to imitate an office setting, once with a relatively high illuminance level (1700 lx) and once with a relatively low illuminance level (450 lx). Lower delta waves (the delta activity of an EEG indicates tiredness) are associated with higher illuminance levels of illumination, indicating that bright light has an alerting effect on the central nervous system. Non-visual flicker under fluorescent lighting has been shown to alter performance and mood, with individuals reporting a more pleasant mood under 2000 lx than under 300 lx in office environments (Daurat et al., 1993). Although 500 lx is considered the standard, it has been suggested that lower illuminance levels might be achieved without compromising the user experience (Fotios, 2011). Revell et al. (2006) conducted a study to investigate the non-visual effects (such as mood, alertness) of light of four different wavelengths at 420, 440, 470, and 600 nm on 12 participants. The results indicate that light with a wavelength of 420 nm produced more wakefulness than light with a wavelength of 470 nm or even 600 nm. The effects of illuminance (300 lx or 500 lx) and color temperature (4000 K or 6500 K) were assessed in specially designed office rooms for the study that participants preferred 500 lx and warmer (4000 K) lighting. There were also some impacts of spectral power distribution rather than simply CCT (Islam et al., 2015). In a study, Rossi and Casciani (2018) investigated natural lighting conditions in an indoor environment to explore the contribution to the well-being of the elderly and the invisible effects of lighting. The results sugget that older people might be exposed to low levels of natural lighting in the morning, which is essential for activating invisible responses and, as a result, synchronizing their circadian systems.

Since the millennium, new lighting solutions and advancements have focused on research themes such as light and health, user comfort, and the circadian system. Many studies have been conducted to determine how LED lighting conditions affect visual comfort under various illuminance levels (Avci and Memikoglu, 2017; Fortunati and Vincent, 2014). Light has been demonstrated to have significant non-visual impacts on a variety of biological functions, including the regulation of the human circadian system. In any case, advances in technology can provide useful tools for designing circadian lighting. In this respect, LEDs provide crucial characteristics for manufacturing lighting solutions that previous light sources did not allow for, or only partially allowed for, due to low efficiency and high costs (Rossi, 2019). In the literature, there are many studies related to the effects of LED lighting on the human circadian system from different viewpoints (Cajochen et al., 2011; Chaopu et al., 2018; Figueiro et al., 2018; Nie et al. 2020). However, OLEDs, which emit less blue light than regular LEDs, are considered low-energy and medically friendly artificial lighting. A study by Avci and Memikoglu (2021) found that OLED lighting exposure is more comfortable than LED lighting exposure in terms of some visual comfort criteria in the indoor environment. Ngarambe et al. (2021) investigated the impact of Spectral power distribution (SPD) on visual comfort, work performance, circadian energy, and mood. They used two types of lighting: LED and organic light-emitting diode (OLED). Participants preferred OLED for visual comfort, whereas LED was chosen for improved job performance and mood. However, Park et al. (2020) researched light exposure on circadian system and sleep. Participants were randomly assigned to one of three different light conditions (OLED, LED, and dim light). Melatonin onset was considerably delayed under LED lighting when compared to dim lighting, but did not vary under OLED lighting.

Yamagata University constructed the "Smart Mirai House" to test future lighting and other organic electronic devices. Various lighting conditions may be researched by using different types of OLED lighting displays to identify appropriate lighting for comfortable sleep and a well-controlled circadian rhythm (Sano et al., 2021).

Furthermore, Jo et al. (2021) conducted a study to assess the influence of OLED lighting exposure on sleep quality and the circadian system, which investigates the effects of LED and OLED lighting conditions on the human circadian system at night. Jo et al. (2021) suggest that OLED can be a suitable replacement for LED since its spectrum contains less blue light, which has the most significant impact on melanopsin in intrinsically photosensitive retinal ganglion cells. In addition, the effects of OLED lighting conditions on the human circadian system, visual comfort, and well-being in an indoor office environment have been an interest for the authors of this article, where they have been investigated as part of a scientific research project.

In contrast to earlier studies on the human circadian system, it aims to investigate the effects of OLED lightingas an environmental factor on the circadian system, visual comfort, and well-being of the participants who perform their daily work in an office environment. Finding the physiological and psychological effects of indoor lighting conditions on users is also among the research objectives. The circadian rhythmicity activity during the daytime is monitored using wrist actigraphy (Actiwatch Spectrum/Philips Respironics). The effects of OLED lighting with two different color temperatures (3000 K and 4000 K) on the user were examined. When the results were discussed, 3000 K OLED lighting conditions were generally found to be more positive. This study is intended to contribute to interior architecture by examining the application of OLED lighting in indoor environments (Avci and Akbay, 2021).

5. Conclusion

To conclude, the primary goal should be to design an indoor environment that addresses health, comfort, well-being, and quality. This paper aims to expand the indoor-oriented use of OLED lighting technologies and shed light on the studies carried out in different areas by considering the user profile. Most significantly, it aims to alter the design approaches by offering architects, interior architects, industrial designers, lighting designers, and lighting companies new knowledge on how to properly approach indoor lighting design with modern technologies for all users. The influence of the circadian system should be included in lighting settings. Since OLED lighting technologies are more advantageous than other lighting technologies, their use should be expanded considering the impact on the user's circadian system and other environmental factors.

6. Funding source declaration

The authors received no specific funding for this work.

7. Conflict of interest declaration

The authors declare that there is no conflict of interest regarding the publication of this paper.

8. Short biography of the authors

Dr. Ayse Nihan Avci - Research Assistant in the Interior Architecture Department, Çankaya University, Ankara, Turkey. Member of the Chambers of Interior Architects of Turkey and the Turkish National Committee on Illumination. Her research interests include human-centric lighting, circadian lighting design, artificial lighting technologies, and color and light.

Assoc. Prof. Dr. Saadet Akbay - Associate Professor in the Interior Architecture Department, Çankaya University, Ankara, Turkey. She received BA and MFA degrees from the Department of Interior Architecture and Environmental Design at Bilkent University, and a PhD degree from Industrial Design at Middle East Technical University, Ankara, Turkey and postdoctoral degree from Architecture at the University of Lisbon, Portugal. Her research interests include colour perception, colour education, color and light, and design education.

Licensing terms

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Virtual interior environment: Influence of colour on the sense of immersion

Firdevs Gökmenoğlu[1] and Saadet Akbay[1*]

[1] *Department of Interior Architecture, Faculty of Architecture, Çankaya University, Ankara, Turkey. iyibilginfirdevs@gmail.com, akbay@cankaya.edu.tr*

Corresponding author: Saadet Akbay (akbay@cankaya.edu.tr)

ABSTRACT

This article investigates the effects of colour on the sense of immersion in virtual interior environments. The perceptual significance of colour in interior design necessitates a critical evaluation of the three dimensions of colour - hue, saturation, and lightness (HSL) - in the context of their application in virtual environments (VEs). The study aims to investigate how the sense of immersion in virtual interior environments varies depending on hue, saturation, and lightness and to examine the extent to which colour dimensions influence the sense of immersion in VEs. In this study, the HSL colour space was employed to create varying degrees of colours, and an online survey was conducted to understand the individuals' sense of immersion in different virtual interior settings. The findings suggest that reducing the degree of lightness of colours in a virtual interior environment enhances the sense of immersion. In addition, the study reveals that whether a virtual interior environment highlights natural or artificial lighting, augmenting the degree of lightness of colours intensifies the sense of immersion in the perceived environment.

KEYWORDS colour perception, colour experience, virtual interior environment, sense of immersion

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1. Introduction

Virtual reality (VR) technology provides users with an immersive experience in virtual environments (VEs) through the stimulation of various senses in virtual spaces. VR has transformed into a potent technology that facilitates the assimilation of fictionality by stimulating human senses, enabling individuals to inhabit an artificial environment, and converting mental stimuli into tangible sensations (LaValle 2018; Kim et al. 2004). Alternatively, VR technology has also been identified as a tool that generates long-lasting emotions and memories that endure even after it has been turned off (Rizzi el al. 2012). The development of VR technology has advanced rapidly, particularly in the domain of computer graphics, and a diverse range of new VR equipment has been utilized to measure the degree of immersion in VEs (Feisst 2011; Cadet and Chainay 2020). Immersion is a concept that has been extensively studies in the domain of in video games to create a captivating VE that captures the player's attention. Design criteria to improve the VR in 3D video games are considered in terms of the degree of immersion, engagement, and presence (McMahan 2003). Our brains possess the ability to easily adapt to stories and disregard the surrounding world. Immersion, or the sensation of being transported, is metaphorically derived from submerging oneself in water. The feeling of being surrounded by water while swimming in the ocean or pool is also described as immersion. Compared to air, the sensation of being in the water is an entirely different reality. For instance, learning to swim is a psychologically immersive experience. An experiment that involves immersing oneself in a virtual environment is typically characterised by three elements: flow, cognitive absorption (CA), and presence (Jennett, et al. 2008). Flow is defined as a situation in which individuals are deeply engaged in an activity in such a way that nothing else matters. Flow represents an elevated level of engagement, while immersion eliminates the momentary lapse. Thus, immersion can be considered as a prerequisite for flow (Skarbez et al. 2017; Siple and Springer 1983). Csikszentmihalyi has identified eight factors that are critical for flow: a balance between challenge and skills, clear goals, clear feedback, a sense of uncertain time, a loss of self-consciousness, a sense of pleasure, and control in an autotelic activity (Roohi and Forouzandeh 2019). Nowadays, VR technology has become popular not only in the field of video games but also in various other areas. Immersion allows users to experience diverse VEs, enhancing their spatial perception and sense of presence using one-to-one modelling and 3D visualisation technologies (Murray 1997).

Numerous studies have explored the concept of immersion in various media, highlighting the importance of colour and light in virtual environments (Wästberg and Billger, 2006). Martini et al. (2004) state that the human visual system (HVS) exhibits variations in colour perception according to luminance, chromaticity, or whiteness image filters, aiming to identify the most effective HSL values within the HSV system in virtual environments. Colour perception is a fundamental distinction between human adaptation capability and colour reproduction. Billger et al. (2004) claim that when individuals view a production in a VR environment as an observer, they approach it "out of context" and behave differently than in a real-life situation "in context." Stimulating human colour perception is required to integrate to this experience in line with reality perception. Zeki and Martini's (1998) study on colour processing has showed that designing images as natural, unnatural and achromatic colour stimulate different regions of the human brain. As a result, three-stage cortical colour processing occurs in the human brain. The first stage comprises wavelength difference, consisting of the presence of wavelength and its intensity. The second stage is an atomic constant perception of colour, without any association with memory, judgment, or learning. The third stage is the colour of the object. All these factors influence colour perception in the human brain in both real-world and VR settings (Zeki and Martini 1998). In addition, Brown and MacLeod (1997) found that different nuances of colours elicit different senses, leading to variations in the sense of immersion in VEs. Although colour perception is considered one of the factors that influence the sense of immersion in a VE, few studies have focused on colour as the primary subject matter of investigating immersion in spatial contexts (Stahre et al., 2009).

This article seeks to investigate the influence of colour on the sense of immersion in virtual interior environments. The study aims to explore how the hue, saturation, and lightness of colours affect the sense of immersion and the extent to which colour dimensions influence the sense of immersion in such VEs. By doing so, this research can offer insight into how colour perception in virtual interior environments can influence the sense of immersion in a technical and practical manner in the field of interior architecture utilising emerging technologies.

2. The Study

2.1. *Participants*

The study involved a total of 228 participants, consisting of 165 females and 63 males, with 14 individuals under the age of 18, 62 between the ages of 18 and 24, 84 between the ages of 25 and 34, 38 between the ages of 35 and 44, 28 between the ages of 45 and 64, and two over the age of 65. Although 25% of participants reported backgrounds in architecture and interior architecture, the remaining participants represented diverse occupational groups to facilitate a more comprehensive analysis. All participants were of Turkish nationality.

2.2 *Visual Stimuli*

In this study, four different interior images were selected from the website of interior architect Kelly Wearstler (https://www.kellywearstler.com/) to evaluate the effects of colour on the sense of immersion virtual interior environments. The HSL colour space of Adobe Photoshop CS6 was utilised to adjust the degree of hue, saturation, and lightness of the selected images, with each image having four different modifications. To make the images appear warmer, the degree of hue in each image was decreased by 10%, while the degree of saturation was reduced by 35% to make the images appear duller. The degree of lightness was adjusted by a range of -35% to +35%, resulting in darker and lighter images (Figure 1). The first image was selected for its warm colour tones dominated by intense brown colours, which featured dotted dark elements with horizontal and vertical lines. The second image contained brown and warm tones and was chosen to examine the contrast of the white chair with the rest of the environment. The third image was chosen due to its visually intense reflection of natural lighting, which allowed for the exploration of the effect of sun on the interior environment. The fourth and final image was dominated by cold tones and combined with the reflectivity of artificial lighting to make a comparison with interiors in warm tones. All modifications were done in a controlled manner to ensure consistency and avoid any potential confounding variables.

2.2 *HSL Colour Model*

The HSL colour model, an acronym for hue, saturation, and lightness, is widely used tool in computer graphics applications. Although the HSL model is based on an RGB colour space, its aim is to describe more perceptual colour relationships. Thus, in this study, the HSL colour model was deemed appropriate for modifying image.

2.3 *Measures and Procedure*

In this study, an online survey was utilized to investigate the sense of immersion in virtual interior environments. The questionnaire comprised three sections: demographic features, colour vision assessment, and selection of the most immersive interior image. The first section requested demographic information such as age, gender, and nationality. The second section assessed participants' colour vision using Ishahara's colour deficiency test, with participants who passed the test being deemed to have normal colour vision. The third section aimed to determine the extent to which the participants felt immersed in the virtual interior environments presented to them, with participants being asked to select one of four sets of images with varying degrees of hue, saturation and lightness that best conveyed the sense of immersion from a total of four different interior images.

Given the COVID-19 pandemic and the resulting limitations on in-person research, the study necessitated the use of monitors and screens instead of VR glasses to display the interior images. To maximize the study's potential accuracy, certain prerequisites were established. For example, participants were instructed to set their monitor colour settings to RGB, turn off night shift or true tone settings if using a phone, and adjust screen brightness to between 80% and 90%. Additionally, participants were advised not to take the survey in bright daylight or in the dark. These measures were implemented to minimise potential variability in participants' responses due to differences in screen settings or lighting conditions.

3. Results and Discussion

After data collection through an online survey, statistical analysis was conducted using IBM SPSS Statistics 23. The data were analysed for frequency distribution, and the results are discussed in relation to each of the four images presented in Figure 1.

In the first set of images (see Figure 1a), a notable 31.1% of participants identified the image with a -35% degree of lightness (referring to #1) as providing the most immersive virtual interior environment in comparison to the other images. In contrast, 24.1% of participants found the image with a -10% decrease in hue (referring to #3) to be immersive, while 23.2% of participants found the image with a -35% decrease in saturation (referring to #4) to be immersive. The results demonstrate that 18.9% of participants found the image with a +35% increase in lightness (referring to #2) to be immersive.

In the second set of images (see Figure 1b), the image with a -35% degree of lightness (referring to #1) was identified as providing the most immersive virtual interior environment by 32.9% of participants, in comparison to the other images. However, 26.3% of participants found the virtual environment with a +35% increase in lightness (referring to #2) to be immersive, followed by the image with a -35% decrease in saturation (referring to #4), which was identified as immersive by 23.2% of participants. According to the results, only 14.5% of participants found the image with a -10% decrease in hue (referring to #3) to be immersive.

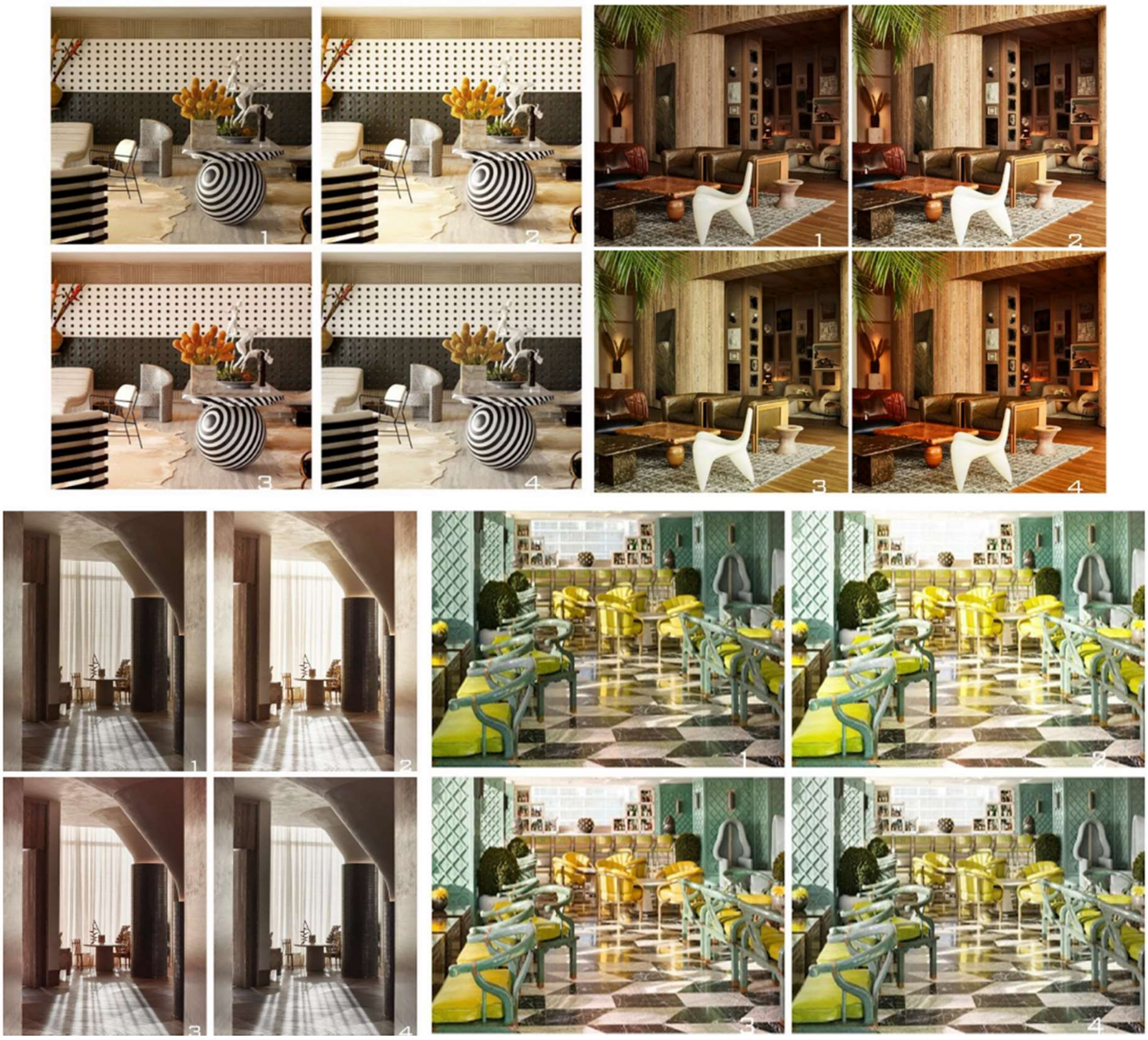

Fig. 1. Interior images used in the study; in each image: 1) lightness: -35%, 2) lightness: +35%, 3) hue: -10%, 4) saturation: -35%

In the third set of images (see Figure 1c), 33.3% of participants perceived the image with a +35% increase in lightness (referring to #2) as providing the most immersive virtual interior environment, followed by the image with a -35% decrease in saturation (referring to #4), which was identified as the second most immersive by 27.2% of participants. Meanwhile, 22.4% of participants regarded the image with a -35% decrease in lightness (referring to #1) as immersive, and 14.9% of them perceived the image with a -10% decrease in hue (referring to #3) as immersive.

In the final set of images (see Figure 1d), the majority of participants (55.7%) perceived the image with a +35% increase in lightness (referring to #2) as the most immersive virtual interior environment when compared to the other images. The next most immersive virtual environment was the with a -10% decrease in hue (referring to #3), which was considered immersive by 21.9% of participants. The image with a -35% decrease in lightness (referring to #1) and a -35% decrease in saturation (referring to #4) were perceived as immersive by 14.5% and 4.8% of participants, respectively. Figure 2 displays the frequency distributions of the sets of images.

The findings of the present study align with previous research that suggests that perception of colour plays a significant role in the sense of immersion in VEs. More specifically, the study revealed that decreasing the degree of lightness of colours in virtual interior environments enhances the sense of immersion in that environment. In addition, the findings indicate that increasing the degree of lightness of colours, whether in the context of natural or artificial lighting, heightens the sense of immersion in the VE. Previous research conducted by Siess and Wölfel (2019) has examined the effect of colour temperature on the sense of immersion, demonstrating that different nuances of colour can elicit diverse perceptions, leading to variations in the sense of immersion in VEs. Similarly, Kumoğlu's (2013) study on how colour temperature affects wayfinding behaviours in virtual airport simulations indicated that the participants' wayfinding performance varied depending on the colour temperature, as measured by factors such as time spent, deviations, indecision, and direction choice.

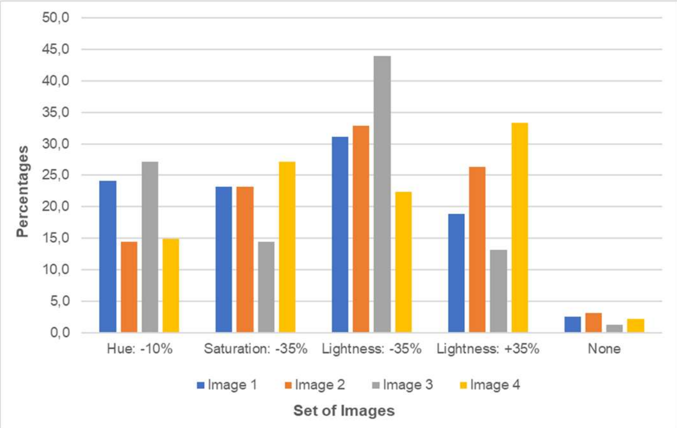

Fig. 2. Frequency distribution of the sets of images

The perception of space and mental construction of space in the virtual environment are linked to the colour temperature, which suggests that colour values can also influence the sense of immersion in virtual interior environments. Stachoň et al. (2018) found that participants' locations, directions, and sense of reality vary depending on the hue, and that the hue has an impact on the virtual environment. Taherzadeh (2018) investigated the effect of hue on task performance, and the study's findings suggest that changing the hue caused participants to behave differently. The various hues that cause differences in behaviour in the spatial setup differ in the sense of immersion of the participants in virtual environments.

The present study examined the impact of hue, saturation, and lightness on the sense of immersion in virtual interior environments. Consistent with prior research, the results suggest that colour perception plays a crucial role in shaping the sense of immersion in VEs. It is worth noting that the use of 2D virtual interior environment images in this study, along with the use of online surveys due to the pandemic restrictions, are potential limitations. Consequently, the findings can be considered as a preliminary investigation that provides a basis for further research on the impact of colour on the sense of immersion in 3D virtual interior environments.

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5. Conflict of interest declaration

The authors declare that there is no conflict of interest.

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7. Short biography of the author(s)

Firdevs Gökmenoğlu - • Master's student and scholar in the Interior Architecture Department, Çankaya University, Ankara, Turkey. She received a BS degree from the Department of Interior Architecture and a BS degree from the Department of Architecture at Çankaya University. She studied at Bauhaus University as an exchange student. Her interests include interior design, furniture design, colour design, computer and VR aided design.

Saadet Akbay - • Assistant Professor in the Interior Architecture Department, Çankaya University, Ankara, Turkey. She received BA and MFA degrees from the Department of Interior Architecture and Environmental Design at Bilkent University, and a PhD degree from Industrial Design at the Middle East Technical University, Ankara, Turkey and postdoctoral degree from Architecture at the University of Lisbon, Portugal. Her research interests include colour perception, colour education, colour and light, and design education.

Licensing terms

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A comparative study of lipstick shades preferences by geographical areas

Hélène de Clermont-Gallerande[1], Emmanuelle Mauger[1], Nicolas Rolland[1]

[1] *Chanel Parfum Beauté, Innovation, Research & Development, 8 rue du Cheval Blanc, Pantin, France.*

helene.declermontgallerande@chanel.com, emmanuelle.mauger@chanel.com, nicolas.rolland@chanel.com

Corresponding author: Hélène de Clermont-Gallerande (helene.declermontgallerande@chanel.com)

ABSTRACT

International cosmetics companies manufacture make-up products that are then sold in all countries where the brand is distributed. Lipstick ranges today each include about 30 shades and each brand offers several ranges with different effects of the make-up result. A couple of years ago, Chanel lipsticks provide 142 shades divided into several ranges: 34 classic lipsticks, 48 shiny lipsticks, 39 intense lipsticks and 21 matt lipsticks. It seemed to us worth looking too, at the 20 best-selling lipsticks by specific geographical area. So, the areas studied are not of comparable size because they are those where detailed sales figures are available. These areas are France, Italy, the UK, the USA, Asia and South America. The best sales per area are statistically analyzed to establish shade preferences in each of these areas. A Principal Components Analysis then made it possible to establish the geographical areas whose lipstick color choices are closest. A red satured, middle ligthness was unanimously preferred internationally. Italy and France were the two markets most representative in terms of lipstick shades.

KEYWORDS Shades, Preference, Lipsticks, Color, Geographical area

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1. Introduction

Before the health crisis induced by COVID-19, lipstick was the best-selling make-up product. Although wearing a mask has drastically reduced lipstick sales, it remains the quintessential feminine attribute. CHANEL is one of the world's leading sellers of lipsticks. Like all international cosmetics companies, its products are sold in every country where the brand is distributed. However, where cosmetics are concerned, the success of a product is linked to the whole marketing mix (advertising, media communication, packaging, brand impact, texture and performance complaints) but, above all, to the color on offer. Therefore, CHANEL exhibits to its customers a wide range of shades with the aim of appealing to women from all cultures, in all age ranges and of every style. Like all CHANEL's make-up ranges, the lipstick lines are divided into two parts: firstly, a core range including iconic shades that are found all over the world, and secondly the freedom to use colors that respond to the needs and specific characteristics of the markets. We thought it would be interesting to study which were the 20 best-selling shades in each part of the world where CHANEL's products are distributed. A couple of years ago, CHANEL offered 142 lipstick shades splitted over five ranges: 34 classic moisturizing lipsticks (Rouge Coco), 48 shiny, transparent lipsticks (Rouge Coco Shine and Rouge Coco Stylo), 39 intense lipsticks (Rouge Allure) and 21 matt lipsticks (Rouge Allure Velvet). There are six regions of the world studied: France, Italy, United Kingdom, USA and Asia (Korea, Japan, Singapore, China and Taiwan). The geographical areas studied are not of identical size because Maison CHANEL compiles its figures by continent. In this article, the best-selling lipsticks were analyzed to determine color preferences by geographical area through PCA methodology, to establish specificities of each market of the world and to understand similarities between the markets. The most similar geographical areas will thus be distinguished from the most dissimilar ones.

2. Materials and Methods

2.1. *Color measurement*

The color of the products was measured using an Xrite VS450 contactless spectrocolorimeter in the CIEL*a*b* color space. The color measurements were done in specular included mode, with a 45/0 geometry and a D65 illuminant.

2.2. *Statistical analysis*

A first mapping of the 142 shades available on all the markets was produced using a Principal Components Analysis (PCA) performed on the L*, a* and b* parameters (Everitt, Landau, Leese and Stahl, 2011). Based on this summarised information, groups of shades were identified (figures 2 a, b and c). Afterward, to regroup products with similar shades, a clustering method was applied on the previous PCA components (Jobson, 1992). A 2nd PCA was carried out to determine the geographical similarities and regional benchmarks of the markets.

A response surface model using standard least squares was used to analyse the ranking in a specific market. The main effects of the model are the lipstick rank and the second order the geographical area.

The ranking of the 20 best-selling shades per country or continent at the end of the studied year was supplied by the company's marketing division (Chanel, 2016). These results are based on sell-in figures, except for Asia where only sell-out figures were available. The product classified as number 1, the most frequently sold, will then have 20 points. The points assigned will then decrease to 1. A shade which is not present in the 20 best-selling shades in a given region will, therefore, have a mark of 0 as hhown in figure 1. The color classification previously built was used to determine the shades unanimously liked all over the world and those which are more favoured or even specific in a geographical area.

Pays	ROUGE ALLURE 104 PASSION	ROUGE ALLURE 109 ROUGE NOIR	ROUGE ALLURE 136 MELODIEUSE	ROUGE ALLURE 138 FOUGUEUSE	ROUGE ALLURE 149 ELEGANTE	ROUGE ALLURE 152 INSAISISSABLE
France	15	9	0	0	3	0
Italie	18	0	0	0	0	0
UK	14	0	0	0	0	0
Amérique Sud	7	0	0	0	0	0
Asie	0	0	13	2	0	10
USA	0	0	0	0	0	0

Fig. 1. Extract of scoring matrix for lipsticks based on their classification out of the 20 best-sellers in each region. 20 = 1st in the classification. 0 = not mentioned in the classification.

3. Results

The lipstick color analysis is resumed on the figure 2.a. The first axis represents the a* and b* parameters. The lipsticks on the bottom left are darker. The one on the right are redder and yellower. The classification led to obtain 8 clusters. To visualise the classification, the previous graph was rebuilt using color of the lipstick and the shape corresponding to the classification. The figure 2.c is a focus on the 20 best-selling shades in the six regions. They are not always the same from one region of the world to another. Therefore, 50 lipstick shades of the 142 offered by Chanel are represented.

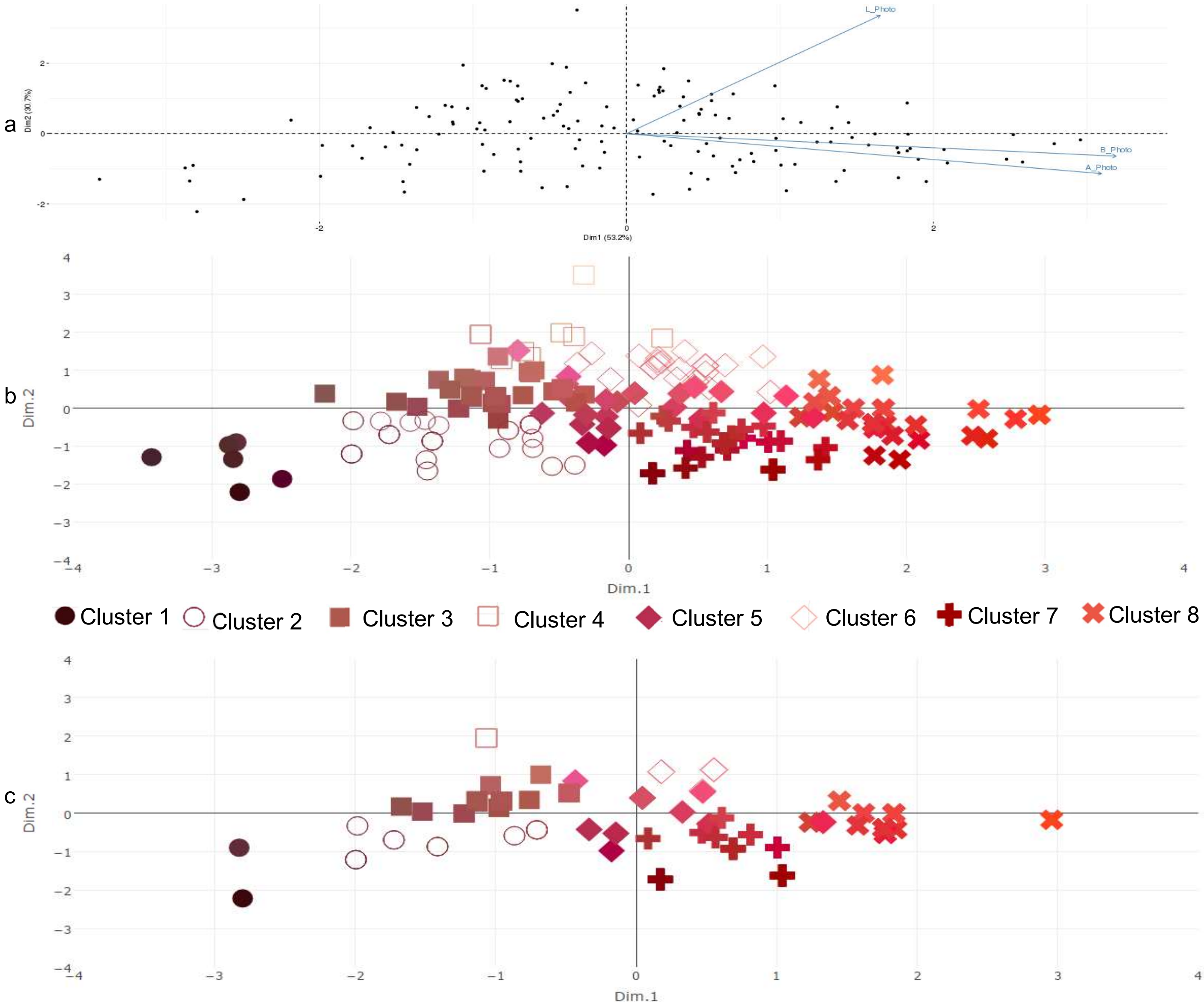

Fig. 2. Lipstick color classification analysis

a. *Simultaneous representation of the first factorial map of the PCA on the 142 lipsticks color parameters.*

b. *Graphic representation in the colorimetric space of the 142 shades offered by Chanel. The shape corresponds to the lipstick colors classification.*

c. *Graphic representation of the 50 shades mentioned in the rankings of the six regions studied.*

Figure 3 shows the distribution of the 50 lipstick shades mentioned at least once in the top 20 best-sellers in the 6 markets studied and in the different lipstick ranges.

The color measurements established that these 50 shades represented the 8 clusters already established with the 142 lipsticks on sale worldwide. For these 50 shades we can see that all the measurements reported in the L*c*h* color space are in the first quadrant for hue h* between 0 and 45°, which logically corresponds to the space for reds.

For lightness L*, they are between 5 and 70, with most lipsticks between 40 and 50, so with medium lightness figures.

The greatest variability observed is in chroma c*. The range varies between 7 and 90 and is of course linked to the lightness of each shade. For both light and dark shades, we see lower chroma due to the geometry of the color space. The 8 clusters can be described as detailed. The 8 statistically defined groups are sometimes very close on one of the parameters L*a*b*c*h* and overlap.

Fig. 3. The 50 shades of the five ranges classified in the rankings of the six regions studied.

The algorithm model chosen makes each shade appear in a given cluster, but it would have been possible for the shades on the borderline to be attached to a neighbouring cluster. Cluster 1 corresponds to the darkest shades, also known as 'nearly black'. Only 2 shades out of the 50 mentioned among the Top 20s for the various markets are in this cluster. The L* value is below 30. The chroma is low. Cluster 2 includes 6 dark shades: dark, burnished or purplish reds, or burgundies. Cluster 3 is the most represented with 11 shades. They all have medium lightness, around 50, and are unsaturated. These shades include antique pinks, faded reds and browns. There is only one shade in cluster 4. This shade is very light, saturated and has a red tinge. It is a light pink. Cluster 5 contains 9 shades with medium lightness, slightly lower than cluster 3. They are quite saturated. Cluster 6 includes 3 shades. They are light, with lightness above 50 and are quite saturated. Cluster 7 is made up of 9 shades, like cluster 5. The lightness is medium, the shades are saturated and the chroma is red. This is the bright red group, ranging from true reds to reds with a bluish undertone. Cluster 8 also includes 9 shades. They are of medium lightness, with high saturation and a red-yellow tone. They include salmon and orangey shades.

4. Discussion

The spectrocolorimeter measurements of the range are positioned in a limited space as the Chanel lipstick range does not include atypical shades (yellow, green, blue) but is concentrated in the reds area (de Clermont-Gallerande et al., 2018). It is interesting to note that while numerous studies have been conducted on global color preferences, they have never focused on a color space as limited as a lipstick range (Sakamoto, 2014).

All the shades are relatively classic, even though some might seem extravagant, such as the very dark shades in cluster 1, as shown figure 4. The shades in cluster 3 are the most represented among the Top 20 shades for each market, because they are number 11 out of the 50 shades listed in the classification. They, therefore, correspond to 22% of the shades classified in the various Top 20s. Clusters 5, 7 and 8 are of equal size among the 50 shades studied and each composed of 9 shades. It should be noted that these 3 clusters group together the saturated shades.

Two shades are classified among the Top 20 of the six regions studied: *Rouge Allure Pirate* and *Rouge Coco Gabrielle*. However, the rankings of sales of *Rouge Allure Pirate* are systematically better than those of *Rouge Coco Gabrielle*, making *Rouge Allure Pirate* Chanel's best international seller. *Rouge Allure Pirate* was launched by Chanel in 2005 and *Rouge Coco Gabrielle* in 2015. The two shades are saturated dark reds with a hint of yellow. They are both in cluster 7, which gives the impression that this cluster represents lipstick shades which are appreciated whatever the culture and geographical area (Premium Beauty News, 2017). Considering both the presence of the six regions in the ranking and their positioning within that ranking, the most frequently sold shades are *Rouge Allure Pirate, Rouge Coco Stylo Message* and *Rouge Coco Gabrielle. Rouge Coco Stylo Message* is in cluster 2.

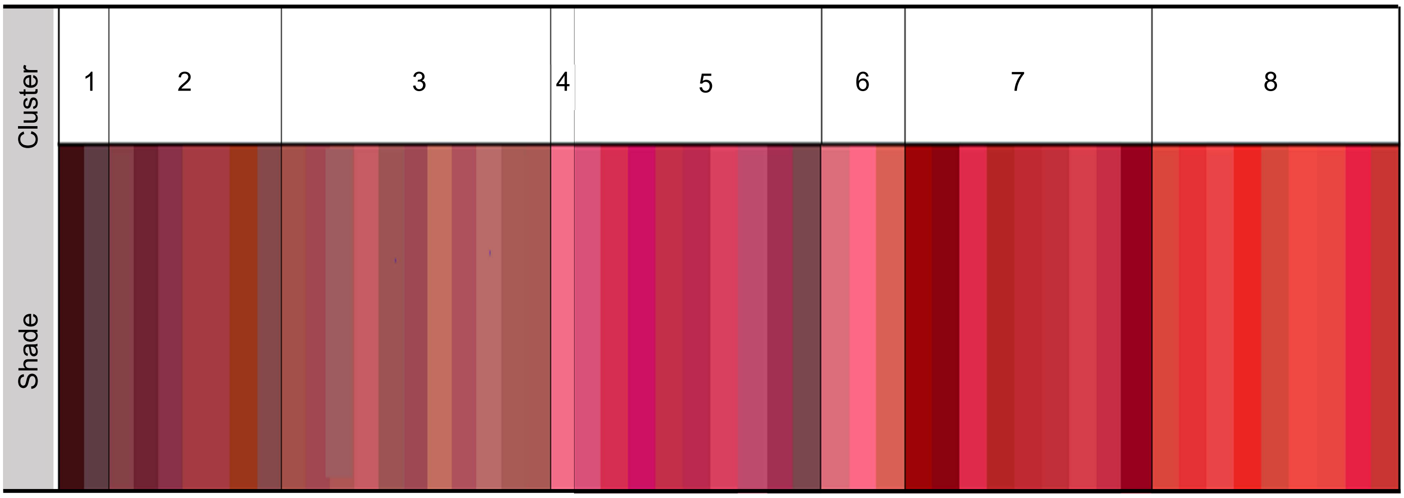

Fig. 4. Classification of the 50 shades mentioned in the Top 20 for the 6 studied regions in the 8 clusters.

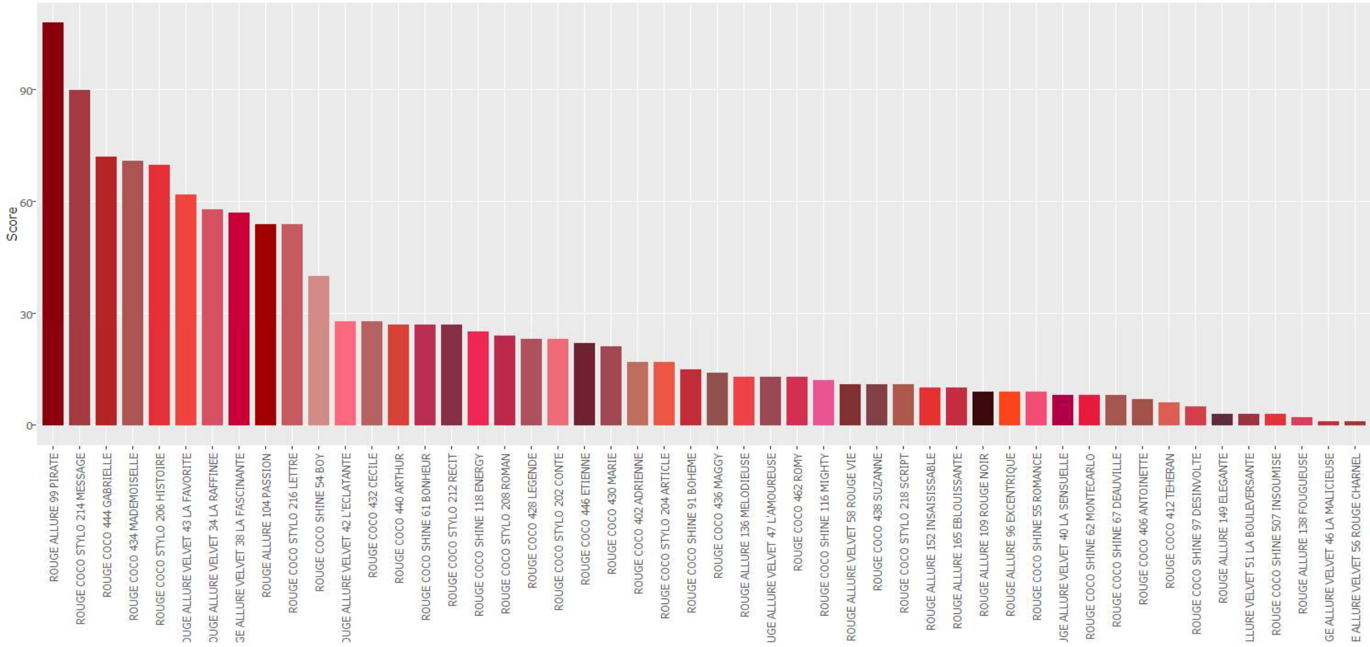

Fig. 5. The score of the 50 shades most frequently represented of the Top 20 in the six geographical regions, comparing their presence and ranking within that classification.

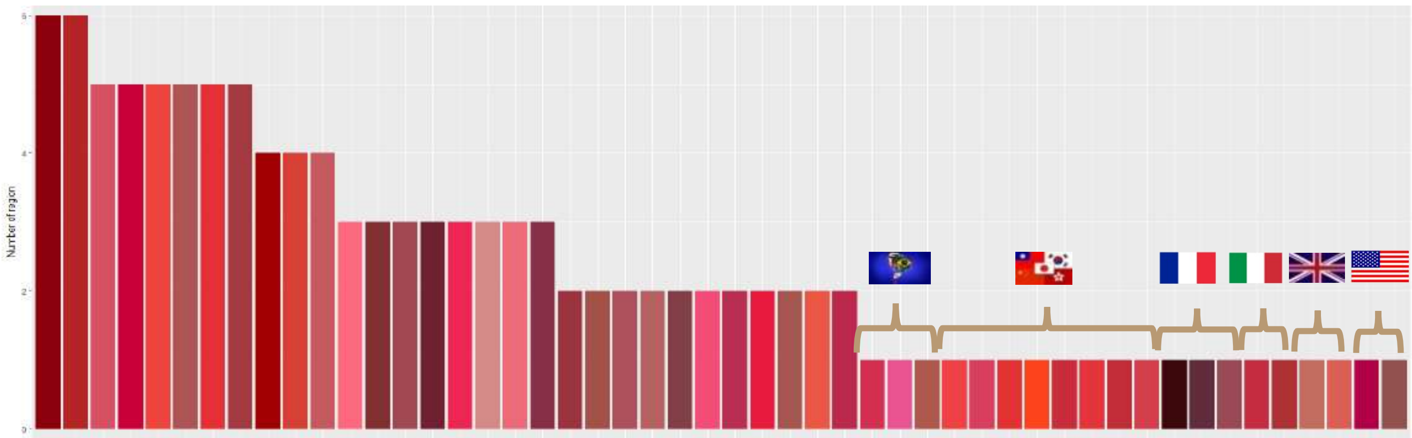

Fig. 6. Presence number in the rankings of the Top 20 in the six geographical regions.

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Six shades are present in five of the six regions studied: *Rouge Allure Velvet La Favorite* (cluster 8), *Rouge Allure Velvet La Fascinante* (cluster 7), *Rouge Allure Velvet La Raffinée* (cluster 5), *Rouge Coco Stylo Mess*age (cluster 2), *Rouge Coco Stylo Histoire* (cluster 8) and *Rouge Coco Mademoiselle* (cluster 3). It is interesting to note that among those excellent sales, three are matt lipsticks. Three shades are among the 20 best sellers in four regions: *Rouge Allure Passion* (cluster 7), *Rouge Coco Arthur* (cluster 8) and *Rouge Coco Stylo Lettre* (cluster 3). Eight shades are represented in this ranking in three geographical regions: *Rouge Allure Velvet l'Eclatante* (cluster 6), *Rouge Allure Velvet Rouge Vie* (cluster 2), *Rouge Coco Etienne* (cluster 2), *Rouge Coco Marie* (cluster 3), *Rouge Coco Shine Boy* (cluster 4), *Rouge Coco Stylo Energie* (cluster 5) , *Rouge Coco Style Récit* (cluster 2) and *Rouge Coco Stylo Conte* (cluster 6). Eleven shades are present only twice in the Top 20 ranking: *Rouge Allure Velvet La Bouleversante* (cluster 2), *Rouge Coco Cécile* (cluster 3), *Rouge Coco Légende* (cluster 3), *Rouge Coco Suzanne* (cluster 2), *Rouge Coco Antoinette* (cluster 3), *Rouge Coco Shine Bonheur* (cluster 5), *Rouge Coco Shine Romance* (cluster 5), *Rouge Coco Shine Deauville* (cluster 3), *Rouge Coco Shine Monte-Carlo* (cluster 8), *Rouge Coco Stylo Roman* (cluster 5) and *Rouge Coco Stylo Article* (cluster 8). Lastly, 16 shades are specific to one region:

Three shades are specific to France: *Rouge Allure Velvet L'Amoureuse* (cluster 3), *Rouge Allure Rouge Noir* and *Rouge Allure Elégante* (both cluster 1). France is the only market that ranks shades from cluster 1 in its Top 20. French women therefore show a specific preference for very dark, almost black, desaturated shades and deep purplish browns.

In the case of Italy, two shades: *Rouge Allure Velvet Rouge Charnel* (cluster 7) and *Rouge Allure Velvet La Bouleversante* (cluster 2). Even though the 2 shades are very different, it is interesting to note that Italian women differ in preferring matt make-up results, as the 2 lipsticks that are specific to this market are matt formulas. Italy also shows a preference for shades in cluster 7, with 6 of them ranked among the 20 best-sellers. Cluster 7 includes red and bluish-red shades with medium lightness and high saturation.

As for the United Kingdom, two shades are noticed: *Rouge Coco Téhéran* (cluster 6) and *Rouge Coco Adrienne* (cluster 3). As the other European countries, UK is centrally positioned in the PCA but its inclination is for American preferences. The 2 specific shades are of medium lightness and have reddish-yellow hints, with one orangey and one brown shade.

The United States have a single specific shade: *Rouge Coco Maggy* (cluster 3). The United States indicate their preference with an antique pink shade. The United States have a real preference for the shades in cluster 3, as they represent 7 of the 20 best-selling shades. Cluster 3 includes somewhat darker shades, with medium saturation. More generally, the Anglo-Saxon countries prefer rosewood and nude shades.

There are three specific shades to South America: *Rouge Coco Romy* (cluster 5), *Rouge Coco Shine Mighty* (cluster 5) and *Rouge Coco Stylo Script* (cluster 3). This market appreciates shades with bluish tinges. There are, therefore, obviously 3 pink shades among their specific selection. However, while the 2 pinks in cluster 5 are very bright, the one in cluster 3 is desaturated. It is cluster 5, with its medium lightness, high saturation and pink and bluish red hue that is most widely represented among the 20 shades sold most on the market. Fuchsia shades are appreciated in this region.

Interestingly, the Asian market shows a real preference for the shades in clusters 7 and 8, which they are often the only market to prefer (Saito, 1996). This is the geographical area where we find the largest number of specific shades, as 8 shades in the Top 20 only appear in this market. All the shades in cluster 8 are present among the 20 best-sellers, i.e., 9 shades out of 20. Cluster 8 includes the light to very light, highly saturated shades, with very bright colors. Thus, Asia is the most differentiated part of the world compared with the other geographical areas. It is distinguished by different color choices from those of the other markets studied.

Asians tend to prefer pinkish shades, while other parts of the world tend to prefer redder shades. However, although the preferences of France, Italy and the United Kingdom are relatively similar compared with other countries, differences can nevertheless be discerned between South America and the United States. South Americans are inclined to prefer brown shades like *Rouge Allure Rouge Vie* while North Americans tend to prefer reds. Thus, similarities and countries whose choice of shades is very close can be observed (Choungourian, 1968), (Urien and Divard, 2000).

For example, Italy and France share a preference for 13 of the 20 best-selling shades. There are mainly issued from clusters 2 and 3, which shows similar preferences for desaturated, brownish, intermediate lightness shades.

Asia and USA are the most distant with only 4 out of 20 shades in common.

Areas	Italia	UK	South America	Asia	USA
France	13	11	11	8	10
Italia		12	12	9	8
UK			10	8	11
South America				6	10
Asia					4

Table 1. Number of shades shared by two regions of the 20 shades present in the ranking.

The first criterion of similarity in the choices seems to be linked to geographical proximity. Europeans share a preference for certain shades. As an illustration, Italy and France share 13 of the 20 best-selling shades. The United Kingdom shares 12 shades with Italy and 11 with France mainly from clusters 3 and 5.

Similarly, countries whose culture is Latin make similar choices in their shades and South Americans and Italians share 12 out of 20 shades, while France and South America share 11.

Lastly, there seem to be certain affinities between English-speaking countries, although they are somewhat less marked. Ten shades are shared by the United Kingdom and the United States but also by South America, the United Kingdom and the United States, a 50% similarity in all those cases.

The part of the world which is really very different from the others is Asia with a maximum of nine shades in common with another region, Italy, sharing only four shades out of 20 with the United States. Those two continents are the most distant in their shade preferences.

The countries which best represent world preferences are those of Europe, with France and Italy in the lead, closely followed by the United Kingdom.

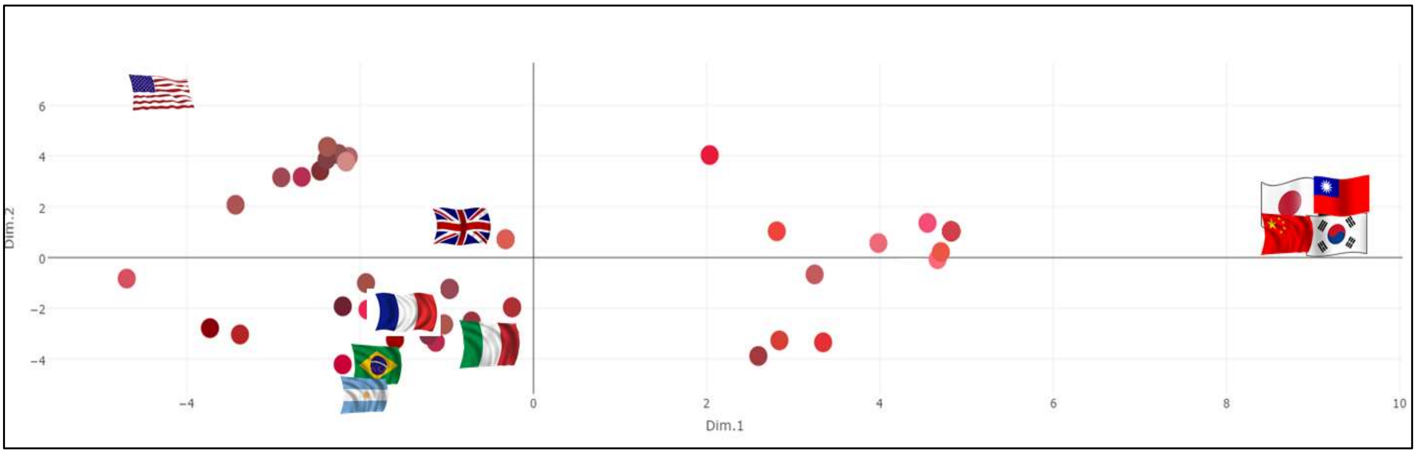

Fig. 7. Graphic representation of the 50 shades classified in the Top 20 sells of the 6 markets. Each point represents a shade. Market information is superimposed on shade information.

To study the color preferences in each region, the link between the ranking and the lipstick color classification was studied. The figure 5 is a cluster representation in the Top 20 ranking according to geographical region. France is the only region which presents shades in cluster 1 in its 20 best-selling shades. Italy shows a preference for cluster 7. Despite the United Kingdom is centrally positioned, like all European countries, its inclination is for American preferences. For the United Kingdom and the United States, cluster 3 is most frequently represented in the survey of their best sellers. Although South America shows a preference for cluster 5, a taste for saturated pinks suggests a degree of Latin proximity to France and Italy. Lastly, Asia is the most differentiated part of the world with a nearly 50% preference for light saturated shades (cluster 8). The specific shades which appear in a country's ranking but not in the five other regions are shades characteristic of the country's color preference. Although the results of this study make it possible to highlight differences in colorimetric preferences according to the regions of the world, it should be borne in mind that CHANEL's customers may have a specific appetite for the shades offered by this brand. Indeed, each company has a colorimetric "signature", related to the choices of the make-up artist of the House, the pigments referenced internally, the habits of the colorists of the research and development department, the marketing positioning of the brand etc (de Clermont-Gallerande, 2021).

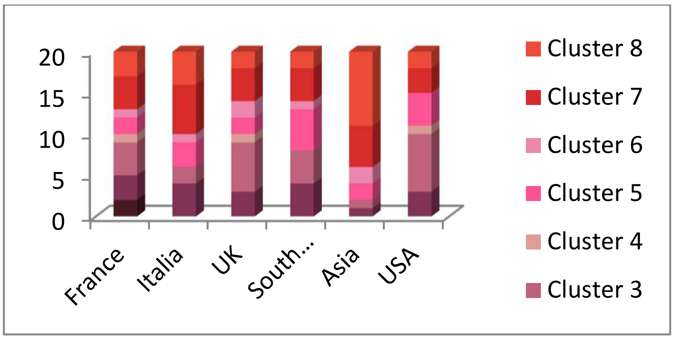

Fig. 8. Cluster representation in the Top 20 ranking according to geographical region.

5. Conclusion

The 50 best-selling lipstick shades in six regions of the world showed that the shade called *Rouge Allure Pirate*, a satured red with medium ligthness was unanimously preferred internationally.

The two most representative markets in terms of lipstick shades were Italy and France. The markets of Europe, France, Italy and the United Kingdom, were close in their choices while Asia was the geographical region where the best-sellers were the most different from the rest of the world. Lastly, a proximity in the choices of the Latin countries and a tendency towards proximity for the English-speaking countries was apparent. The best-selling lipstick colors differ from one area to another. Americans prefer pink or rosewood shades as do the British, while Asians opt for very fresh, light and saturated shades. In South America, bluish and saturated shades account for good sales figures. Each region shows its cultural difference through these color preferences. It would be interesting to repeat this analysis in few years on the same geographical regions to see if preferences remain stable or if they change over time.

6. Conflict of interest declaration

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sector.

7. Conflict of interest declaration

The authors declare that there is no conflict of interest with other people or organizations.

8. Short biography

Hélène de Clermont-Gallerande - Technological Innovation Manager at CHANEL. She has an experience of 30 years in color and make-up formulation and is inventor of more than 20 cosmetics patents. She published a collaborative book on Sensorial cosmetic raw materials.

Emmanuelle Mauger - Data Scientist at CHANEL Fragrance & Beauty's research center, in charge of data and their analyses to create insights. She achieved the statistical analysis of the study.

Nicolas Rolland - Colorist in CHANEL Color Development Laboratory for 8 years. Previously, he worked at L'Oréal also as colorist and has an expertise in color data management.

Licensing terms

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Colour, texture, and luminance: Textile design methods for printing with electroluminescent inks

Delia Dumitrescu [1], Marjan Kooroshnia [1], Erin Lewis [1] and Kathryn Walters [1]

[1]The Swedish School of Textiles, University of Borås, Sweden; delia.dumitrescu@hb.se, marjan.kooroshnia@hb.se, erin.lewis@hb.se, kathryn.walters@hb.se

Corresponding author: Marjan Kooroshnia (marjan.kooroshnia@hb.se)

ABSTRACT

Printable smart materials offer textile designers a range of changeable colours, with the potential to redefine the expressive properties of static textiles. However, this comes with the challenge of understanding how the printing process may need to be adapted for these novel materials. This research explores and exemplifies the properties and potential of electroluminescent inks as printable smart colours for textiles, in order to facilitate an understanding of designing complex surface patterns with electroluminescent inks. Three conventional textile print methods – colour mixing, halftone rasterization, and overlapping – have been investigated through experimental design research to expand the design potential of electroluminescent inks. The result presents a set of methods to create various color mixtures and design complex patterns. It offers recipes for print formulation and documents the outcomes, offering a new design resource for textile surface pattern designers to promote creativity in design, and provides fundamental knowledge for the creation of patterns on textiles using electroluminescent inks.

KEYWORDS electroluminescent printing, smart textiles, textile design, texture, colour mixing

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1. Introduction

Smart materials have been defined as materials capable of changing from one state to many in response to external stimuli (Addington and Schodek, 2005). As raw materials for design, smart materials entered the textile practice decades ago (Braddock and O'Mahony, 1998; McQuaid and Beesley, 2005). Their presence has enriched the material palette traditionally used by textile designers, and the expressive language specific to the field (Kooroshnia, 2017; Mossé, 2014). Light has proven to be a highly valued design material in the form of LEDs, optical fibers, and electroluminescent wires, and has been used to complement the expressive vocabulary of textile design, such as in artistic applications (Bobeck Tadaa, n.d; Layne, 2006; Loop. pH, 2012; Kettley, 2015) and research practices (Jansen, 2015; Taylor and Robertson, 2014; Persson and Worbin, 2010). In these examples, which combine light and textile construction methods, light sources have been embedded in the design of textile structures or added by embroidery to the textile surface, defining a new category of textiles. Accordingly, the intangible materiality of surface design expressed by light combines with the physicality of textiles and produces a hybrid category of expressions resulting from the mixture of these distinct material characteristics: transformative/static, sharp/soft, digital/physical, visual/tactile.

These projects exemplify and expand the potential for textile designers to embed directly light into textile structures. Yet working with light using textile printing methods, which create a flexible light-emitting surface, is still an undeveloped field.

1.1. *Electroluminescence*

Electroluminescence (EL) was discovered in 1907 and named in 1936. Thin film EL (TFEL or ACTFEL) panels, which provided printable light materials for surface applications, were developed in the late 1950s and became commercially available in 1974. In the 1990s, thick dielectric EL (TDEL) was introduced and was shown to be brighter and more reliable, and could be produced using screen-printing (Kretzer, 2015; Deferme and Verboven, 2018).

EL inks work by sandwiching an illuminating layer between conductive and insulating layers: a transparent conductive substrate on which the EL ink is printed, followed by the printing of a dielectric and a second conductive layer. When a high voltage, at least 20V, and typically around 200-250V, is applied to the conductive layers, the device emits a short light pulse from the EL layer. Applying standard alternating current (AC) power allows this process to operate repeatedly, appearing as a continuous light source (Smet, et al., 2010).

The colour range of EL inks is biased towards blues, greens and yellows. The brightness and colour of EL inks may change relative to both voltage and frequency (Song et al., 2018). In industrially-manufactured EL products, the colour range can be extended through the use of dyes to change the colour of the light (Silver et al., 2008).

While there are exemplary works using EL inks in architecture (Kretzer, 2015), interaction design (Franinović and Franzke, 2015), interior design (Loop pH, 2012) and product design (Barati et al., 2018; Olberding et al., 2014), their focus is on the process of creating non-textural and geometrical light-emitting patterns, using a single colour of ink, and/or methods for controlling the light. This leaves space for further research exploring the design potential of the raw material – printed EL ink – in terms of expanding its colour palette and aesthetic range by experimenting with textile design methods – forming diverse colour mixtures, overprinting, and halftones. Thus, this research aims to explore and exemplify the properties and potential of EL inks as printable smart colours for textiles, in order to facilitate an understanding of designing complex surface patterns with EL inks. The methods proposed by this research offer new resources for surface pattern designers to expand their creativity and craftsmanship in the printing design process.

2. Set up for the experimental work

The technique of silkscreen printing by hand was used to print the EL inks directly onto a transparent, conductive surface (polyester film coated in indium tin oxide (ITO film); Gwent F2071018D1). The size of the silkscreen mesh was 43 threads per inch. The EL ink was covered by a white dielectric insulator print layer (Gwent D2070209P6), followed by a silver conductive print layer (Gwent C2180423D2), producing an EL device with a standard build per the manufacturer's guidelines. This produces an EL light emitted through the transparent substrate, meaning layers printed first sit at the top of the print when illuminated (Figure 1). The print cannot be illuminated to assess the design outcome until all layers have been printed and dried. To see the light range, samples were illuminated within a range of 8VDC to 20VDC through a DC/AC inverter and viewed in darkness. Colour measurements were also made in darkness, with a Datacolor Spyder5 colorimeter, using DisplayCAL 3.8.7.1 software. Five measurements of each sample were made, and outliers were calculated and discarded before the mean L*a*b* figures were calculated for each sample. It should be noted that the photos taken in a dark room were colour-managed to match as closely as possible the perceived appearance of the print when viewed in darkness.

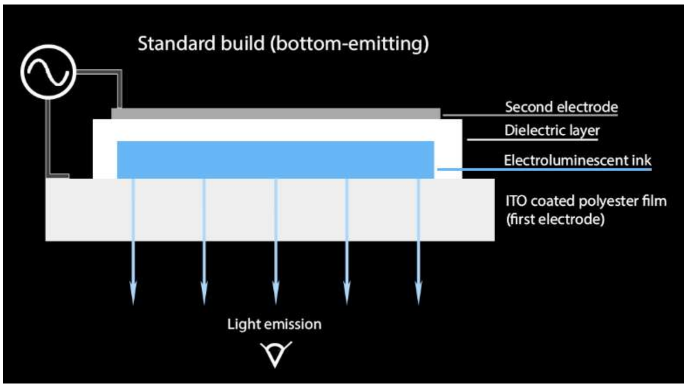

Fig. 1: The standard build illustrated as printed. When illuminated, the device is turned upside down, and the light emits from the bottom, throught the transparent film.

3. Design Methods

3.1. *Colour mixing*

Experiments were conducted using blue (Gwent C2061027P15), green (Gwent C2070209P5) and orange (Gwent C2070126P4) print pastes. The colour palette was obtained with mixes of two-colour blends in 10% increments. Each colour was also printed unmixed (100%), and a 1:1:1 (33% each colour) swatch was printed to test three-colour mixing. The result in daylight was a white print, however, once illuminated with an inverter at 20VDC and viewed in darkness, the effects were different coloured lights similar to mixtures of RGB lights: 80% green and 20% blue produced cyan, 20% green and 80% orange produced yellow light, and 80% orange and 20% blue produced magenta. The other mixes produced a smooth coloured light gradation. The 1:1:1 swatch appeared as a blue-green light and not white light. This is because white light is produced by the proper mixture of red, green and blue light. The green EL ink is perceived as more toward turquoise, while the orange is far from red (Figure 2).

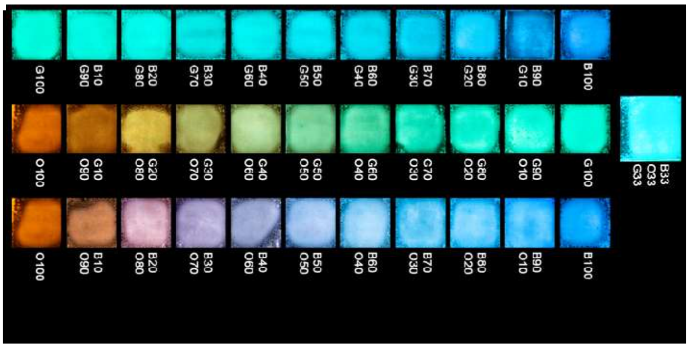

Fig. 2: Three colour scales produced by mixing two colours of EL inks using blue, green and orange, illuminated with an inverter at 20VDC and viewed in darkness.

The emitted light of each mixed colour was measured using the colorimeter, resulting in CIE L*a*b* values for each colour (Figure 3). While this provided useful information about the gamut and range of colours available through this method, the low L* (lightness) values of the colours did not represent them as they are perceived by the eye. In order to enable simulation as a design tool when using mixed EL ink colours, an RGB value for each colour was sampled from the photograph of the colour mix print. These RGB figures have been given alongside the measured L*a*b* values in table 1. These can be used in graphic design software such as Photoshop when designing and preparing patterns for EL prints. This provides a visual representation of the colours achievable with particular combinations and gives the designer the ability to predict the result before starting to print.

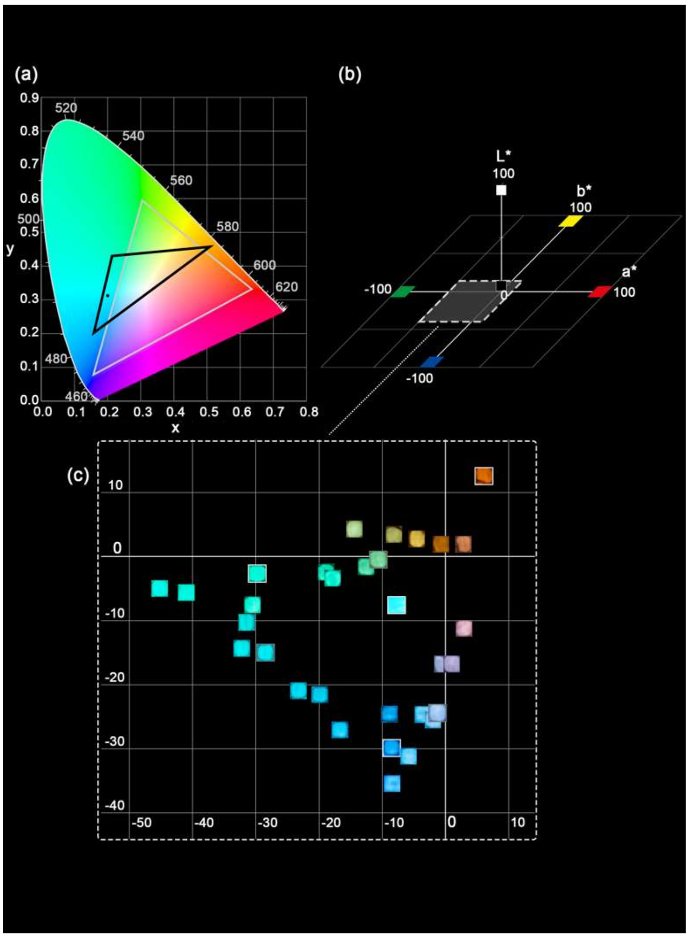

*Fig. 3: (a) the black triangle shows the gamut of the EL colour mixture palette, with the dot indicating the 1:1:1 colour mixture. The sRGB gamut is included (in grey) for comparison, and shows that the blue and green EL colours and their mixes cannot be fully represented in an sRGB environment (e.g., on-screen). (b) the CIE L*a*b* colour system, used to measure the colour palette values. (c) the EL colour palette mapped against *a and *b values (indicated in figure b by the gray square).*

Colour	L*	a*	b*	R	G	B
B100	12.47	-8.51	-29.9	167	208	253
B90G10	8.79	-9.02	-24.62	157	213	251
B80G20	15.53	-16.83	-27.02	154	219	248
B70G30	13.71	-19.99	-21.43	139	220	242
B60G40	15.97	-23.35	-20.92	131	221	236
B50G50	16.92	-28.59	-15.04	137	229	237
B40G60	17.83	-32.38	-14.34	136	236	234
B30G70	15.44	-31.54	-10.26	139	238	235
B20G80	23.18	-45.33	-5.03	147	244	232
B10G90	19.77	-41.13	-5.67	137	243	225
G100	11.63	-29.94	-2.64	90	227	194
G90O10	13	-30.73	-7.49	96	219	188
G80O20	8.55	-18.02	-3.3	100	207	176
G70O30	8.52	-18.83	-2.36	111	200	166
G60O40	6.05	-12.5	-1.62	92	144	114
G50O50	5.58	-10.63	-0.43	99	138	108
G40O60	8.25	-14.34	4.21	112	129	97
G30O70	6.08	-8.11	3.4	116	121	90
G20O80	4.58	-4.69	2.82	147	133	89
G10O90	1.6	-0.53	1.95	160	115	69
O100	7.64	6.2	12.46	209	113	0
O90B10	6.98	2.92	1.94	202	146	150
O80B20	14.66	2.88	-11.04	201	162	186
O70B30	11.16	0.88	-16.56	181	169	211
O60B40	10.29	-0.33	-16.8	177	175	219
O50B50	14.2	-1.37	-24.36	172	183	230
O40B60	15.31	-2.01	-25.37	174	194	238
O30B70	12.26	-3.62	-24.91	168	197	244
O20B80	17.68	-5.86	-31.21	169	201	247
O10B90	17.4	-8.37	-35.45	173	209	252
B33G33 O33	5.12	-7.73	-7.67	83	131	140

*Table 1: Measured L*a*b* values, and suggested RGB values, for the EL ink colour palette.*

3.2. *Overprinting*

An overprinting experiment was conducted to test the potential for blending colours through overprinting the three unmixed, 100% EL orange, green, blue inks. All possible two-colour overprints, including inversion of each overlap order, were tested, waiting for each layer to dry before printing the next. It was expected that the effect obtained by the overprinting of two different colours would result in a similar effect as if they were mixed equally and then printed. However, the results indicated that the printing order had a significant impact on the resulting colour when overprinting, with the top layer colour (printed first) dominating the resulting blended colour (Figure 4). When the EL prints were activated, they showed some errors such as unwanted particle gathering and uneven paste distribution that occurred during the hand-screen printing process. Careful fabrication is thus important when planning and producing high quality designs. The results of this experiment guided the research towards exploring rasterization.

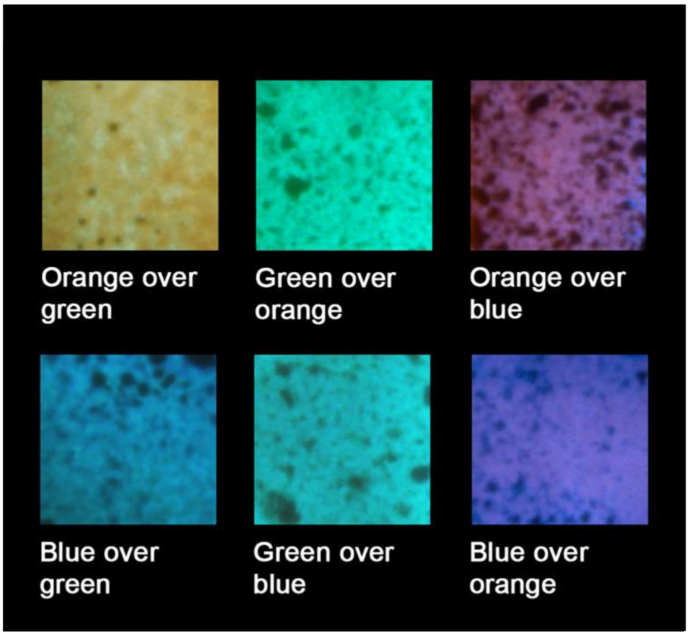

Fig. 4: There was a perceivable difference in green on top of orange and orange on top of green, for example; both combinations of orange and green resulted in a different coloured lights.

3.3. *Rasterization*

An experiment was conducted to determine the best resolution for rasterizing when printing with EL inks. A stepped gradient, of 10% to 90% density, in 10% increments, was used to create 'dot' and 45° 'line' halftones, using 30, 25, 20, and 15 lines per inch (lpi). The result after activating the print indicated that the dot halftone had clear definition at low densities, across the range of resolutions from 30 lpi to 15 lpi. The 45° lines, however, were only clear at 20 and 15 lpi, even at low densities. The results of this experiment suggest that coarser resolutions of 15 or 20 lpi are more effective for producing detail, and that either only two or three densities should be used, or lower densities than were tested, to ensure visible differences between areas (Figure 5).

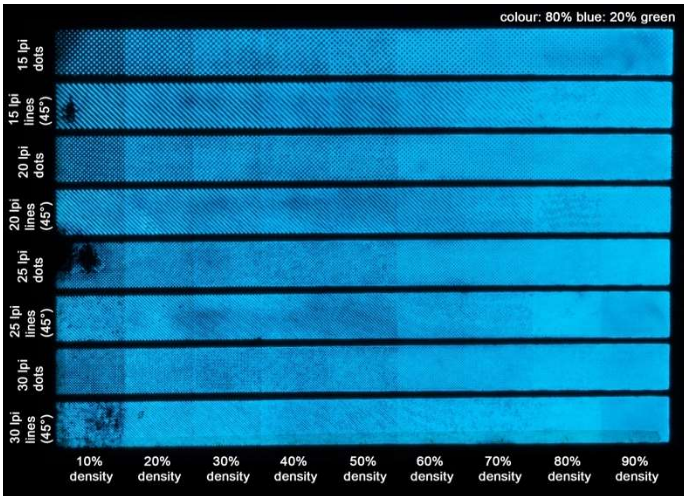

Fig. 5: The result of the rasterization experiment.

Two experimental sets were conducted to evaluate colour mixing through halftone rasterization, again using the three print paste colours unmixed at 100%. These were split into two colour groups: analogous colours – blue followed by green – and complementary colours – orange followed by blue. The first set (Figure 6, prints 1 and 2) was made using the 20 lpi dots, 15 lpi lines, and 15 lpi dots, each at 10% and 20% density, with the screen slightly offset so the two colours did not overlap and would mix optically. The second set (Figure 6, prints 3 and 4) used the same rasterizations for the first colour layer, however, the second colour layer was printed with 30% and 40% density, turning the screen 180°, so the 15 lpi dots were covered with 20 lpi dots and vice versa. The result indicated that colour mixing using rasterization is different to colour mixing through overprinting the two colours or mixing the two colours. For instance, the colour mixing of 10% blue and 40% green in print number three appeared equivalent to the 20% blue and 80% green (B20G80) mixture in Figure 2, and these were equal in terms of colour proportion but they represented two different coloured light mixtures (Figure 6).

4. Result

4.1. *Designing surface patterns using EL*

After understanding how El inks behave and how this may impact the design process, a set of surface patterns inspired by a twill woven fabric and two knitted textiles featuring patterns of dots and lines were designed, with the aim to exemplify how the different methods for colour mixing developed by this research can be used when forming a design. The surface patterns were designed as two-screen prints using Photoshop consuming data from table 1, and aware that the colours of positive and negative spaces were reversed in darkness (Kooroshnia, 2014).

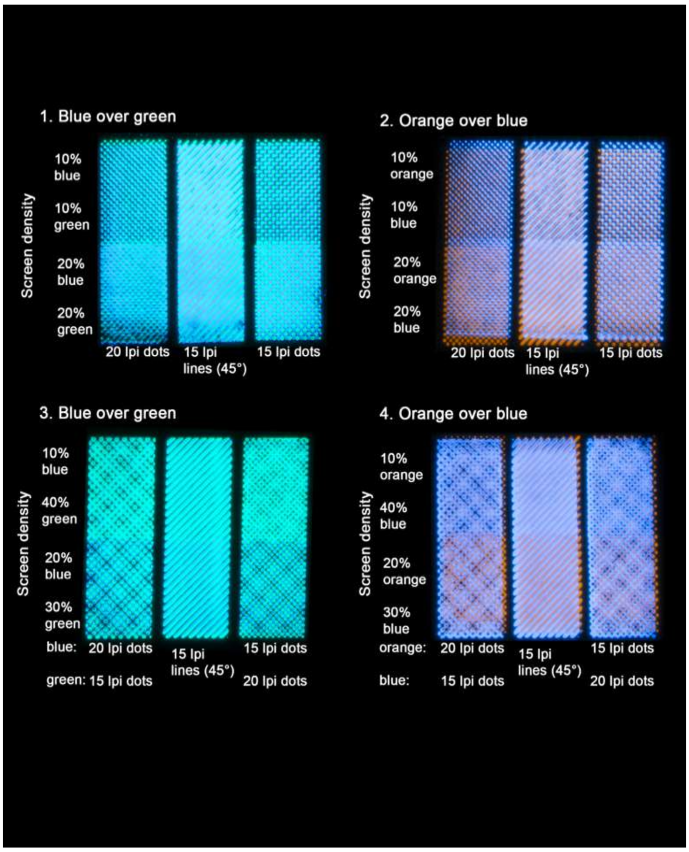

Fig. 6: three-dimensional effects were observed in all the prints. In prints 3 and 4 moiré effects were created due to the interaction of the different rasterization lpi values for the two overlapping colours.

Two pairs of colours were selected from the colour mixing experiments. Design 1 used 100% blue (B100) EL ink in the first layer and a mix of 20% green with 80% orange (G20O80) for the second layer. Design 2 used 100% green in the first layer (G100) and a mix of 20% blue with 80% orange (B20O80) for the second layer. Design 3 was printed with a mix of 20% blue with 80% green (B20G80) in the first layer, and a mix of 20% blue with 80% orange (B20O80) in the second layer.

To enhance the textural expression of the printed EL patterns the technique of halftone rasterization was used with the aim to mimic the visual effect of surface patterns printed on textiles. Likewise, to enhance the colour palette, the technique of overprinting was used to create complex colour mixtures as visual effect in both the foreground and background of the designs (Figure 7). The results were compared to the sketches made in Adobe Photoshop. The printed EL patterns demonstrated that visual effects such as complex color mixtures, form intervals, perception of movement, and spatial illusion can be achieved through printing with EL materials.

These effects occured mainly because a combination of dim and bright coloured lights resulted from the overprinting.

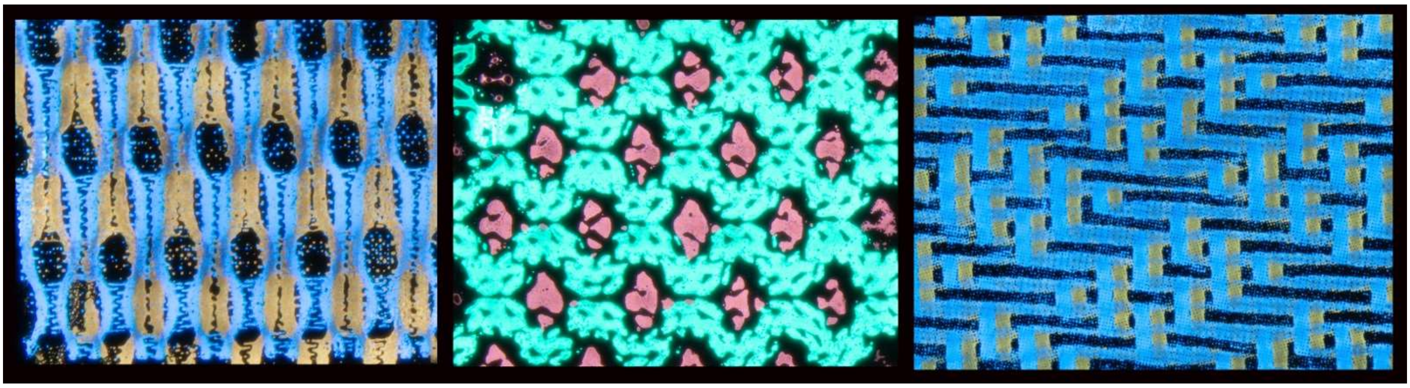

Fig. 7: Designers can use EL inks to print light-emitting surface patterns, using the same methods used for surface pattern pastes. From Left to right: designs 1, 2 and 3.

5. Discussion

By demonstrating the potential of EL inks when approached using textile design methods for printing such as colour mixing, overprinting, and halftone rasterization, this research expands the design possibilities of EL crafted displays in producing a novel, coloured, rich textural character to light as a material for surface design. We suggest digital RGB values for mixed colours, enabling computer simulation of designs, removing some of the risks from this technique, and freeing designers from the flat, monochromatic designs that characterize current EL offerings.

The experiments were evaluated in a dark room using an AC/DC inverter supplied with a variable direct current (DC) power supply to illuminate the prints. Stepping the DC voltage through 20V, 16V, 12V, and 8V dimmed the coloured lights, creating an illusion of space in the surface pattern (Figure 8).

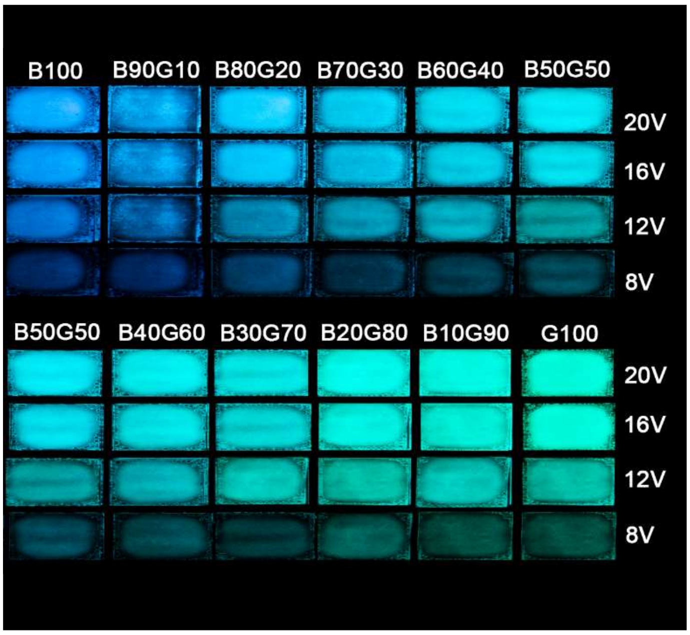

Fig. 8: Illuminating the prints with 8V creates the dimmest coloured lights and 20V creates the brightest coloured light.

In addition, while EL printing typically produces static colour, it can be used in the design of segmented displays to produce transformative digital textiles with temporal variations through changes in brightness (i.e., through variable voltage sequencing) and as such offers an alternative to complex multi-LED arrays, or the linear restrictions of optical fibre. It has the potential to open new territory in textile design for flexible, luminous, and dynamic textile displays with complex textures and surface patterns and temporality.

Recent research in material engineering has proved it is possible to print basic EL inks directly onto textiles, maintaining their intrinsic flexible properties to create functional lighting surfaces (Verboven, et al., 2018). From a design perspective, the replacement of plastic substrate with textiles demonstrates more expressive potential by enhancing the haptic perception of the printed patterns. However, more cross-disciplinary research is needed to be able to combine the two perspectives into the development of aesthetic and functional products. This research mirrors the LED-based work of Mueggler Zumstein et al. (2016), in providing colour reference tools to enable textile designers to approach designing with smart materials.

In daily life, we are used to communicating and being surrounded by visual and haptic displays which are hiding complex technologies. By proposing methods to create complex surface patterns with enhanced colours and textures, the result of this research suggests more creative ways to express smart technologies for the automotive or home environments when designing displays with tactile and visual feedback. Likewise, EL printing as applied in product design or architecture offers as a design asset the familiar expression of textiles. This could provide an interface for lighting technology which might enable alternative ways to experience peripheral information or adapt interior atmospheres to ensure well-being.

6. Conclusion

The experiments conducted during this research suggest that the print potential of EL inks is wider than has been explored in art, design and research so far. Even with the limited colour range of commercially available EL inks, broader aesthetic and textural expressions are possible than the typical flat blue of the technology to date. Textile craftsmanship and design methods such as colour mixing, halftone rasterization, and overprinting may be applied to electroluminescent inks, and the design potential of these techniques can be used to produce light-emitting smart textiles, where the intangibility of light combines with the physicality of textiles to define a hybrid category of expression.

7. Conflict of interest declaration

No financial/personal interests have affected the authors' objectivity(s).

8. Funding source declaration

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9. Short biography of the author(s)

Delia Dumitrescu is Professor in Textile Design at the Swedish School of Textiles. Her research focuses on the development of smart textile design methodology and how smart textile design methods can be expanded to related design fields with the aim of developing cross-disciplinary practices.

Marjan Kooroshnia is a colour researcher and associate professor at the Swedish School of Textiles. Her PhD research explored the design properties and potentials of thermochromic colours printed on textiles in order to expand the range of colour-changing effects and to facilitate communication regarding, understanding of, and designing with, these smart materials.

Erin Lewis is a PhD researcher in Textile Interaction Design at The Swedish School of Textiles. Her research explores electromagnetic textile expressions in the form of interactive, wearable, and ambient textile prototypes.

Kathryn Walters is a PhD researcher in Textile Design at The Swedish School of Textiles. Her research area includes complex woven structures and changeable textile materials.

Licensing terms

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Imaging colorimeters to evaluate Camera Monitor Systems image quality

Cristian Bonanomi[1] and Kedar Sathaye[2]

[1] *Konica Minolta Sensing Europe B.V., Milan, Italy. Cristian.Bonanomi@seu.konicaminolta.eu*

[2] *Konica Minolta Sensing Europe B.V., Nieuwegein, Netherlands. Kedar.Sathaye@seu.konicaminolta.eu*

Corresponding author: Cristian Bonanomi (Cristian.Bonanomi@seu.konicaminolta.eu)

ABSTRACT

Over the last few years, we have experienced a gradual increase in autonomous and driver assistance technology. Generally, we refer to these systems as ADAS (Advanced driver-assistance systems). A particular aspect of ADAS is Camera Monitor Systems (CMS), a system composed of a camera, a software that performs image processing operations, and a monitor for the driver. These systems help increase the overall safety aspect of the vehicle and increase the visibility of the drivers' surroundings; therefore, the original equipment manufacturers (OEMs) must adhere to country specific regulations, necessary to test the robustness of the system. There are several test procedures for assessing CMSs, in this paper we will focus to the optical performance evaluation of the system. This includes lighting system, test patterns and an imaging colorimeter accompanied by a software which performs measurements according to the regulations mentioned in ISO16505:2019 (ISO, 2019).

KEYWORDS Advanced Driver-Assistance Systems, Autonomous Driving, Camera Monitor Systems, 2D Colorimeters, Display Evaluation

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1. Introduction

Over the last few years, we have experienced a gradual increase in autonomous and driver assistance technology and according to ABI research forecasts almost 8 million cars with autonomous or semi-autonomous level by year 2025 (ABI research, 2021).

The Society for Automotive Engineers (SAE) defines six levels of driving automation when talking about vehicles (SAE, 2021): from no automation (level 0) to full driving automation (level 5). Beyond these levels, many efforts have been made to provide systems that facilitate enhanced driving situations. Generally, we refer to such systems as ADAS (Advanced driver-assistance systems) as electronic systems that assist users in driving and parking functions.

A particular case of ADAS is the Camera Monitor Systems (CMS): a system composed of a camera, a software that performs image processing operations, and a monitor to illustrate the possible dangers as well as the blind spots around the car, mainly integrated in rear view mirror or side view mirror. Although the technical name used in the standards, is Camera Monitor Systems, the automotive market uses different names, and these systems can be referred to as virtual mirrors, digital mirrors, or electronic mirrors. Whatever name is used, these systems help increase the overall safety aspect of the vehicle and increase the visibility of the drivers' surroundings; therefore, the original equipment manufacturers (OEMs) must adhere to country specific regulations, necessary to test the robustness of the system.

In this paper we will discuss about the ISO 16505: 2019 "Road vehicles — Ergonomic and performance aspects of Camera Monitor Systems — Requirements and test procedures" (ISO, 2019), with particular attention to the optical performance evaluation of the system. To ensure image quality, several tests need to be performed to evaluate monitor characteristics e.g., directional uniformity, luminance, color rendering and sharpness, etc. The components (camera and display) can be measured separately, to easily discover where degradation has occurred, however sometimes it is necessary to test the complete system, a task that requires a high-resolution imaging colorimeter.

In the following, we will focus on the materials and methods necessary to test the robustness of the system, which include: a lighting system to simulate different lighting conditions, i.e., direct sunlight or diffuse sky exposure, several test patterns to be used and imaging colorimeter accompanied by a software which performs measurements according to the standard regulations mentioned in ISO16505:2019 (ISO, 2019). The state-of-the-art imaging colorimeter and the dedicated software ensures that CMS under test is correctly validated.

2. Camera Monitor Systems

A CMS is a possible technology to replace exterior mirrors, to display the side or rear view on a monitor inside a vehicle (see figure 1).

Fig. 1. Example of a CMS system for a truck. Top row: CMS camera, bottom row: CMS display

However, since exterior mirrors are fundamental for the safety, it is important to evaluate if a CMS can be a source of reduced safety or provide equal or more information to the driver. Generally, a CMS improves the aerodynamics of the vehicle decreasing wind resistance coefficient and noise. Furthermore, it reduces the blind zone area, improving the safety of driving.

In 2015 an extensive work (Schmidt *et al.*, 2015) was done to evaluate CMS as replacement for exterior mirrors in cars and trucks. The authors tested technical aspects as well as human-machine interaction scenarios. Although it has only been seven years since the report, many technical issues have been overcome, though some of the aspects underlined in the document are still of interest and concern. We recall some of them in the following, leaving to the reader the task of reading the complete report.

Both external mirrors and CMSs have advantages and disadvantages. Some of these are related to technical aspects, such as optical quality; for example, resolution, color and contrast rendering, or time behavior properties that happen in critical situations. Additional aspects such as exposure adjustments when entering or exiting from a tunnel, or when a road surrounded by trees creates a succession of shadows and sunny areas are considered. These situations and aspects have been improved in the last years, thanks to technological advancements.

Other aspects are related to intrinsic properties of the two systems: a mirror follows the reflection law, and movements of the head can add 3D information to the driver, while these movements do not affect the vision on a display.

Furthermore, weather conditions can affect the two systems in different way: under the rain, the drops on the driver's side window as well on the mirror itself can reduce the mirror visibility, while this condition seems to affect less the CMS, if the camera is in a well-covered position and since the display is inside the vehicle. Direct sunlight, snow or night driving are other non-standard conditions that must be considered.

Finally, there are aspects related to the human-machine interaction: some experiments with human drivers have been carried out, resulting in a different perception of speed and distance when objects are viewed through a CMS. However, generally, people can adapt quite quickly to this new situation.

All these aspects need consideration when using a CMS, therefore a procedure performing a range of tests on these systems has been developed in ISO16505:2019 (ISO, 2019). The standard includes several tests dealing with operating readiness, time behavior properties (evaluating frame rate, system latency), failure behavior, quality and ergonomic requirements, etc.

In the following section we are going to focus only on image quality tests.

3. Testing Camera Monitor Systems

Testing Camera Monitor Systems requires several items:

- Test charts to evaluate different properties of the CMS. These charts can be found in specialized stores (i.e., (Imatest, 2021)).
- Illumination of the charts, to simulate different lighting conditions.
- The CMS camera installed outside of the car.
- The computer that elaborates the data of the camera.
- The CMS monitor used by the driver.
- A digital camera or a 2D colorimeter to evaluate the result of CMS monitor.
- A light source that illuminates the CMS display, to simulate i.e., direct sunlight.

An image presenting the setup and the necessary elements for evaluating the image quality of the CMS is shown in figure 2 (the bottom row represents a schematic view of the same setup). However, other light sources can be added to this setup to evaluate other conditions, like the contrast rendering under different ambient illumination conditions (please refer to section 3.2).

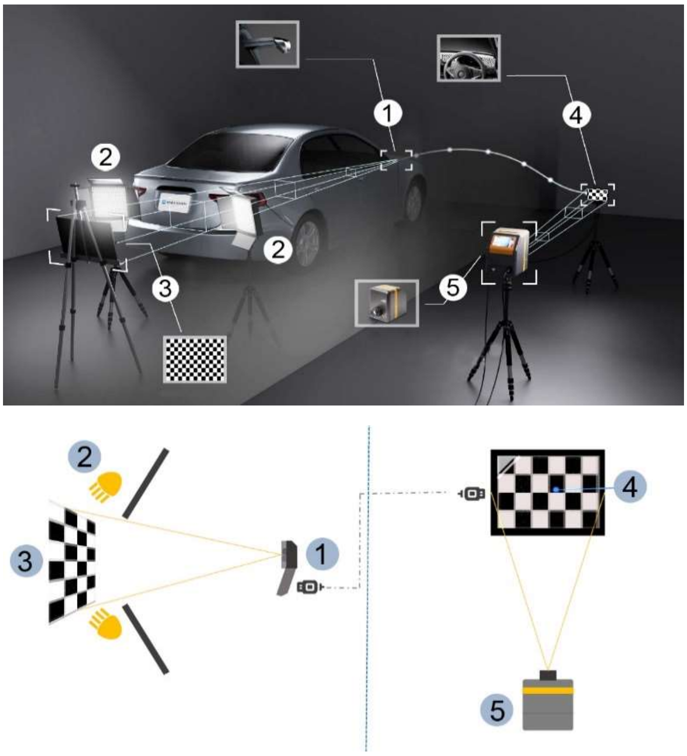

Fig. 2. Setup to evaluate a CMS system: 1) CMS camera, 2) lighting system for the target, 3) printed target, 4) CMS display, 5) 2D colorimeter for CMS evaluation.

The evaluation of a CMS requires several tools and a dedicated facility. For this reason, such tests are usually conducted directly by OEM (Original Equipment Manufacturer) or by specialized independent third-party laboratories. These laboratories provide technical services offering verification, inspection, and certification of several products in accordance with international and national standards as well as audits for systems management certification (i.e., (TUV, 2021)).

In the following, we are going to address the previous elements, with particular attention to the evaluation of the optical characteristics of the CMS system. These tests can be divided in five sets: 1) to verify the basic characteristics of the display like luminance, contrast and uniformity; 2) to evaluate potential issues related to the driving conditions: readability of the display, lens flare due to direct light, etc.; 3) to ensure the colors are correctly reproduced, i.e., for identifying the traffic lights; 4) to take in consideration or alert the driver about possible artefacts, and 5) to assess the resolution and sharpness of the system, in order to identify details.

3.1. *Monitor Isotropy*

The Monitor isotropy test aims at evaluating the optical characteristics of the display according to different positions and viewing directions, using a uniform 70% gray scale image. Measurements of the directional uniformity are performed using a goniometer or a conoscope. A conoscope (figure 3, left) is a special lens that can be plugged to a 2D colorimeter to measure the angular distribution of luminance, contrast and color of a display. Lateral uniformity is measured on 9 positions on the display which coordinates are specified in the standard.

3.2. *Luminance and contrast rendering*

The evaluation of luminance and contrast rendering is done on five different ambient illumination conditions that can affect the monitor readability. These conditions simulate: direct sunlight, diffuse skylight in day condition, night condition and sunset condition.

Generally, a test chart composed by a white and black chessboard, is illuminated by two light sources, with a defined spectral power distribution, color temperature and illuminance value.

The sunset condition is simulated using a direct light source reflected in a mirror towards the CMS camera, to evaluate artifact like blooming, smear and flare.

3.3. *Color rendering*

This test is used to verify the CMS capability to reproduce eight specific colors (red, green, blue, yellow, cyan, magenta, black and white, placed on a 18% neutral gray background), in an accurate way.

The test chart used for the color rendering should satisfy a range of conditions, including (see also figure 4c):

- The color patches are placed on a circle, in order to keep the same distance from the center.
- Opposite patches should have complementary colors.
- The illumination of the chart should simulate CIE D65 and have a CCT of 6500 K +-1500K.

To verify the accuracy of color rendering, a spectroradiometer or a colorimeter should be used to measure the chromaticity of the chart as well of the CMS monitor and convert them to the CIE 1976 uniform color space. The measurements done on the monitor are converted in chromatic hue angle to verify that they are in the correct range, while the measured data of the chart are not used for any calculation but to confirm the appropriateness of the used color chart and illumination.

3.4. *Artefacts*

The possible artifacts and their drawbacks should be listed in the opertaor’s manual: smear, blooming and lens flare, can cause partial occlusion of the field of view that shall not cover more than a specifc percentage; point light sources, simulating low beam headlamps of another car, should be rendered as distinguishable lights; color noise and chromatic aberration should be avoided or minimized details.

3.5. *Sharpness and depth of field*

Other important tests of CMS regard the sharpness and the related properties: resolution and depth of fields. Sharpness is measured evaluating the $MTF50_{(1:1)}$ (modulation transfer function) of a chart composed by five black squares slightly tilted. In order for a CMS to recognize object of interested behind the vehicle, also the depth of field needs to be measured.

3.6. *Regulation No. 46 – Addendum 45*

European regulation No. 46 (ECE R46, 2020) regulates the principles for the approval of motor vehicles for the installation of rear-view and side-view mirrors, in Europe. This standard is based on ISO 16505: 2019. The addendum 45 specifically, addresses considerations and procedures about the display-based systems as an alternative to conventional mirrors. This addendum adds a couple of tests for evaluate CMS:

- Gray-scale rendering: this test aims at verifying that the CMS can display at least 8 tonal gray steps distinguishable from the darkest to the brighter.
- Point light sources: this test is used to verify that the CMS can recognize and render as distinguishable two-point light sources (to simulate passing beam headlights). In particular, a set of two point light sources located at a distance of 250m from the CMS camera, having a luminous intensity of 1750 cd and separated each other by 1.3m, should be distinguishable.

4. Using a colorimeter for CMS evaluation Systems

All the mentioned tests need a specific instrument able to inspect luminance, color and fine-details. A spot meter device (both a filter-based chroma meter or a spectro-radiometer) could be used, due to its capability of measuring the luminance and color in an accurate way.

However, doing repeated measurements is time consuming, and spatial measurements, like sharpness or blooming test, cannot be performed.

Fig. 3. Example of a 2D colorimeter, used for CMS evaluation. On the right, the colorimeter with a conoscopic lens mounted.

On the other hand, a digital camera can provide high resolution images, but cannot measure luminance in accurate way or a traceable color rendering. To follow this standard, color accuracy is an extremely important factor, and digital cameras, which are typically used in consumer photography, are designed to please the viewers, enhancing color saturation, rather than reproduce color accurately. Furthermore, the color generation in digital cameras is achieved by a Bayer pattern, and the process of raw conversion can affect color.

	Spot meter	Digital camera	2D colorimeter
Directional uniformity	D	X	Y (conoscope)
Lateral uniformity	D	D	Y
Gray scale rendering	D	D	Y
Color rendering	D	X	Y
Point light source	D	Y	Y
Sharpness / D.o.F.	X	Y	Y

Table 1. Comparison between devices to perform specific tests. X: cannot be done, Y: can be done, D: can be done with difficulty.

An imaging colorimeter, also known as 2D colorimeter, (figure 3) is the optimal solution to evaluate the image characteristic of the CMS, since it comprises the accuracy of a chroma meter and the flexibility of a digital camera. The color measurement is done through four filters that carefully simulate the CIE color matching functions. The fourth filter is used to simulate the small peak of the $\bar{x}$ CMF in the blue side of the spectrum. These filters are placed on a rotating filter wheel, so that four different images are taken, to maximize resolution without spatial interpolation, as happen in typical digital cameras. This is a key point to consider, since for testing CMS, the 2D colorimeter needs much higher resolution than the camera and monitor that constitute the CMS.

Another significant point requested by the standard is the necessity to evaluate the directional uniformity of the monitor. Some colorimeters allow the use of a special conoscopic lens (figure 3, right), which through Fourier optics can map an emitting spot so that each pixel of the sensor corresponds to a different emission angle. Radiant Vision Systems (RVS, 2021), provides hardware that fulfills the standard requirements and a comprehensive software suite to evaluate Camera Monitor Systems. Table 1 shows the ease to perform the required tests using different type of devices.

In figure 4 three screenshots from the software are presented. Figure 4a) shows the interface, which allows the selection of an Analysis test (top image), and the parameters that can be set for the specific function (bottom image). In the example, the test “Contrast rendering” is selected, with the “Direct sunlight” as lighting condition, to reflect one of the standard requirements. Figure 4b) shows an image taken with the conoscope. This is a false color representation of the luminance in a specific point of the display, expressed in polar coordinates. For the display under test, the luminance decreases with the angular viewing. When observed perpendicularly (white area), the luminance is around 700 cd/m^2. At the cursor point, with coordinates [Inclination 50°, Azimuth 135°], luminance is around 380 cd/m^2 (light blue). For this specific display the image shows that the display is very dim when observed from below, a condition that of course does not occure in a car. Figure 4c) is an acquisition of the color rendering chart. The software helps the user to correctly register the patches, and after the execution of the analysis, returns a pass/fail result according to the standard requirements. Figure 4d) shows how two point light sources appear in the acquisition that simulates passing headlights. To perform this test, it is usually used a lighting device composed by two high intensity LEDs placed not too far from the CMS camera. Figure 4e) represents the typical checkboard pattern to evaluate the contrast of the display, under various daylight conditions. Figure 4f) shows the acquisition of the gray scale rendering pattern, to evaluate if the CMS is able to display at least eight distinguishable tonal gray levels.

5. Conclusions

In this paper we have seen how CMSs offer technological innovation yet create a set of new challenges for inspection that must be validated for the use in advanced levels of autonomous driving.

Since replacing side and rear mirrors is a safety concern, a complete protocol to test these new technology platforms is necessary. Different regulations are in force in different countries (i.e in US: (FMVSS111, 2019) and in Canada (CVMSS111, 2017)). In Europe UN Regulation No. 46 (ECE R46, 2020) concerns the approval of devices for indirect vision and of motor vehicles with regards to the installation of these devices. This regulation incorporates test standard from ISO16505:2019 (ISO, 2019), which primary is to offer a guide to evaluate in an objective and critical way the quality and reliability of the CMSs. All the tests need instruments able to measure photometric and colorimetric properties as well as some spatial characteristics. In principle, different types of devices can serve the scope: spot meter devices, calibrated digital cameras or 2D colorimeters. However, only the latters can be considered as the optimal solution to evaluate the optical performance of the CMS, combining the accuracy of a chroma meter and the flexibility of a digital camera. Futhermore, the use of a special conoscopic lens can measure in a single step the luminance at different emission angle. All these aspects have been reviewed in the paper, with a special focus on the optical properties evaluation described in the European standard, and on the necessary tools that an OEM or a third part laboratory should use to carry on these tests.

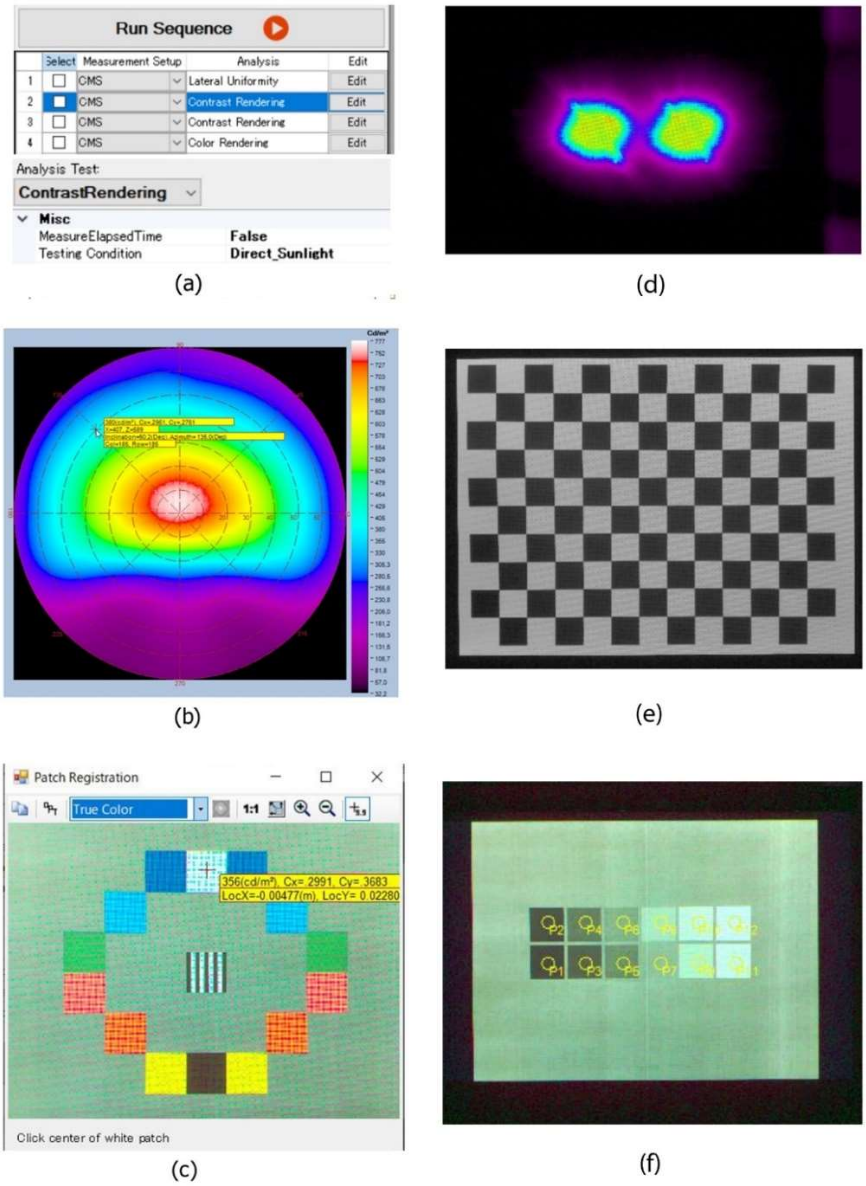

Fig. 4. Screenshots from CMS evaluation software: a) analysis selection, b) conoscope measurement for evaluating directional uniformity, c) patch registration for the color rendering test, d) simulation of two-points light source, e) checkboard pattern to evaluate contrast, e) gray-scale rendering pattern.

6. Conflict of interest declaration

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9. Short biography of the authors

Cristian Bonanomi – He received his degree and PhD in Computer Science, at Università degli Studi di Milano, where he worked as research fellow for six years, on colorimetry, human perception, digital imaging. He is currently employed in Konica Minolta Sensing, as Light and Display sales specialist.

Kedar Sathaye - He received the PhD from Telecom Bretagne, where he focused on Optics and Photonics. He is now Product Manager of Light and Display in Konica Minolta Sensing. Previously he worked as display expert in Panasonic Automotive, and in Valeo as Optical Innovation Engineer. His fields of experience are in Optical Engineering, Spectroscopy, Lighting, Liquid Crystals, and Product Development.

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An experimentation on children's colour preferences in generic terms and applied to a school context

Camilla Giani[1], Cristina Boeri[1]

[1] *Color Lab, Department of Design, Politecnico di Milano, Italy. milly.giani@hotmail.it, cristina.boeri@polimi.it*

Corresponding author: Camilla Giani (milly.giani@hotmail.it)

ABSTRACT

The aim of the paper is to present an ongoing study on the evaluation of children's colour preferences in the school context. In particular, two experiments have been planned and partially conducted in order to evaluate both the differences that may be found between colour preferences expressed in generic terms and contextualized in a school environment, and the differences that may be found between digital simulations displayed on the computer and experimented using the CAVE technology. The paper presents the methods of the two experiments and the results of the first experimentation conducted on children between the ages of 6 and 10 using an online questionnaire that showed children both digital colour samples and digital colour simulations of the same colours applied to a classroom environment.

KEYWORDS Colour design, colour preference, school design, children colour preference

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1. Introduction

Several authors have highlighted the importance of colour in school environments in relation to both functional and emotional values, also offering indications regarding the colours and schemes to be adopted (Birren 1969, Mankhe 1998, Grube 2014, Engelbrecht, 2003). In the framework of the studies about the evaluation of the emotional response to colour in children, and therefore on children's colour preferences and associations, some experiments were conducted by circumscribing these evaluations to specific contexts. In these studies, simulations of differently coloured interior environments are subjected to the evaluation of children instead of generic or abstract colour samples. In particular, the studies by Read and Upington (2009) and Dalirnaghadeh (2016) assessed children's colour associations and preferences in preschool interiors using the image of a school environment manipulated to create different colour alternatives. In the study by Park (2014), the correlations between colour attributes and children's colour preferences for interior room colours were analysed using scale-models. These studies contribute to the discussion regarding the role of the context in which the emotional response to colour is evaluated and therefore the possible design implications related to the study of colour preferences and associations in children. On the other hand, the limits linked to the simulation of reality and its simplification, even in monochromatic terms, raise the need for more circumstantial studies and research to concretely guide the design choices (Boeri, 2019).

In this framework two experiments have been planned and partially conducted in order to evaluate both the differences that may be found between the colour preferences expressed in generic terms and contextualized in a school environment, and the differences that may be found between digital simulations displayed on the computer and experimented using the CAVE technology.

2. Methods

The study focused on the design of two experiments for the evaluation of children's colour preferences in a general and contextualised situations using digital simulations of a primary classroom environment. Both the experiments were designed to involve children (age 6-10) in the evaluation of a selection of 26 colours firstly showed just as digital colour samples and then applied to digital simulations of the same classroom using a 3D model to be experienced in monitor for the first experimentation and in a CAVE for the second one. CAVE technology will allow the display of a 360 ° image of the classroom created as a 3D model.

The model used for the simulation consist in a traditional classroom of 25 children set up with desks, chairs, wardrobe and shelves. The furnishings used have a gray-coloured metal structure and natural coloured beech wood seats, backrests and shelves (*Figure 1*).

Fig. 1. The classroom view used in the study.

Different colours were applied exclusively to the walls in a monochromatic solution of the classroom environment, which means all the walls were coloured with the same colour. This solution has been used in several studies both to verify the psycho-physiological effects of single colours (Hettiarachchi and Nayanathara 2017; Kwallek et al. 1996; Kwallek and Lewis 1990), and to probe colour preferences related to a specific environment (Read and Upington, 2009; Dalirnaghadeh, 2016).

The colours selected were decided on the base of their recurrence in the literature addressing the children's colour preferences taking into consideration the belonging to the same age group (6-10 years), and the adoption of material coloured sample for the methodology of investigation (Child et al., 1968; Boyatzis and Varghese, 1994; Terwogt and Hoeksma, 1995; Hettiarachchi and Nayanathara, 2017). These colours are: Red, Blue, Green, Yellow, Purple, Pink, Orange, and as achromatic colours White, Black and Gray. As specific colour notations relating to the colour samples adopted in the previous studies considered were not always available, the selection of the samples was carried out using NCS - Natural Colour System. The chromatic colours, except pink, were chosen with maximum chromaticness, i.e. the sample closest to the apex of the NCS colour triangle. In addition, for each hue two additional samples were selected in order to obtain a lighter and darker colours option. Even for the Gray colour two more samples were selected with different blackness.

Thus, the total number of samples selected for the study was 26 (*Figure 2*).

Fig. 2. The 26 NCS standard colours identified for the experimentations. At the top the high chromaticness colours followed by the lighter and darker colour options.

Once the colours were identified, the walls of the classroom image were modified using Photoshop software, in order to obtain one classroom chromatic configuration for each colour, and then 26 different colour configurations of the same classroom to be evaluated.

3.1. *Experimentation I*

The first experimentation aimed to collect and evaluate preliminary data on abstract and contextualized children's colour preferences using digital colour samples and digital colour simulations of classroom environments to be compared with each other and with the reference studies.

The experimentation consisted in the administration of an online questionnaire to school-age children, between the ages of 6 and 10, of both sexes. The questionnaire was designed to be easy for the child to understand and to fill out quickly. One of the main advantages of using the online questionnaire is the ease in reaching a large number of subjects in a short time. On the other hand, the supervision of children delegated only to parents and not done by an expert, may either not be sufficient, or on the contrary, be too intrusive, affecting the children's responses (Punch, 2002).

The questionnaire was divided into two main macro sections, and preceded by the request to complete some general information about the children age and gender.

The first section of the questionnaire focused on the investigation of abstract colour preferences. In the first question children were asked to specify the preferred colour among those shown: Yellow, Orange, Red, Purple, Blue, Green, Pink, White, Black and Gray. The options to choose from for this question are presented all together, but in a random order, automatically generated by the Google form. The participant was given the opportunity to provide only one answer to the question. Despite the awareness that colours displayed on unknown and different devices would be different from those identified in the preliminary phase, the form presented visual reference of all colour samples, together with a corresponding colour name, to create a subsequent comparison with the same colour applied in the classroom environment. In the second question of this section, children were asked to assign a grade for each colour (from 1 to 4, where 1 is the lowest and 4 the highest), in order to create a ranking of preference. This method allows to gather more information on the same subject regarding not only the preferred colour, but also to all the other samples (Guilfort and Smith, 1959). In the third question children were asked to further express their preference on the colour they already chosen as the favourite in comparison with two more samples of the same hue and different blackness and chromaticness that would appear lighter and darker.

The second section of the questionnaire was about colour preferences applied to classroom images. The structure of this section was the same as the previous one. Children were asked firstly to choose their preferred coloured classroom among those shown, then to assignee a grade for each coloured classroom image (from 1 to 4), and finally automatically directed to the question that involved the coloured classroom they already chosen as the favourite in comparison with two more variants that would appear lighter and darker.

The period in which data were collected was from April 2020 to May 2020. Thanks to the collaboration of the teachers, the answers were given by children attending five different primary schools of Lombardia region in Italy. Specifically, the number of children who participated in this experiment was 101, of which 53 were females and 48 were males. The children's average age participating in the survey was 8.5 years.

3.2. *Experimentation II*

The second experimentation, not yet conducted, involves the use of CAVE technology to simulate both abstract colours and the context of colour preferences. The colours and the 3D representation of the classroom used in this experimentation are the same as those illustrated previously for the first experimentation (*Figure 3*).

The CAVE (Automatic Virtual Environment) of the ED-ME LAB - Laboratory for environmental design and multisensory experiences, of the Politecnico di Milano, is used for the experimentation. The simulation of this CAVE is semi-immersive, through the use of three synchronized projection screens. The projected images are not stereoscopic. The screens on which the image is projected are touch and therefore allow an interaction between the image and the viewer in the CAVE. Furthermore, it is also possible to reproduce sounds and interact vocally with the CAVE system.

The structure of the questions addressed to children is the same as the first experimentation. The differences are in the physical presence of the children participating in the trial and in the smaller number of children involved. The results obtained from this second experimentation will be compared with those of the first experimentation in order to evaluate the different degrees of control over the accuracy in digital colour reproduction as well as to estimate the effects of children's involvement.

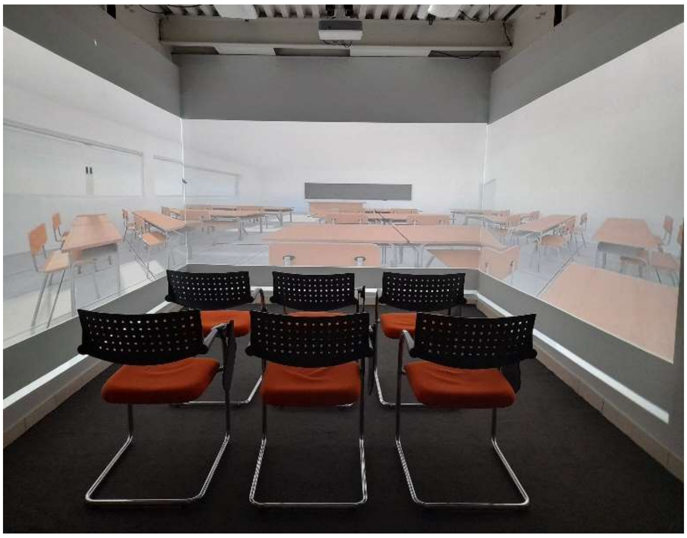

Fig. 3. The CAVE (Automatic Virtual Environment) of the ED-ME LAB, Politecnico di Milano, used for the experimentation.

4. Results

The results of the first experimentation allow us both to understand if the colour preferences expressed by children in abstract terms using digital colour simulations are consistent with the results of the reference literature, and to understand if the preferences for the abstract colour are consistent with those expressed for the digital simulation of the class.

With regard to colour preferences expressed in generic terms, the answers to the questionnaires were analysed both as a whole and on the basis of the age and gender of the participants. The most preferred colour was Blue. This result appears consistent with Child et al. (1968) and Terwogt and Hoeksma (1995). The colours with the lowest preference scores were Orange, Black and Gray, that was also found in Boyatzis and Varghese (1994) and Hettiarachchi and Nayanathara (2017). No child has

chosen White as their favourite colour. The percentages of preferences attributed to each colour with respect to the entire sample of children (101) were: Blue 20.8; Red 17.8; Purple 13.9; Yellow 13.9; Pink 10.9; Green 9.9; Black 5.9; Orange 5.9; Gray 1.

The analysis of the responses on the basis of the number of females and males who participated in the experimentation (53 females and 48 males) showed, as already emerged in other studies (Ellis and Ficek, 2001; Hurlbert and Ling, 2007), a gender difference in colour preferences (*Figure 4*). The preferred colour for females was Purple, while for males Blue, as it was found in Boyatzis and Varghese (1994).

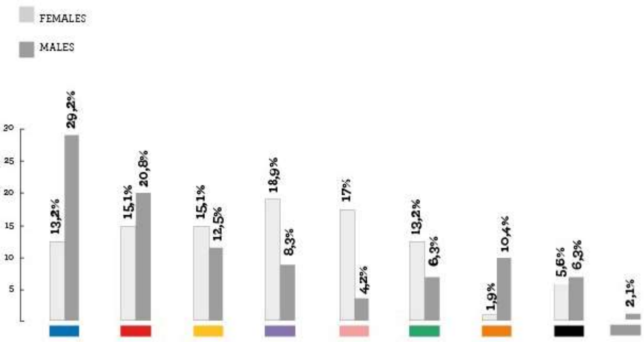

Fig. 4. Abstract colour preferences referring to the number of females and males who participated in the experiment (53 females and 48 males).

The analysis of the responses on the basis of the children's age who participated in the experiment, highlighted, as already emerged in other studies (Garth and Porter, 1934; Boyatzis and Varghese, 1994; Terwogt and Hoeksma, 1995; Zentner, 2001) a greater number of preferences for warm colours in children of 6-7 years compared to other age groups where more marked preferences for cold colours emerged.

The preliminary results of this first part of the experiment, aimed at evaluating colour preferences in generic terms using digital colour visualizations, show consistencies with respect to the studies taken into consideration that used material colour samples (Child et al., 1968; Boyatzis and Varghese, 1994; Terwogt and Hoeksma, 1995; Hettiarachchi and Nayanathara, 2017).

Moreover, the results of the first experiment allow us to understand whether the colour preferences expressed by children in general have been confirmed or not once applied to the classroom context. The percentage of children who expressed a different colour preference in relation to the differently coloured classroom displays was 54 percent (of which 58% were males and 52% were females).

Comparing the preferences given for each colour in the two situations (abstract and applied to the class image) in relation to gender (*Figure 5*), we can observe an increase in preference for Pink in males and an increase in preference for Blue in females. Furthermore, White appears more appreciated in both males and females when contextualised. Even preferences for Black are increased when contextualised compared to preferences for the abstract colour.

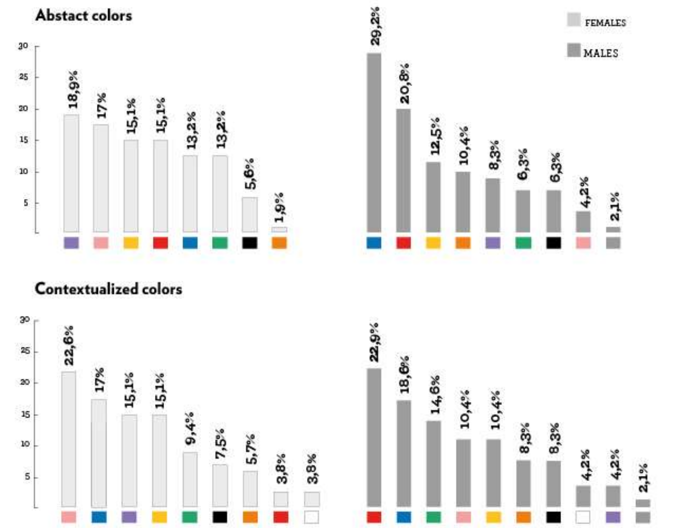

Fig. 5. Preferred abstract and contextualised colours for females and males.

A further comparison with respect to the lightness parameter given for each colour (*Figure 6*), shows how in the contextualized situation there is an increase in appreciation for the lighter variation of the colour chosen as the favourite.

Therefore, we can say that preferences for the contextualized colours appear both different and more diversified compared to abstract colour preferences.

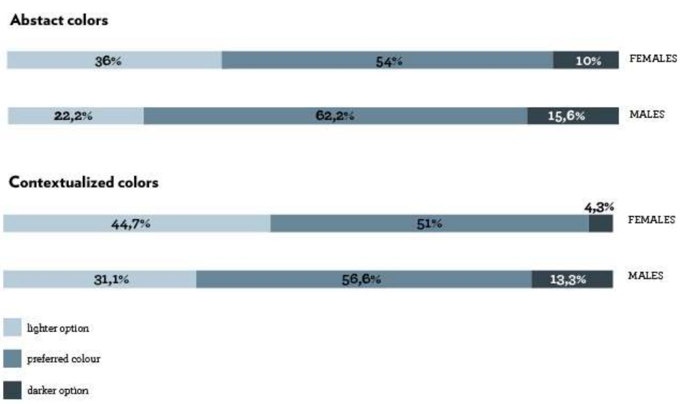

Fig. 6. Preferred abstract and contextualised light-dark options of the favourite colour for females and males.

5. Conclusion

The aim of the study is the evaluation of children’s colour preferences in general and contextualised situations using digital simulations. The two experiments had the common purpose of probing the children's colour preferences, both abstract and contextualized, and to identify any differences among the two.

Although it is clear the difference between the digital simulation of an environment and the experience of a real environment, there are many advantages offered by the possibility of using the digital simulation to understand if and how the colour preferences in children can be affected by the contextualization in specific and different contexts. Therefore, this study aims to use digital simulation with varying degrees of control over accuracy in colour reproduction as well as varying degrees of realistic feeling of environment and children’s involvement, in order to contribute to explore the design implications of colour preferences and associations.

6. Conflict of interest declaration

The authors declare no conflict of interest related to this publication.

7. Funding source declaration

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9. Short biography of the authors

Cristina Boeri - Architect, PhD, she deals with the perceptual and design aspects of color, combining design, research and educational activities. Since 2001 she has been carrying out and coordinating teaching and research activities at the Color Laboratory, Department of Design, Politecnico di Milano. Since 2013 she has been adjunct professor of Color and perception at the School of Design, Politecnico di Milano. She is co-founders and current president of the Color Placemaking Association.

Camilla Giani - Graduated in Interior and Spatial design at the Politecnico di Milano in 2020 with a master's thesis *The experimentation of children's colour preferences in a school context* under the supervision of professors Mario Bisson and Cristina Boeri. Since 2020 she has collaborated with the Color Laboratory of the Politecnico di Milano for the development and advancement of her work started with her thesis.

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An analysis of chromatic and luminous environment of healthcare establishment.

Estelle Guerry

LARA-SEPPIA EA 4154 (UT2J), Université de Toulouse, France.

Corresponding author: Estelle Guerry (eguerry.contact@gmail.com)

ABSTRACT

This paper presents a protocol for analyzing the color and light parameters of a sanitary environment, based on the study of the chromatic and luminous atmospheres of the Sanatorium Paimio's main building, designed by the architect Aalvar Alto. Thanks to this protocol, it is a question of identifying and deciphering the sanitary plans of the architect. For this, I based my exploratory work on the development of a chromatic and luminous "identity card" which lists the different colors and lighting modes used. The study is divided into three phases: color observation, light observation and observation of interactive movements. This study highlights the work carried out by the architect on the behavior of chromatic atmospheres under different light and their influence on human reactions and needs, ensuring the most favorable conditions of vision and rest for the patients who stayed at the within the sanatorium thanks to the combination of the fields of physics, aesthetics, physiology and psychology.

KEYWORDS Care, Color-design, Comfort, Hospitalization, Interdisciplinarity, Lighting, Well-being.

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1. Introduction

Finnish architect Alvar Aalto designed the Paimio sanatorium (1929-1933) for welcomed patients from all over the world suffering from tuberculosis. This facility allowed patients to enjoy complete rest in optimal conditions. The architect considered the following situation: a patient lying in bed, forced to spend most of his time there. His primary objective was that the technique serve the needs, sensitivity and emotional demands of patients (Kim, 2009). As convalescence can last several years, the architect designed an environment conducive to community spirit and social cohesion between patients and caregivers through the design of equipment and spaces accessible to all. Moreover, in a functional [1] and biodynamic [2] purpose, he designed an architectural program that makes the built environment itself active during the convalescence of patients. So, the exposure of each wing of the building made it possible to respond to "the deep needs of each person in accordance with nature" (Menin & Samuel 2004, p.57). For each of its architectures, Aalto has relied on color, light, space and materials to design atmospheres conducive to the psychological and physical needs of users (Arnkil, 2018).

Color was therefore one of the major elements in the design of this building, used as a therapeutic principle. The architect designed the color palette of the Paimio Sanatorium in collaboration with the artist Eino Kauria, responsible for coordinating the color scheme and directing the painting work (Eylers *et al.*, 2016). Thanks to the use of various types of psycho-sociological effects, the architect associated the design of atmospheres with the associations of ideas, both subjective and objective, conveyed by the representations associated with the colors. They decided to rely on Western codes, identifiable and recognized by the majority of patients.

But colors also played a physiological role that did not only depend on these cultural representations. Inspired by the principle of chromotherapy, according to which colors can have a curative action, the polychromy of the sanatorium aimed to relieve the ailments of patients. The choice of wavelengths (Kent, 1947) (Déribéré, 1968) was inspired by work involving the physiotherapeutic principle, today called phototherapy, according to experiments carried out between the 19th and 20th centuries, particularly for the treatment of measles (Chatinière, 1900) or smallpox (Rehns, 1904). For example, newborn jaundice is treated by exposure to blue light. This treatment is based on exposing to visible monochromatic blue light between 390 and 495 nm. The wavelength most used today in phototherapy is 450 nm. It effectively reduces the level of bilirubin in the baby's blood. (Ennever, McDonagh and Speck, 1983) (Shirzadfar, 2019).

2. Material and method

The following case study therefore aims to define the chromatic and luminous properties of the Paimio Sanatorium's main building (health establishment) to identify the architectural parameters influencing the recovery of patients. The study is divided into three phases of observations:

1/ Color observation consists of identifying color samples of architectural elements (floors, walls, joinery, stair railings and balustrades). Not having been able to personally experience this place, the study was conducted based on photographs and color board painted by Kauria (Riksman, 2016) and optical color matching [3], compared to the colors of the NCS color chart. A margin of error is therefore inevitable but deemed acceptable because the objective of the study is to translate a thought and not to develop a reproducible reference. The chromaticity values identified in this study can, reduced to their spectral property, present a difference of 1 to 2 nm with the original colors for colors ranging from blue to orange, and up to 6 nm for violet. and reds, values corresponding to the threshold of differentiation of hues in wavelength of the human eye (Wright *et al.*, 1934 cited in Treméau, 2016). In addition, the photographs did not allow me to identify the nature (matte or glossy) of the paints used nor the reflection value of the paints used. The same work was carried out on the furniture (tables, chairs, lights). The main spaces are represented (outdoor environment, reception hall, dining room, meeting room, bedrooms, corridors, stairs) and reproduced in the form of a map [4] making it possible to identify the sociostyles used [5].

2/ The light observation made it possible to identify the different artificial lighting modes used as well as the types of lighting, supplemented by the natural lighting methods. I was unable to collect the elements relating to the characterization of the light sources. Only the different types of artificial lighting and natural light were observed.

3/ The observation of interactive movements (Lassus, 2004) consists of observing all the chromatic variations, according to the principle of light reflection and their mutual influences on our perception.

3. Results

3.1. *Phase 1 – Color Observation*

For the chromatic observation of the interior environment, I therefore rely, in addition to the photographic archives, on the finalized color scheme of the main building painted by Eino Kauria (fig. 1.), which can now be found in the collections of Alvar Aalto museum, Jyväskylä, Finland (Riksman, 2016).

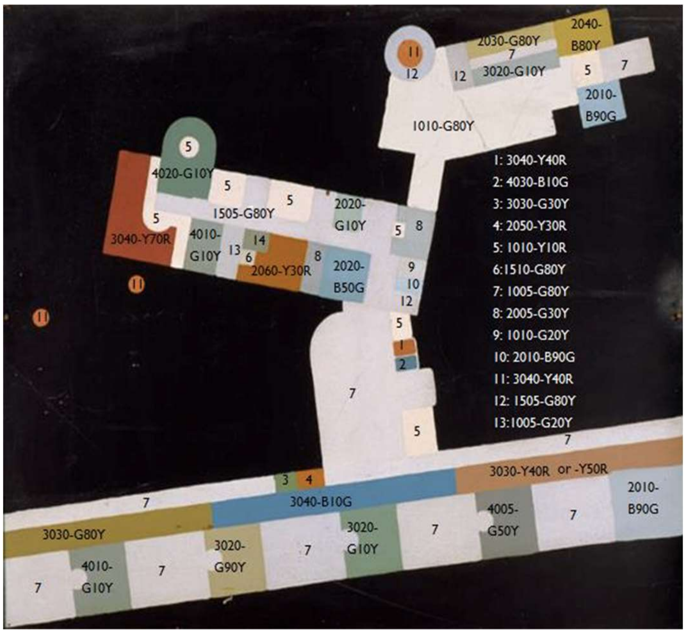

Fig. 1. Color scheme of Paimio Sanatorium's main building. Is probably the original board produced by Eino *Kauria.*

In parallel with the listing of the NCS colors present on board Figure 1, I sought to identify the colors present in the photographs (fig. 2.) in order to then correlate them and obtain a representative referencing of the interior and exterior chromatic program and of the furniture (fig. 3.).

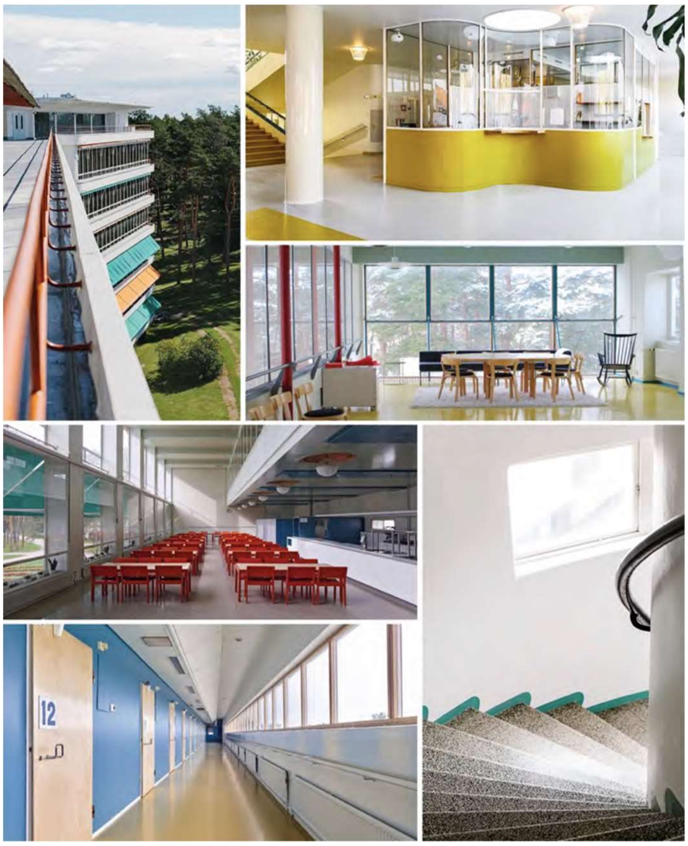

Fig. 2. Photographic sample (interior and exterior environment) of the Paimio Sanatorium based on photographics archives of Alvar Aalto Foundation.

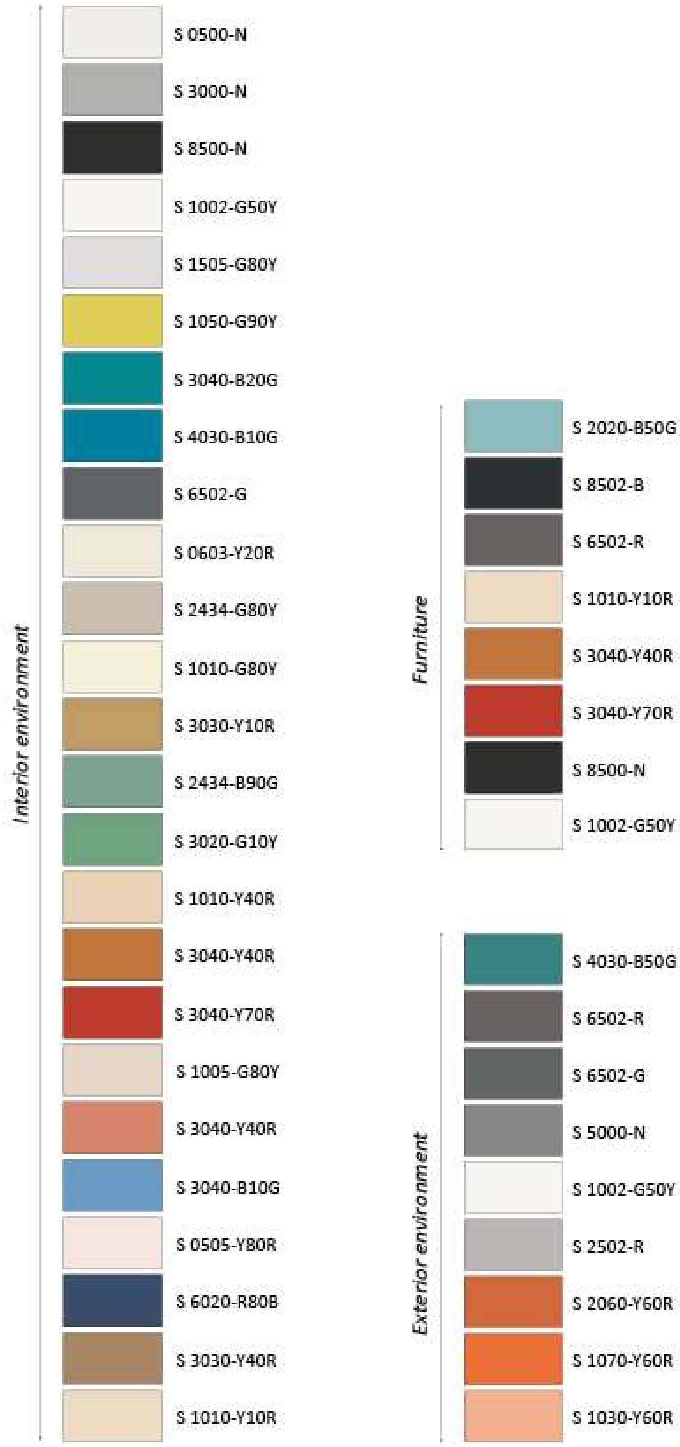

Fig. 3. Color measurements in NCS S based on photographic observation and Kauria's color scheme board.

We observe a wide polychromy built around thirty-five shades (fig. 4). It is divided into four categories of color effects: warm, cool, neutral and achromatic colors. There is also a complementarity between certain colors of the furniture elements, between a blue-green and red, associated with a play of neutrals and punctuated by the use of darks. In addition, we observe a majority of warm colors and achromatic ones, representing almost a third of the colors (table 1).

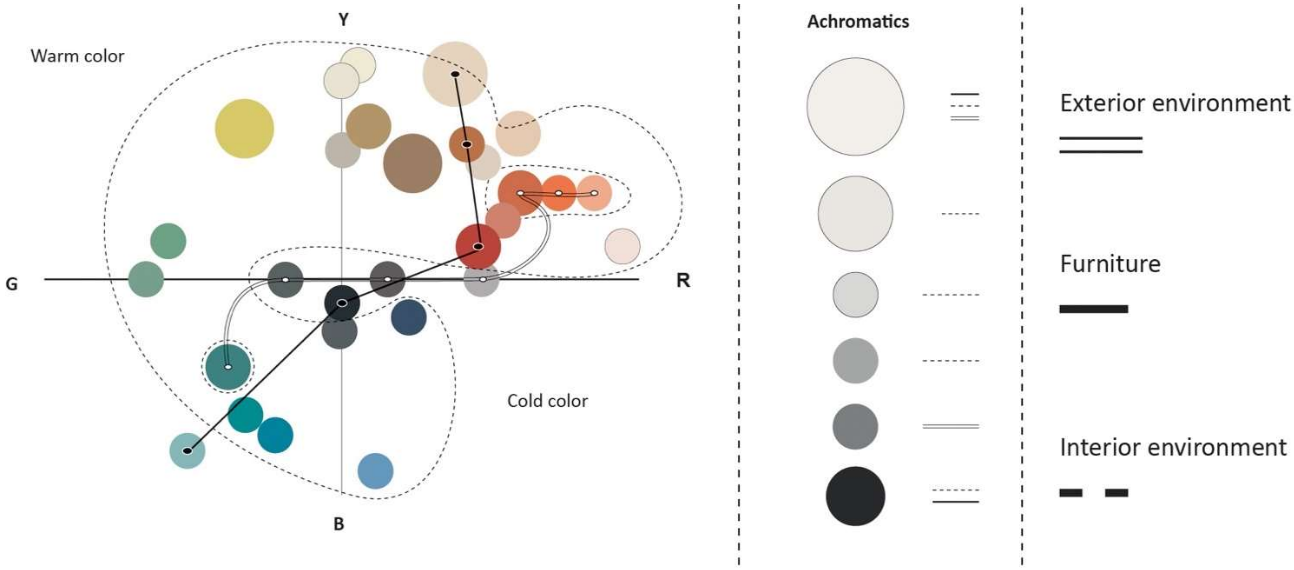

Fig. 4. Chromatic cartography of the sanatorium program. It represents the proportion of each color and their use. Colors are classified according to their hue and achromatic ones according to their degree of lightness.

	Warm	Cool	Neutral	Achromatic
Exterior				
Light	6%	3%	2%	6%
Dark	-	-	3%	-
Interior				
Light	19%	5%	17%	19%
Dark	-	1%	2%	3%
Furniture				
Light	5%	2%	-	3%
Dark	-	-	2%	2%

Table. 1. Chromatic distribution according to hue and lightness degree according to the previous mapping.

Light colors [6] are mainly used and are the only ones used for warm colors [7]. These nuances are distributed between the exterior, interior environment and furniture elements. The colors used for the interior environment represent more than half of the shades used for this architectural program. So, we observe different families of atmosphere in interior spaces according to different color combinations.

The development of chromatic combinations results in the design of combinations that respond to the collective imagination. Relative to specific atmospheres, this schematization is representative of the color universes previously established by the sociostyles. These combinations put into action the qualities of each color in order to transcribe a particular effect. They confer on the subject who benefits from them an identity character which must be recognizable by the user.

A chromatic combination thus inscribes this subject in its time and the use that is made of it. It is defined in terms of chromatic typologies (dominant and tonic) and proportions. The dominants result in light, pastel, neutral, natural tones; the tonics are saturated, lively, dark tones of collective images, of representations conveyed according to the associations.

The different combinations observed on the Paimio program (fig. 5.) are as follows: 1/ natural (similar composition of warm colors and shades), 2/ dynamic (strong contrasts and dominant colors warm), 3/ modern (cold colours, strong contrasts), 4/ relaxed (complementary to contrasting colours, neutrals associated with a tonic), 5/ romantic (neutrals associated with a tonic).

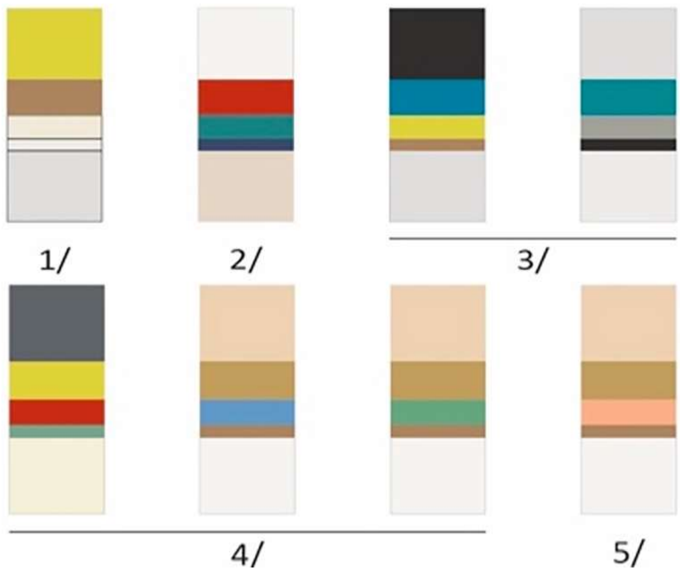

Fig. 5. Set of combinations identified according to families of atmospheres previously observed.

3.2. *Phase 2 – Light observation*

There are two types of dominant openings intended to capture natural light: the zenithal and lateral opening. On the facades, there are window strips and large openings completed by a configuration of multiple leaves. We also observe frames with small footprints, except for large openings, as well as openings in the roof.

	Opening	**Lamp**	**Lighting**
Bedroom	Casement window	Wall lamp, portable lamp.	Task lighting, Mood lighting.
Common Area	Skylight, window banner, casement window, glass facade.	Portable lamp, hanging lamp.	
Passage Area		Wall lamp, hanging lamp, recessed lamp.	General lighting, Mood lighting.
Dining Room	Glass facade.	Hanging lamp.	

Table. 2. Directory of openings, lighting and type of artificial lighting according to the needs of use.

Regarding artificial lighting, there are different types of lighting allowing the production of general lighting (recessed and suspended luminaires), ambient (wall and suspended luminaires) and task lighting (localized extra light thanks to free-standing luminaires and portable lamps).

3.3. *Phase 3 – Observation of interactive movements*

We observe variations in the perception of colors according to four modalities: reflection of exterior elements (fig. 6.), interaction with furniture, between two opposite walls, one of which is white, and between two different opposite walls (fig. 7.).

Fig. 6. Chromatic variations resulting from the reflection of exterior elements.

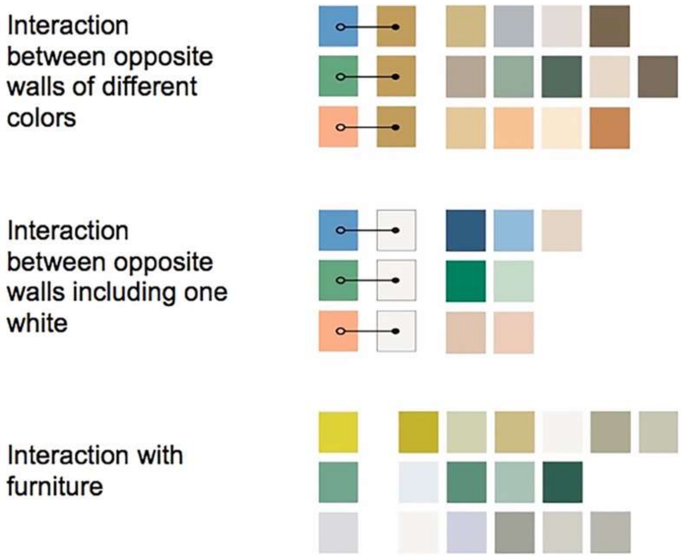

Fig. 7. Directory of the different chromatic variations resulting from the influence of light reflection on the built environment and furniture.

External element reflection relates to the effect of color reflection from blinds when deployed. The blinds, in blue-green and orange colors, slide towards warmer tones. This shift is also taking place on the paintings and the interior furniture. Blue becomes green, neutrals become blue and pink-orange, dulls slip into warm pastels.

The interaction with the furniture leads to the observation of many nuances. It is induced by the shadows cast by the furniture depending on the reflection factor of the floors and/or walls. If the chromatic dominant remains present, we observe a shift towards lighter or darker shades and going as far as a neutralization of the original color but without distortion of its tone. Only saturation and lightness are impacted.

Regarding the interaction between two opposite walls, one of which is white, we can observe the lightening of the original color, to tend towards a neutralization of it. Conversely, taking physical distance leads to a clouded perception of this tone. Finally, the interaction between two different opposite walls leads to the observation of a game of chromatic complementarity.

In the case of the projection of blue on brown, the complementarity of these two colors calls on brown to become dominant and to cancel the projected tonality. Only the nuances of this dominant are perceptible to us, from the clearest to the most flattened, from the most saturated to the most neutral. On the contrary, for a projection of green on brown and pink on brown, leading to similar associations, the perception of green and pink are preserved. They only undergo a slight neutralization. We therefore observe a variation in their saturation, but also in their degree of lightness.

4. Discussion

The chromatic combinations and lighting devices that we have previously observed can reflect the architect's desire to generate a harmonious chromatic and luminous scheme capable of generating a general feeling of well-being, comfort and serenity.

The colors observed for the outdoor environment create a dynamic landscape thanks to the use of complementary colors that punctuate the white architecture. The major use of achromatic (white) generates a strong visual imprint. We can assume that the architect wanted to refer to hygienist representations [8], thus echoing the care provided in the establishment. The neutrals may have been used to attenuate the signal effect of the complements without canceling their function as spatial markers and uses. But the architect made the choice of an assumed polychromy, thus generating multiple atmospheres. It echoes the work of Harry Sherman on visual ergonomics. It was strongly impacted by the omnipresence of whiteness, artificial lighting creating many dazzling situations. The coloring of the environment then becomes a solution to counter this glare (Sherman, 1914). The use of cold colors, minority and applied to the rooms, allowed him to create a peaceful atmosphere, calm and conducive to rest. On the contrary, warm colors and neutrals refer to comfortable and warm living spaces. Yellow, mainly used in the entrance hall and meeting areas, could have been used for its soothing properties on nervousness (assuming the nervousness of patients arriving in this establishment). As for the achromatic ones, they offer breathing spaces in a punctuated and structured atmosphere around the color. The "broken complementary colors" [9] make it possible to neutralize the natural force of the combination of complements in favor of a light dynamic because "in the case of simultaneous perception […] a tone turns towards the complement of the opposite tone" (Dumond , 1957). On the contrary, the "discordant harmony" [10] accentuates the signal effect and makes it possible to underline the spatial landmarks.

Beyond these methods of association, polychromy also makes it possible to generate various universes, according to the use lent to the spaces, recalling the systems of sociostyles (Kobayashi, 1992) anchored in the collective imagination, according to the needs conveyed by the actions carried out in the areas concerned. The natural atmosphere induces a comforting image and an impression of serenity conducive to reassuring users, especially when entering the premises, while waiting to take exams or receive their care. The modern atmospheres, inducing an impersonal image, emphasize the functional character of the spaces. The relaxed atmospheres offer a welcoming and joyful image of these living spaces. The romantic atmosphere is considered ideal for rooms that must be calm, relaxing, conveying tenderness and benevolence. The dynamic atmospheres are also intended to be joyful and welcoming while encouraging action.

But the sensitive dimension of color cannot dispense with its connection to light, which participates in particular in the evolution of visual perceptions. Light, whether natural or artificial, can thus be designed to reinforce chromatic qualities but can also lead to their evolution by the reflection of colors on each other. These interactive movements (Lassus, 2004) thus make the place active and tend to reveal multiple spaces over the course of the day. Weather conditions play a major role in modifying the nature of the available natural light and generate variations in color perception. But above all, natural light improves the well-being and comfort of users, particularly in care practices (Déoux *et al*., 2011). The different openings then have the role of filtering, guiding and distributing the light in order to maximize its capture. The combination of top and side openings then offers optimal autonomy in terms of natural lighting. This combination allows a significant light supply and this throughout the seasons. It also provides optimal exposure to the cyclical rhythm of natural light, known today for its benefits on the circadian rhythm, or biological process, of patients (Zielinska-Dabkowska *et al.,* 2017).

But constrained by natural lighting conditions, it is necessary to use artificial lighting to compensate for natural light variations and thus produce quality lighting, free from the constraints of natural light. The use of different types of luminaire then corresponds to specific functionalities and makes it possible to meet different needs thanks in particular to the production of general, ambient and task lighting. General lighting is used to ensure the movement of users in the corridors and passageways, as well as the execution of common tasks in the common rooms. This type of lighting is characterized by a uniform, diffuse and homogeneous distribution of light thanks in particular to the use of large recessed and suspended luminaires offering direct lighting. Ambient lighting, on the other hand, offers light dedicated to a momentary activity and qualifying a limited space. This type of lighting can be found in all types of interior spaces. The use of wall lights and suspended luminaires are thus conducive to the production of localized and diffuse lighting. The projection of light, thanks to indirect, semi-direct, semi-indirect and mixed lighting, towards light surfaces thus ensures the diffusion of a soft and even light. Finally, task lighting results in an increase in localized light thanks to mixed lighting, combined with general lighting, allowing the execution of tasks requiring a high level of focused and focused lighting.

Mostly seen in common areas and bedrooms, floor standing fixtures or portable lamps provide this directional light that can be adjusted as needed. Thus, if well-designed lighting is therefore defined by a sufficient quantity of light and the choice of a device that eliminates visual discomfort by glare, it is appropriate to choose and combine lighting modes adapted to the needs and thus make the secure interior space conducive to comfortable living.

5. Conclusion

We evolve daily in the midst of color and light, but apprehending a chromatic and luminous environment is above all receiving and interpreting visual information.

They not only convey an aesthetic dimension; they are designed to meet challenges and a defined aim, to give the user a view. Signs thought out by the designer and sent to the user, color and light will be received and interpreted. Whatever the target, these signs must be in line with the images shared collectively, the local culture, the senses and the sensitivity of those who receive them. The designer then defines a color/light combination for its psychological effects (combination appreciated by the receiver, allowing him to invest his affect in the place and for it to provide him with some beneficial effects), and/or visual (choose a combination for its ability to attract the gaze or on the contrary repel it, to play with proportions and architectural organization as a visual landmark), influenced by a trend (so as to identify with what is happening elsewhere and now) or the collective cultural heritage (allowing to federate a community around signs that are common to them as an element of identification) (Caumon, 2017). These reference frames of influence will thus make it possible to build an identifiable and identified chromatic and luminous environment, which can lead to affective reactions of pleasure or displeasure. But whether instinctive or conscious, the social role of lighting and color-design should be considered as a factor of well-being thanks to the combination of "physics, aesthetics, physiology and psychology" (Déribéré, 1964).

This study also questions the healing power of color and light. It is therefore a question of being concerned with the behavior of chromatic and luminous atmospheres and their mutual influences on human reactions, because using light and color is not only to illuminate and decorate, it is above all to ensure the conditions of vision and more particularly in this case study, conditions of rest and healing that are as favorable as possible to the patients. This therefore opens the way to additional studies to affirm or refute their curative effects on health, then considered as non-drug treatment.

6. Conflict of interest declaration

I indicate that no financial and personal interests have affected my objectivity as author. There are no potential conflicts.

7. Funding source declaration

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8. Short biography of the author

Estelle Guerry – Doctor in design-color and design-lighting from the University of Toulouse. Its main scope of research applies to an interdisciplinary definition and application of the parameters of comfort and well-being of users presenting a vulnerability (ageing, handicap, illness, deficiency, etc.). It provides its expertise both in the research environment and in the socio-economic world.

Notes

[1] Functionalism is an architectural principle according to which the form of architecture is the expression of its use. The essence of modern architecture is linked to this principle. Inspired by the teaching of Viollet-le-Duc, Le Corbusier will thus formulate the "Five points of modern architecture" as the synthesis of a new modern architectural conception. These five points relate to the pilotis (disappearance of load-bearing walls in favor of concrete or steel pillars to support the structure), the roof terrace (principle of flat roof intended to accommodate terrace and vegetable garden), the free plan (disappearance of walls load-bearing allowing free modulation of space and being able to accommodate large glazed surfaces), the band window (horizontal windows crossing these non-load-bearing walls along the facades, offering uniform light and a view of the horizon) and the free facade (the load-bearing pillars being present inside the building, the facade becomes a thin and light skin, ensuring no more than an insulating role). The free plan as well as the window in bands will be two recurring points in the work of the Finnish architect Alvar Aalto (Jencks, 1973).

[2] Bioclimatic architecture is based on the exploitation of the properties of the site on which it is established. The climate, vegetation, sunshine, topography thus become key elements on which we can rely to create a comfortable environment for future users. Bioclimatic architecture is also characterized by particular attention paid to respecting pre-existing landscape characteristics, trying to integrate as well as possible into the surrounding environment (Tucci, 2021).

[3] The practice of matching results in the collection of the different colors that make up the architectural program. This involves drawing up an inventory of the colors of the main architectural elements (floors, walls, joinery, stair railings and balustrades) and furniture (tables, chairs, light fixtures). The visual readings are operated by calibration using the NCS color chart. The NCS system, the Natural Color System, is a universal color repository, whose classification logic is based on the human perception of colors. This qualitative inventory is based on a photographic study. Admittedly, photographs cannot be used for accurate color

reproduction, but the conveniences of digital still allow for a representative study to be conducted when field trips are not possible. These chromatic witnesses, extracted from their context, are of major interest when grouping and reconstructing the information which is the basis of the synthesis result.

[4] Developing the maps makes it possible to produce a qualitative and quantitative restitution of the colors previously collected, in order to draw up a visual synthesis. This makes it possible in particular to count the tones and shades composing the chromatic set(s). Analyzing the readings thus makes it possible to transpose them according to their recurrence. The colors of the roofs and the walls make up a first palette made up of the architectural chromatic dominants which represent the major part of the exterior built space. A second palette, the main palette, shows the colors used for the interior built space. It is the most consistent palette due to the large number of tones observed. Finally, the last palette is made up of the tones of the details relating to the furniture. These palettes, represented in the form of maps, make intelligible the visual observation of the chromatic state of the site at an instant T. This synthesis thus constitutes a representative test of the quantitative ratios of the different tones. The samples are classified according to an ordered composition on two axes, each presenting a double reading inspired by the NCS system. A first axis will be readable from yellow to blue, the second from green to red. In addition, the double reading of these axes allows a reading of the degrees of lightness of the samples, the lightest at the ends and the darkest in the center. Achromats have been excluded from the mapping to allow efficient reading of the shades involved.

[5] Applying the Color Image Scale repository produced by Shigenobu Kobayashi, this system based on a principle of tri-chromatic composition makes it possible to categorize the colors observed according to the different universes that they can evoke. This classification of the color samples is carried out according to a purely qualitative criterion, the colors being considered in isolation, according to their representation(s). This sensitive approach leads to the production of chromatic combinations in respect of the interrelation between colors, according to the individual character of each of them, leading to the production of collective images, of representations conveyed according to the associations (Kobayashi, 1992).

[6] In NCS referencing, a so-called "light" color will have a black content index of less than 50, while so-called "dark" colors have an index equal to or greater than 50. (Discover how the NCS System works).

[7] In the West, color design is based on a principle of thermal color polarities, giving colors psychological and thermal properties. Our culture separates colors according to the concept of warm tones (yellow, orange, red...) and those with cold sensations (blue, green...) by placing the "warm" and "cold" poles on a chromatic disc in front of orange and blue (Silvestrini and Fischer, 2011).

[8] Florence Nightingale, a nurse in the middle of the 19th century, is undoubtedly the most significant person in the influence of the relationship between care practices in hospitals and color. Its objective: to achieve an absolute degree of purity, both in terms of cleanliness and fittings. "The indisputable relationship between ventilation and cleanliness is demonstrated by this fact: a light-colored paper keeps clean" (Nightingale, 1860). This will become a majority posture in the health sector, inducing that the idea of clarity leads to that of cleanliness, itself a premise of purity. And conversely, the ideal of purity engenders the notion of cleanliness, itself manifested by lightness, and concretely by whiteness. Architectural design rules are emerging, such as the generalization of a suburban establishment to try to reduce the risk of contagion. Whiteness becomes a quest, then considered as an antibacterial response. The discoloration of textiles by chlorine is born and becomes the disinfectant solution according to the health authorities in the hospital sectors. White then appears gradually, from changing rooms to earthenware, including paintings and furniture. Thus, all aspects of an ornamental or decorative nature are prohibited. Achromatic becomes the norm, a guarantee of cleanliness and health safety (Fagot, 2020).

[9] Association of a color with the two tones located alongside its complementary (Caumon, 2017).

[10] Association of a primary color with one of the adjacent colors of its complementary (Caumon, 2017).

Licensing terms

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Enquiry into the colours of the MoGao murals at DunHuang from the Sui Dynasty, the Tang Dynasty and the Five Dynasties period

Elza Tantcheva-Burdge[1], Zhaohua Lei[2], Vien Cheung[3]

[1] *Independent Art Historian, United Kingdom. etan711@talktalk.net*

[2] *Interior Designer, China/Italy. lzhdesign2018@gmail.com*

[3] *School of Design, University of Leeds, United Kingdom. t.l.v.cheung@leeds.ac.uk*

Corresponding author: Vien Cheung (t.l.v.cheung@leeds.ac.uk)

ABSTRACT

In 1961 the site of the MoGao cave temples was recognised as one of the State Priority Protected Sites by the State Council of the People's Republic of China and was put under the protection of the national laws including the Law on the Protection of Cultural Relics. To a great extent, this was a result of the work of the DunHuang Academy, which was established in 1944 for research into and preservation of the site. In 1987 UNESCO added the MoGao Caves to its protected World Heritage Sites as one of intrinsic unmatched historic value to humanity. In the following year, the Getty Conservation Institute became involved in an international collaborative project aimed at furthering research into the site and expanding its conservation programme. The present paper enquires into the appearance of colours used in the representational system of the murals from periods of the Sui Dynasty (581-618 AD), the Tang Dynasty (618-907 AD) and the Five Dynasties (907-960 AD). The selected periods demarcate the golden era in the history of the MoGao temple complex. The historically grounded enquiry aims at gaining a deeper understanding of the DunHuang murals as emblematic of Chinese civilisation and increasing awareness of them amongst a non-Chinese speaking audience. The use of colour will be discussed in the context of the traditional 'five colour system'.

KEYWORDS DunHuang murals, Colour appearance, Chinese culture, Wuxing, Ancient Chinese art

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1. Introduction

DunHuang in the Gansu province is one of the oasis towns in northwest China. It was established as a garrison under Emperor Wu (141-87 BC) of the Han Dynasty in 111 BC as a defence against the Xiongnu, a confederation of nomadic, non-Han tribes. DunHuang was strategically placed, controlling the entrance from the west at the frontiers of the Hexi Corridor. The narrow Hexi passage led to the Chinese plains and the ancient capitals of Chang'an and Luoyang.

DunHuang was also at the crossroads of the ancient Southern Silk Road, the main route leading from India via Lhasa to Mongolia and Southern Siberia. This allowed continuous communications between central China and the Western regions, a term often employed by Chinese historians to refer to all the lands to the west of China, such as the Indian subcontinent, Central Asia, the Middle East and Europe.

Though the Silk Road aided military operations it was primarily intended for long-distance trade. The active exchange of material goods between many nations along the route inevitably provided the means and the opportunities for active cultural exchange. Ideas, beliefs, ideologies, technology, and art flowed easily from one country to another. One of the greatest impacts on China was the introduction of Mahāyāna Buddhism and the subsequent development of the school of Chinese Buddhism. It was introduced by travelling monks, believed to be from the region that was known as Gandhāra. Today the territory of Gandhāra is mainly within Pakistan, but some parts are also within the borders of Afghanistan (Fowler, 2005)

The introduction of Mahāyāna Buddhism resulted from the effort of numerous Buddhist missionary monks who began propagating the faith somewhere between the first and second century AD. By the fifth century AD, Buddhism had become established, gaining a privileged position amongst the array of beliefs and practices that already existed in China. A significant role in the propagation of the new religious belief was played by the Chinese nobility, who were amongst the first converts and had the means to sponsor the missionaries in their travels and work.

Where the development of Buddhism in China is concerned, there appears to have been a cross-fertilisation of ideas and beliefs, where the incorporation of elements and practices from the prevailing Taoist and Confucian schools resulted in the creation of a new strand of Mahāyāna Buddhism around the sixth century AD, the Chinese school of Mahāyāna, also known as Chan Buddhism (Lin, 2009). The Hexi Corridor and the interconnectivity of the Silk Road allowed this school of Buddhism to be disseminated across China and eastwards to Japan (Zen Buddhism in Japanese) and southwards to Vietnam and Korea.

Both Confucianism and Taoism are Chinese philosophical schools of thought that date from around 550 BC. The two seem to complement each other in their attempts to find ways in which to refine, order and harmonise the life of humans either as individuals or as part of a social structure. Confucianism focuses on the creation of orderly social life via the rational organisation of the individual's life by following a framework of ethics and ritual. If those two are followed they build or transform the inner nature of human beings. There is no such concept as immortality or the afterlife as Confucianism is interested solely in the present. Taoism focuses on both the natural world and, through an understanding of it, gains an understanding of human nature. A balanced individual life creates a balanced society. It teaches that immortality is achievable via personal practices of meditation and self-knowledge. (Maspero, 1981: 46)

The ultimate goal of a Buddhist's life is achieving salvation. Mahāyāna Buddhism is a school that shows the way to the Pure Lands (Paradise) not only to those under monastic orders but also to those who are in the world. The permeation of ideas from both Confucianism and Taoism at the formative stage of Chinese Buddhism was made possible because of some liminal similarities with ideas at the heart of Buddhist doctrine, for example, Confucianism's concern with high ethical standards, reliance on specific rituals and adherence to spiritual discipline. With Taoism, the associations with the ideas of Mahāyāna Buddhism are even closer, for example, meditative practices and distancing from the secular world paving the way to immortality/ salvation (Lin, 2009).

From the very beginning, the missionaries disseminated Buddhism mainly by teaching and translating their holy scriptures into the Chinese language. The earliest preserved translation is from the second century AD. It seems to have arrived via the Empire of Kushan along the Silk Road. At that time Kushan occupied territory that at the present day includes Afghanistan, Pakistan, Nepal and northern India. Kushan patronised several religions, including Buddhism, hence the origin of the translated scripture.

The similarities in the conceptual frameworks allowed mainly Taoist but also Confucian terminology to be used in the translation of the Buddhist texts. The use of familiar Chinese terminology then helped in the acceptance of a theology that was principally foreign. (Fowler, 2005: 79) Moreover, this allowed the three ideologies to coexist rather than compete, other than during four periods of Buddhist religious persecution carried out within the first five centuries after the establishment of Buddhism. They were unsuccessful attempts to return to Taoism, but inflicted great destruction on Buddhist monasteries and temples in the process (Li, 2011).

The oasis towns on the Hexi Corridor, which provided the major stations on the long and arduous journeys of the travelling monks, naturally assumed the role of spiritual hubs. Some of the missionaries eventually settled and founded shrines and monasteries. The latter were housed in grottoes carved into the sandstone rocky areas surrounding the oasis towns and gradually developed into grotto complexes.

There are about one hundred and fifty Buddhist complexes along the Hexi Corridor, more than in any other region in China. Four of those complexes are associated with DunHuang. They are: the MoGao Grottoes, with four hundred and ninety-five surviving cave temples in a relatively well-preserved state, though there are in total seven hundred and thirty five cave cells and temples; the Yulin Grottoes, which number forty two cave temples; the Western Qianfodong Grottoes, which number sixteen and the Eastern Thousand Buddha Grottoes, which number twenty three. At the last three complexes, the surviving caves have been over-painted at a period later than those which this paper is concerned to investigate.

The most significant of these complexes is The MoGao Buddhist complex in DunHuang, also known as the Caves of the Thousand Buddhas. At the beginning of the twentieth century it rose to fame by being associated with the discovery of the DunHuang manuscripts, all dating from between the fourth and eleventh centuries AD. They were discovered by the Taoist monk Wang Yuanlu. At that time he began persistently to petition the authorities in an attempt to draw their attention to the quality of the temples' decoration, the level of damage they had sustained and the urgent need for remedial work (Duan, 1994: 52)

Eventually, in 1941, a group of artists led by the prominent traditional Chinese painter Chang Dai-chien, worked on the creation of copies of the wall paintings mainly of the MoGao but also of some of the Yulin Grottoes. In 1943 an exhibition of their work brought to nationwide prominence the MoGao temples. The same year the DunHuang Art Institute was founded and in 1944 it was expanded to create the DunHuang Research Academy, which was established to preserve and research the MoGao caves.

Because of the sheer number of surviving cave temples, the wide time span through which those temples were developed and their relatively good level of preservation, the MoGao caves are considered, both nationally and internationally, to provide a compendium of Chinese art, particularly evidencing the evolution of Buddhist art in the north-west region of China. In recognition of its significance in 1961, the site of the MoGao cave temples was made as one of the State Priority Protected Sites by the State Council of the People's Republic of China and was put under the protection of the national laws including the Law on the Protection of Cultural Relics.

Initially, international attention was drawn to the significance of the MoGao wall paintings as early as 1945 when some of the copies made by Chang Dai-chien were displayed throughout Europe by a European travelling exhibition of contemporary art organised by UNESCO. However, it took until 1987 for UNESCO finally to add the MoGao Caves to its protected World Heritage Sites as one of intrinsic unmatched historic value to humanity. In the following year, the Getty Conservation Institute became involved in a long-term international collaborative project aiming at furthering research into the site and expanding its conservation programme.

All the MoGao cave temples are elaborately decorated with murals, the total area being about 45,000 square metres, and over 2,000 coloured sculptures. In some of the temples, the decoration covers not just the walls but also the ceilings. One of the best accounts of the exquisite quality of the decoration at the site was given by a Persian emissary to the early fifteenth century court of the Ming Dynasty (1368-1644 AD), not long after the last of the MoGao temples was created in the Yuan period (1220-1368 AD). He arrived via the Silk Road and, having visited the MoGao murals, he noted that these were "of such character that all the painters of the world would be struck with wonder." (Maitra, 1970: 39)

The aim of this paper is to make an initial enquiry into the appearance of the colours used in the cave temples, limiting the scope of the enquiry to the Sui, the Tang and the Five Dynasties periods. This will be to evaluate the relative constancy in the use of certain colour hues in these caves. Using the suggested timeframe for the study will aid in gaining a further, historically grounded understanding of the use of colour in the period of the most intense development of the MoGao complex. Our hypothesis is that the number of colour hues used will be relatively constant. This is not just because of the limited number of pigments available, but also because of the influence of Taoist cosmology within Chinese culture.

2. Putting the MoGao murals in historic context

The MoGao complex was carved over 1,000 years (366-1386 AD) into the sandstone cliff that is almost two kilometres long and is about twenty-five kilometres southeast from the town of DunHuang. It has been accepted that the complex was modelled on the existing

Kizil cave Buddhist complex, situated sixty-five kilometres west from the town of Kucha. The Kizil grottoes were excavated into the rocks of the northern banks of the river Muzat. Scholars consider Kizil to be the earliest major Buddhist cave complex in China, with development occurring between the third and eighth centuries AD. It comprises a set of two hundred and thirty-six cave temples excavated into the rocks and extending for some two kilometres in a generally east-west direction. At present only one hundred and thirty-five of them are in good condition (Whitfield *et al.*, 2015: 55-93)

At the time of their creation, the Kizil cave temples were part of another Buddhist Kingdom, that of Kucha, though its territories are now part of the Aksu Prefecture, Xinjiang, China. However, the Tang Dynasty ruled Kucha after 658 AD and this caused a reversal, with its Central Plains culture increasingly influencing the paintings in the Kizil cave temples, evidenced by the adoption of styles and colours found in the seventh and eighth century AD decoration of the MoGao temple caves (Li 1994: 83-85).

As in the Kizil paintings, the decoration of the early MoGao temples reflects more Greco-Indian and Gandhāran influences and the facial features of the personages depicted are distinctly Indo-European. The later MoGao murals stylistically are more akin to the murals from the Persian Sassanian Empire (224-657 AD). Though the official religion of the Sassanian Empire was Zoroastrianism, in the far eastern part of the country both Buddhism and Hinduism were well established and widely practised. Those eastern parts were known also as Bactria (Song, 2013).

Bactria was part of the Silk Road network and held a key position between China, Persia, India and the Mediterranean world. It is believed that in the first stages of the propagation of Buddhism, craftsmen from India and Bactria worked in a number of Chinese Buddhist cave complexes. As in the case of Kizil, the personages depicted are distinctly Indo-European.

Other influences shaping the art of the Kizil caves are believed to have come from the cultures of South Asia and the coastal areas of China. The introduction of foreign formative ideas and aesthetic influences was aided by the fact that Kucha was an important commercial centre on the Silk Road. This enabled Kucha, and in particular the Kizil Buddhist complex, to play a major role in the dissemination along the Silk Road of Buddhist teaching and art. The early cave temples took a shape similar to that of the Bamiyan Buddhist caves in central Afghanistan and the murals suggested the influence of Gandhāra arts. The predominant colour used in the earliest Kizil caves is red, using cinnabar and red earths, while in the later murals there is an abundance of blue colours, deriving from lapis lazuli.

At MoGao the early murals mainly display the use of three chromatic colours in the construction of the pictorial compositions, as could also be seen in Kizil. Those were green (malachite), blue (lapis lazuli) and red (cinnabar). The expensive minerals necessary for the production of these colours were imported via the Silk Road.

The first MoGao grottoes were dug into the rocks in the fourth century AD by missionary monks. Apparently, they were just hermits' abodes. None of the very first caves survive but some from a slightly later period do. In total, only three of the earliest cave temples survive in reasonably good condition. They were built between 419 and 439 AD and are believed to have served not just individual hermits but several small monastic communities. These developed in the North Liang (397-439 AD), a dynastic state during the Sixteen Kingdoms period (366-439 AD). In total there are seven MoGao grottoes from that period.

In 439 AD, the Northern Wei Dynasty (386-534 AD) was successful in the unification of northern China. The state actively worked towards establishing Buddhism to replace the fading Confucianism, to reinforce unification and to create order out of the chaos of the preceding centuries. The speed of creation of the cave temples at MoGao accelerated and their size increased. About ten temple caves are identified as having been built at that time. The decoration of these has been constructed in an Indian style. For the next two dynasties that ruled northern China, the Western Wei Dynasty (535-556 AD) and the Northern Zhou Dynasty (557-580 AD) altogether twenty grottoes were constructed and decorated.

The following period, known as the Sui Dynasty (581-618 AD) marks the dawn of the golden era of Chinese civilisation and the MoGao complex in particular. The Dynasty was short-lived but had an aggressively expansive foreign policy and an extremely ambitious, far-sighted domestic policy aimed at expanding the infrastructure in order to boost the economy and defence. To begin with it unified the territories of northern and southern China. The most impressive project completed by the Dynasty, and one which had immeasurable effects on the economy through subsequent ages was the Great Canal. Another was the reconstruction of the Great Wall which, at that time, reached DunHuang (Guo, 2010).

The propagation and affirmation of Buddhism as a dominant religious belief was sought actively as both Sui Emperors declared themselves to be Buddhists. Consequently, the period was marked by the extensive repair and reconstruction of old Buddhist sites and the construction of new buildings. The imperial patronage was strongly felt in MoGao. During the thirty-seven-year rule of the Sui Dynasty the number of cave temples there increased by eighty, though only seventy now survive. This meant that on average two grottoes were built and decorated each year at the MoGao site alone. Extensive building of monasteries and temples went on in the capital and at other Buddhist complexes.

Imperial patronage was apparent not only in the speed at which the temples were constructed. A number of the most beautiful cave temples are associated with the Sui Dynasty. The best quality of painting materials was used, allowing the colours to retain their fresh and bright appearance. A sense of opulence was complemented by the addition of gold leaf. However, the most significant aspect of the pictorial compositions is that they display the early stages of a specific Chinese style. The personages are presented in passive poses and they have distinctively Chinese facial features compared to the dynamic figures from the previous period, which are Indo-European in appearance.

These stylistic tendencies were expanded in the next dynastic period, that of the Tang Dynasty (618-907 AD). Generally, historians recognise four major stages in the development of the Tang Dynasty: (1) the Early Tang period (618-712 AD); (2) the High Tang period (713-766 AD); (3) the Middle Tang period (762-827 AD) and (4) the Late Tang period (828-907 AD). The Tang Dynasty is known as the golden period in ancient Chinese history and the apogee of Chinese Buddhism, of which there is abundant evidence at the MoGao site. During the Dynasty, which lasted for two hundred and eighty-five years, nearly two hundred and thirty new temples were built at the site.

Initially, the sites of temples left unfinished by the Sui Dynasty were completed; the murals in them appear stylistically to continue in the manner of the Sui artistic school. However, 642 AD saw the introduction of a new imperial fashion in religious painting, that prevailed in the capital's grand monasteries and was created by the most famous painters of the day. Though none of the capital's Buddhist sites survived the Late Tang devastation inflicted by the Taoist Emperor Wuzong (814-846 AD), the MoGao murals from the Early and High Tang periods are representative of this new style.

The pictorial scenes appear to be colourful and highly decorative, with elaborate and exquisitely presented detail and carefully balanced colour schemes. The depictions of deities and donors show a delicate three-dimensional treatment, especially of the facial elements of the personages (Wang, 2014). Together with the use of traditional compositions such as that of the Thousand Buddhas, there are innovative compositions that are believed to mirror compositions used in the capital. Most popular in this period seem to be those evoking the magnificence of the Buddhist paradise, the Pure Lands.

However, the style of the MoGao murals from the Middle Tang period is very different from that of the preceding two periods. This is because, although technically the period between 762 and 712 AD was still part of the Tang period, nevertheless from 781 AD the MoGao site was under the rule of the Emperor Trisong Detsen (755-797 AD), the 38th emperor of the Yarlung Tibetan Dynasty. He became instrumental in establishing Buddhism as a state religion. Forty-eight of the MoGao temples are believed to have been constructed during the nearly seventy years of Tibetan rule.

Although thematically the decoration of these temples followed the Pure Land scenes, the exuberance of the Early and High Tang was replaced by a somewhat cruder representational system. This appears to have been a result of the introduction of the Tibetan tantric or esoteric decorative school, in accordance with which each scene was contained within an ornamental floral border which created a crowded and rigid appearance.

When in 848 AD the Tibetans were expelled and Chinese rule was restored the DunHuang area gained greater political autonomy. This was two years after the reign of the Emperor Wuzong (814-846 AD) so the MoGao complex escaped the destruction of temples resulting from the persecution of Buddhism when tens of thousands of sites were destroyed across China. The next ruler, the Emperor Xuangzong (846-859 AD) re-established Buddhism as the dominant, state religion. Consequently, at the MoGao complex the building and the decoration of new temples continued (Dang, 2009).

In the period 848-906 AD, during the Late Tang Dynasty, about sixty temples were completed. The murals continued the Tibetan style but the colouring became much more delicate, even more than in the Early and High Tang periods. Some scholars take the view that this was a result of the continuous turbulence in the western region and the interruption of free trade along the Silk Road, which limited the availability of pigments (Xu, 2007). However, it could be argued that the personal preferences of the artist, the prevailing fashions at the time or the increased technical ability to grind the pigments to a much finer fraction might also have played a role in achieving the described appearance of the colours used.

With the fall of the Tang Dynasty in 907 AD the country disintegrated into a number of much smaller principalities. These were the Five Dynasties (North China) and the Ten Kingdoms (South China). The period of the northern Five Dynasties (907-960 AD) lasted just over fifty years during which a further thirty-two caves were excavated and decorated at MoGao. Twenty-six of them were completed during the governance of DunHuang by the Cao military family in the period 920 to 960 AD. Some of those twenty-six are the largest temple caves carved into the rocks at that time. Another 300 existing caves were renovated or refashioned. Unfortunately, several of the earlier caves were incorporated in new construction and the original decorations were lost (Whitfield *et al*., 2015: 87-89).

The significance of the period when DunHuang was ruled by the House of Cao is not just because they undertook such extensive works and expanded and maintained the MoGao Buddhist complex. Two other elements of their governance had a far greater impact on the development of the MoGao site and on the evolution of the Chinese style in Buddhist art of the region.

Firstly, the Cao family governed DunHuang for one hundred and twenty years, from 920 AD to 1040 AD. It follows that their reign extended well beyond the Five Dynasties, into the Song Dynasty (960-1279 AD). As they were the main patrons of the MoGao site it is not surprising that there is a stylistic continuity between the temple decoration from the Five Dynasties era and that of the Song.

Secondly, their significant influence in the evolution of Chinese Buddhist art was made possible by the fact that shortly after the House of Cao ascended to power they established their own painting academy, drawing into it the leading regional artists, hence the high quality of the temple decoration from the time of Cao, at least from the time of the Five Dynasties.

The last two eras which saw some development of the MoGao site were those of the Song (960-1279 AD) and Yuan (1279-1368 AD) Dynasties. The style of the Five Dynasties also continued to be influential during the Yuan Dynasty. The latter was the time when the development of the MoGao complex was concluded. This coincides with the end of the importance of the Silk Road to the Chinese and to international trade as shipping largely superseded land transport.

3. Enquiring into the colours of the murals the MoGao temples

The enquiry is confined to the periods of the Sui, the Tang and the Five Dynasties, which was the peak time in the development of the temple complex. The methodology used for this investigation was designed to overcome the constraints imposed by the Covid-19 pandemic by conducting the study using images created for the virtual museum of the MoGao caves (Dunhuang Research Academy, 2020). To carry out our investigation, those murals considered by scholarship to be particularly significant examples of Buddhist art from each period will be selected. Each colour in the selected digital images is then identified as the nearest match within the Pantone Colour System using its digitalised version (Lei *et al*., 2021). The use of colour will be discussed in the context of the traditional ‘five colour system’.

3.1. *Wuxing and the Chinese Traditional Five-Colour System*

The Chinese term Wuxing (usually translated as ‘five processes’, ‘five phases’ or ‘five elements’) is used for a conceptual theory that has been a constant feature of traditional Chinese thought and culture. The five elements were considered to be independent, but at the same time interlinked. Before the Han Dynasty, when the initial idea was formed, the elements were associated with natural phenomena and seasonal changes, bringing an understanding of the workings and development of the Universe. These five elements were: Wood, Fire, Earth, Metal, and Water (see Table 1).

Element	Fire	Wood	Earth	Metal	Water
Colour	Red	Blue	Yellow	White	Black
Direction	South	East	Centre/middle	West	North
Season	Summer	Spring	Change of season	Autumn	Winter

Table 1. Relationship between the "five-colour system" and colour, direction and season.

The first proposed universal use of the ‘five elements’ conceptual system is found in “Book of Documents”, one of the “Five Classics” written during the Zhou dynasty (1046-256 BC). In those texts were associations with directions, colours, spirits, and proper rituals that were later enshrined in the Confucian classics, in particular the books Shijing (Classic of Poetry) and Rites of Zhou, dating respectively from the eleventh to seventh centuries BC and the second century BC. Those were used initially to regulate early Chinese dyeing techniques for the production of maps and paintings during this period thus leading to the development of the traditional Chinese ‘five-colour’ system (Tseng 2003: 192-197). Moreover, Wuxing assisted in describing, analysing or regulating the relationship of the elements within different spheres of human life – political, social and cultural. For example it assisted in complying with rituals and numerous hierarchical regulations such as those relating to the use of colour in people's clothing or the colours of their ornaments. Thus colours began to occupy an important place in all aspects of Chinese culture (Chen, 2015: 369).

In brief, the five colour system includes three chromatic colours and two achromatic ones: red, blue, yellow, white, and black. In a broad sense, they are independent sets of colours. There does not seem to be a suggestion of their optical qualities and thus no interest in the visual interrelationship between them. Moreover, the three colours occupy only part of any western colour system, but instead mirror the Wuxing conceptual system (Xiao, 2013: 185-187).

A relationship between the five colours and the five phases or elements in Wuxing was developed gradually. By its overarching nature Wuxing established a defining association between the five colours and natural phenomena and also concepts of space and time amongst others (Xiao, 2013: 191-195).

In painting, the mixing of pigments or the presence of natural impurities could result in ‘secondary’ colours, which are employed and are also considered within the ‘five-colour system’. For example, green (blue + yellow), cyan (blue + white), red-orange (red + white), amber yellow (black + yellow), purple (black + red) as shown in Figure 1b. In the case of the mixing of chromatic and achromatic colour usually the chromatic one is the defining ‘element’; in case of the colour green it is associated in tandem with the blues and cyans with Wood (Chen, 2015: 368-369).

Research shows that a number of mainly inorganic but also some organic pigments were used in the creation of the DunHuang murals from the three periods investigated here, the Sui, the Tang Dynasty and the Five Dynasties (Xu, 2007). For greater clarity the list of the main pigments so far identified is presented here in tabular form (see Table 2).

Pigment period / Colour	Sui Dynasty	Tang Dynasty	Five Dynasties
Red	Red clay Cinnabar Red lead	Haematite Cinnabar Red lead	Red clay Cinnabar Red lead
Blue	Lazurite Lapis lazuli Azurite	Lazurite Lapis lazuli Azurite	Lazurite Lapis lazuli Azurite
Green	Malachite	Malachite Verdigris	Malachite
Yellow	Ochre Orpiment Gold leaf Organic pigments	Ochre Orpiment Gold leaf Organic pigments	Ochre Orpiment Gold leaf Organic pigments
White	Kaolin White clay Talc	Calcite Kaolin Basic lead Oyster shell Gypsum	Kaolin Calcite Oyster shell Gypsum Talc Muscovite
Black	Carbon black Black lead Plant Soot	Carbon black Black lead Plant Soot	Carbon black Black lead Plant Soot

Table 2. List of pigments identified for the creation of the DunHuang murals from the Sui Dynasty; the Tang Dynasty and the Five Dynasties period.

These would have allowed the creation and use of the above-mentioned ‘secondary’ colours. However, in at least one such case, green, it appears that green-coloured pigments were used. This leaves open the question about the use of any other secondary colour(s), which will be determined in the next part of this investigation.

3.2. *Appearance of the colours in the main palette of the MoGao murals from the Sui Dynasty to the Five Dynasties.*

For the purpose of this enquiry two typical, well-preserved images from the Sui and two from the Five Dynasties periods were selected for examination. For the Tang Dynasty four images were examined, in accordance with the historic subdivision of the period into four distinct sub-periods: the Early, the High, the Middle and the Late Tang. The appearance of each colour in the selected digital images was identified as the nearest match within the Pantone Colour System using its digitalised version. The palette of each of the selected compositions was arranged along one the sides of each scene, bearing the Pantone code. The codes for uncoated paper were selected in order, to an extent, to take account of the matt surface texture of the murals (see Table 3). The nearest matches served to illustrate the appearance and also to act as a record to aid further systematisation of the MoGao colours.

Several variables determined the final appearance of the colours used in the murals of MoGao. Apart from the hue, determined by the molecular structure of a particular pigment, the other significant variables included the presence of impurities, the degree to which the mixing of different colours was employed and, of course, the base over which the coloured paint was applied. The latter will be determined by the way the painted surfaces were prepared initially.

Research shows that there were several steps before the final application of paint and that the preparatory procedure was identical throughout the history of the MoGao complex. The wall surfaces of the freshly dug cave walls would have been both very rough and vulnerable to exfoliation as the grottoes were carved into loosely-structured sandstone aggregate. To remedy the problem several layers of mud were applied. The first layer was a coarse one, a mixture of local sandy earth, straw and water. This was followed by a fine layer of washed clay mixed with fibres and water. Finally, the surface on which the paints were to be applied was prepared by another application of fine mud which was then covered with a thin, smooth layer of powdered kaolin, lime or gypsum.

During the Sui Dynasty the dominating hues of the murals are of cyan and green. Research suggests that the choice of hues at that time was likely to have been influenced from the northwestern regions of the Indian subcontinent, possibly Kashmir. The visual dominance of cyan and green is constructed by the sparing use of other chromatic colours. The chromatic colours that could be counted were usually three, as in the murals from the earlier periods. Though gold leaf has been used, because of its optical qualities, it cannot be considered under any colour categories referred to here.

The third colour was usually red. It is to be found as a background colour to the paintings and consists of low quality cinnabar mixed with red clay. The best cinnabar appears to have been used most sparingly, just for painting the Buddha's lips.

Another characteristic of the murals from the Sui Dynasty that is worth mentioning is that not only were they stylistically different from the murals constructed in the previous historic period, the Northern Zhou, but more often than not they used colours created by mixing different pigments. That gave the colours a somewhat turbid appearance. However, in one instance, as with the appearance of the black colours in the Sui period the mixing of colours resulted in a much deeper colour. Research shows that the blacks were a composite of several chromatic colours and not created by the use of a single pigment. In this case the mixture was made by combining red, yellow, blue and green. This allowed for the creation of a variety of final appearances. The resultant colours could be classified as warm blacks or cool blacks, which allowed for a more balanced appearance of the final picture.

Two of the most representative images have been selected to illustrate this enquiry into the appearance of colours used in the art of the Sui Dynasty. The first is the West Mural of Cave 420 (see Fig. 1a). This composition is constructed over a red background using three colours - dark green, pink-green and grey-green - with different degrees of light and chromatic contrast.The pigments used were red earth, lapis lazuli and malachite. The browns that can be seen are achieved by a mixture of red earth with ink.

The other example of Sui art is from Cave 303 (see Fig. 1b). The compositional background used here is white, while red is used sparingly as a colour of flesh or of garments and furnishings. Again the blue of the roofs and the green of the landscape flora dominate the composition. Scholars consider that the use of a white background can most probably be the result of an influence that had arrived from the Western Regions via the Silk Road. The particular pigments used in the creation of the colours of this scene are talc and calcite, while red is derived from good quality red earths. Blues and greens are derived from lapis lazuli and malachite respectively.

In the Early Tang Dynasty (618-712 AD) the final preparation coat applied to the walls was a thin smooth layer of local iron-rich clay, rather than kaolin or gypsum. As the mural colours were applied over it the final appearance of the compositions appear to be much warmer than compositions from the Sui period and also than compositions from the later Tang periods.

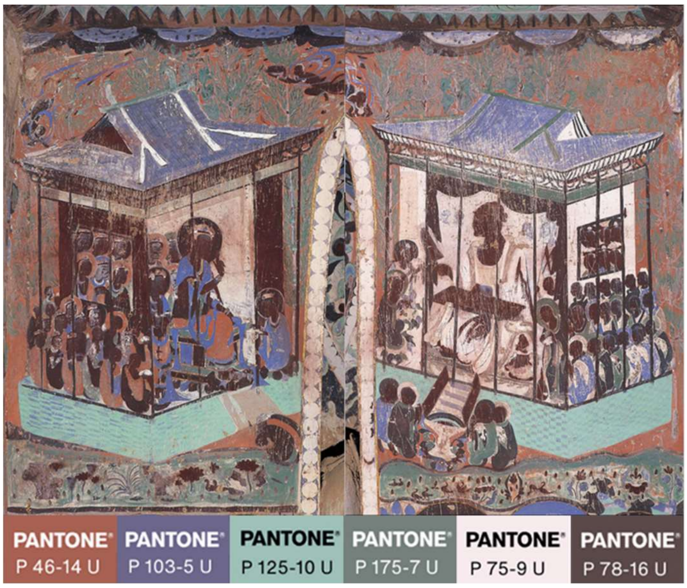

Fig. 1a. Cave 420 in the Sui Dynasty (581-618 AD).

Fig. 1b. Cave 303 in the Sui Dynasty (581-618 AD).

The image that was analysed for the purposes of this paper is the central composition on the south wall of Cave 322 (Fig. 2a). Initial examination indicated that all the general hues in the traditional Chinese 'five colour system' were used in this mural, together with one of the 'secondary' colours, green. Moreover, a new combination of gold and earth yellow had been added. However, because of the specific optical properties of gold, for the purposes of this investigation only the appearance of the colour yellow was considered. Despite the already mentioned foreign influences on the DunHuang style, especially in the Early Tang period, it has to be stressed that the choice of colours is considered to have been primarily influenced by the local Chinese colour preferences (Zhou, 2000).

Over the High Tang period (713-766 AD) the DunHuang style was established. It is considered that ninety-seven caves were excavated and decorated during this period. The mural on the north side of Cave 217 (Fig. 2b) is well preserved and is one of the outstanding masterpieces of the murals executed at the most prosperous time of the Tang Dynasty. The overall tone of the whole painting is again warm, but more intense than that of the murals from the Early Tang period as the colours were made with less mixing of pigments, thus appearing more saturated and vibrant (Zhou, 2000).

Fig. 2a. Colour palettes used in Tang Dynasty: Cave 322 in the Early Tang Period (618-712 AD).

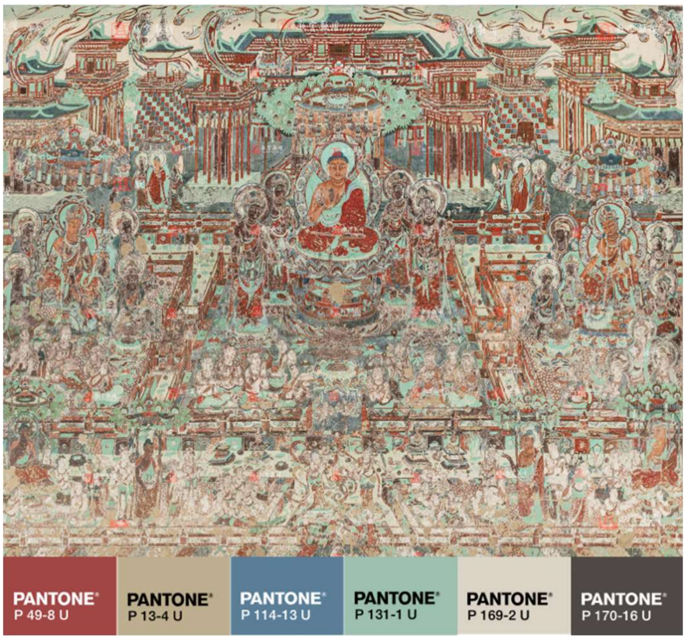

Fig. 2b. Colour palettes used in Tang Dynasty: Cave 217 in the High Tang Period (713-766 AD).

Moreover, there could be noted an even wider use of gold, compared to the previous period. Research considers that to be a result of the increase in the influence of Buddhism as a defining force in the structuring and maintenance of Chinese Imperial power. As a result gold leaf and vibrant, 'secular' colours perceived as 'colours of wealth' began to be widely used in paintings (Meng, 2008).

During the Middle Tang period (762-827 AD) fifty-five new cave temples were created. This was a period of continuous internal and external struggles as there were countless wars, battles and skirmishes with the Tibetan Empire (618-842 AD) resulting in considerable territorial losses. The political and economic instability in the period impacted on the production of art and the opulence and refinement of the murals made in the Early and especially in the prosperous High Tang Period was lost. The early golden and vibrant tones were replaced by a mainly lighter, paler palette. These light paints appear to have been thinly applied, with a dominance of flat green and yellow, and outlined with ink (Meng, 2008).

An example of the Middle Tang period mural art is the image of the central mural on the south wall of Cave 159 (Fig. 2c), where more obvious changes in the use and the appearance of colour can be noted.

Fig. 2c. Colour palettes used in Tang Dynasty: Cave 159 in the Middle Tang Period (762-827 AD).

Green was used on a much larger scale either as a single colour or in a number of very similar adjacent tones, though red and other warmer tones could also be found in the compositions. The base undercoat of the murals was now white earth and the intensity of the colours of the murals appeared to be greater. It could be argued that those changes are to some extent a consequence of periodic changes in the Wuxing rules in general and those relating to art and its production in particular. At the same time, there were still some murals from the Middle Tang period that were painted over an iron-rich undercoat, as in the previous two periods (Meng, 2008).

In the Late Tang period (828-907 AD) DunHuang seventy one caves were excavated. This period saw a continuation of the style of the Middle Tang Dynasty that was dominated by light blue and green tones, as is illustrated in a mural from the decoration of Cave 12 (Fig. 2d). The influence of Tibetan religious art is still noticeable but there are stylistic changes. They have been attributed to the growing cross-fertilisation between the previously separate aesthetics of secular art found in the Western Regions of the Late Tang Empire and that of the existing style of religious paintings. Scholars concluded that this, on the one hand, revitalised the paintings from the period, compared to the Middle Tang period and, on the other hand, prepared the foundation for the emergence of the style of the Western Xia Dynasty (1038-1227 AD) and its significantly different use of colour (Meng, 2008).

Fig. 2d. Colour palettes used in Tang Dynasty: Cave 12 in the Late Tang Period (828-907 AD).

The use of pigments in the Five Dynasties period is similar to that of the Tang dynasty. However, often the colour is less complex in appearance. The colours are predominantly green, red, red-brown, brownish-red and white. The pigments used are again malachite green, red earth, kaolin and oyster shell. In some cases muscovite has been added (Xin, 2018). As in this period there is no use of gold leaf, it could be suggested that muscovite was used in order to add some glitter.

A scene from Cave 61 (Fig. 3a) is one of two selected to enquire into the appearance of the colours in the Five Dynasties frescoes. Here the composition seems to be copied from another with the same subject, but from the Late Tang period. The composition is stylised and lacks the expressionist qualities of the earlier painting. The colours appear flatter and less bright than in the Tang period. This is a tendency that appears to have influenced the style of wall painting in the later dynastic periods of Song (960-1279 AD) and Yuan (1279-1368 AD).

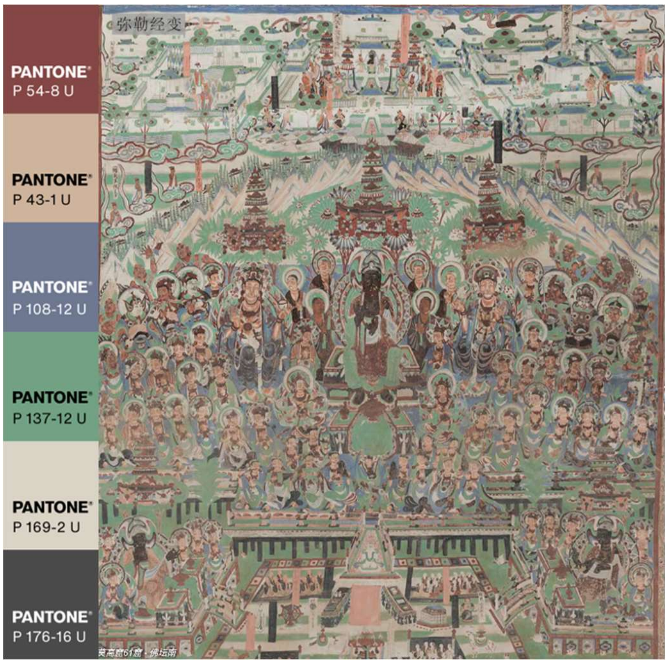

Fig. 3a. Colours used in the Five Dynasties period: Cave 61 in the Five Dynasties (907-960 AD).

The other scene is from Cave 6 (Fig. 3b). The colours are saturated and the dominant chromatic colours are red-orange and blue-green, but there are also two others, red and blue. From the achromatic colours it is white that dominates the picture. White has been used as the background colour and also as a flesh colour. It can be argued that the apparent brightness of the composition is influenced by the continuous juxtaposition of the red-orange and the blue-green. The two form a complementary pair on the Western wheel systematic classification of colours. Both colours are also individually classified as tertiary indicating that the artists must have derived these particular colour appearances by the mixing of pigments. In parallel with the colour contrast a light contrast is also created by the juxtaposition of the chromatic colours with white. Black was not used to create light contrast, but was limited to areas where it was used to define some decorative elements. For the red-orange colour, cinnabar, red earth and white were used. For the blue-green colour, a mixture of malachite, lapis lazuli and white was used. For the red colour the artists appear to have used red earth and for the blue colour, lapis lazuli. The white used in this scene has been found to derive mainly from lead white, but containing a significant level of impurities (Xu, 2007).

Fig. 3b. Colours used in the Five Dynasties period: Cave 6 in the Five Dynasties (907-960 AD).

The findings from the digital identification of the codes for the nearest matches within the Pantone Colour System are arranged in Table 3 below.

Cave no. / Colour	Sui Dynasty	
	Cave 420	Cave 303
Red	P 46 - 14 U	P 49 - 8 U
Yellow	-	P 29 - 1 U
Blue	P 103 - 5 U	P 106 - 16 U
Green	P 125 - 10 U	P 147 - 13 U
White	P 75 - 9 U	P 169 - 1 U
Black	P 78 - 16 U	P 176 - 16 U

Cave no. / Colour	Tang Dynasty			
	Cave 322	Cave 217	Cave 159	Cave 12
Red	P 54 - 11 U	P 49 - 8 U	P 38 - 15 U	P 64 - 16 U
Yellow	P 28 - 11 U	P 13 - 4 U	P 21 - 10 U	P 26 - 10 U
Blue	P 114 - 12 U	P 114 - 13 U	P 109 - 15 U	P 111 - 13 U
Green	P 130 - 12 U	P 131 - 1 U	P 130 - 05 U	P 121 - 13 U
White	P 51 - 1 U	P 169 - 2 U	P 179 - 2 U	P 169 - 2 U
Black	P 170 - 16 U	P 170 - 16 U	P 170 - 16 U	P 108 - 16 U

Cave no. / Colour	Five Dynasties	
	Cave 61	Cave 6
Red	P 54 - 8 U	P 50 - 7U
Yellow	P 43 - 1 U	P 24 - 6 U
Blue	P 108 - 12 U	P 101 - 3 U
Green	P 137 - 12 U	P 127 - 12 U
White	P 179 - 2 U	P 39 - 9 U
Black	P 176 - 16 U	P 176 - 16 U

Table 3. Colour palettes, presenting in the closest match of the PANTONE® CMYK Uncoated guide set, of the DunHuang murals from the Sui Dynasty, Tang Dynasty and Five Dynasties Periods.

Closer examination indicates that the codes for the appearances of colours within the group of each hue vary only slightly. That is to say, the appearances are visually different, but the colours could be described as varying by saturation and lightness and/or generally subtle nuances. It could be argued that these differences are attributable to the use of minimal mixing of pigments and perhaps also to the constancy of the sources from which those pigments were derived. That is a subject for future investigation.

4. Discussion

From an examination of the existing scholarship on the use of colour in Chinese art and, in particular, the MoGao murals from the Sui to the Five Dynasties periods, it became apparent that thematically and stylistically the compositions of the MoGao caves absorbed many influences from Buddhist art mainly from Central Asia, India, Iran and Tibet. Moreover, while the colour scheme of the Sui murals is dominated by blues and greens throughout the Tang period, a greater range of colours was used. Whereas in the Early and High Tang periods the palettes were dominated by reds and yellows with the added use of physical gold, by contrast in the Middle and Late Tang periods the palettes became dominated by light blues and greens. In the Five Dynasties period one of the main qualities sought in the appearance of the scenes - and subsequently of the colours - seems to be brightness. In all periods the number of the actual colour hues was found to have been reduced to the minimum necessary to achieve the desired aesthetic result. The use of colour and light contrast has been identified in some cases as a tool to increase the visual impact of the compositions.

Furthermore, the enquiry indicated that the palettes were always constructed according to the Wuxing conceptual system that ruled every part of human life. Therefore, in every dynastic period, the palette followed the traditional Chinese 'five colour system' without deviation. Moreover, despite the considerable number of pigments found to have been used in the MoGao cave temples, there is only one 'secondary' colour which, it must be stressed, does appear to be part of the extended 'five colour system'. Even for that a separate pigment was used, rather than creating the colour by mixing two other pigments. It is only in the Sui and later in the Five Dynasties period that some mixing of pigments took place, but that was only to enhance the appearance, as in the case of the blacks used in the Sui, or to create more complex tertiary colours to achieve a colour contrast between two light colours, as in the particular example from the Five Dynasties. It can be concluded that the intensity and vibrancy of the colours had a special significance through all the historic periods examined here.

The present work is yet another step towards building an understanding and appreciation of the significance of the DunHuang complex as emblematic of Chinese civilisation.

Moreover, the results of this work prepare the ground for further investigation into the aesthetics of the representational system of these murals, as part of the national and world cultural heritage.

5. Conflict of interest declaration

Potential conflicts do not exist.

6. Funding source declaration

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7. Short biography of the authors

Elza Tantcheva-Burdge is an independent researcher in art and architectural history and archaeometry, with a special interest in colour and light. She holds a DPhil in the history of art and Masters degrees in both art and science and has worked as a scientific researcher, industrial and textile designer and artist. Through the Colour Group (GB) she initiated the annual international conference Colour in Film.

Zhaohua Lei was born in China. She is an interior designer. She completed her studies in Europe with a double Masters degree in Interior Design and Colour Design. She is now working in Shanghai and is passionate in studying traditional Chinese colours.

Vien Cheung holds an academic post as Associate Professor at the University of Leeds, UK. She has published over 100 refereed research papers, book chapters and book in the areas of colour and textiles. She is active in charitable and educational organisations including the International Colour Association (AIC), the Colour Group Great Britain (CGGB) and the Society of Dyers and Colourists (SDC).

Licensing terms

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“Perpetual plum”: Colour naming strategies in Maybelline’s lip products

Isabel Espinosa-Zaragoza[1]

[1] *English Department, University of Alicante, Alicante, Spain. Isabel.espinosa@ua.es*

Corresponding author: Isabel Espinosa-Zaragoza (Isabel.espinosa@ua.es)

ABSTRACT

This study deals with the particularities of “constructed nameables” (Wyler, 2007, p. 117), that is, colour terminology in the context of cosmetic products, more specifically, of lipstick colour names by the cosmetic company Maybelline. How these nameables are created (i.e. word formation processes) and the imagery exploited (i.e. themes) in order to be memorable in a competitive market are the focus of this study. For this purpose, a sample of four lipstick collections with a total of seventy-six shades is manually collected from their official webpage (www.maybelline.com). The analysis reveals the predominance of two nomenclatures: morphosyntactic and semantic. The former is intended to capture the consumer’s attention by deviating from the expected. This is carried out by means of both hyphenated expressions, such as *pink-for-me, mauve-for-me* or *plum-for-me,* and with the use of the determiner *more* and secondary colour terms, like in *more taupe*, *more magenta* or *more truffle*, among others. The latter aims at seducing the customer by exploiting theme consistency based either on romance and compulsion (e.g. *magenta affair, pink fetish*) or on colour longevity (e.g. *everlasting wine, eternal cherry*). In some cases, these are also combined with alliteration (e.g*. timeless toffee, continuous coral, perpetual plum*) and assonance (e.g. *steady red-y*) to further appeal to the potential buyer. The results and conclusions point to the paramount importance of colour terminology in cosmetic verbal identity (Allen and Simmons, 2003). These colour names contribute to a coherent and homogeneous lip product range organisation that is highly memorable and attention-grabbing.

KEYWORDS ESP, colour terminology, verbal identity, naming, lipstick, cosmetics

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1. Introduction

The cosmetic industry is known to resort to eye-catching verbal identities and, especially, evocative colour terminology, to differentiate quasi-identical products in an ever-increasing competitive market. The fact that both cosmetic products and brands are constantly created forces for the invention of impactful and memorable colour names to boost the appeal of the products offered. These colour terms are "constructed nameables" and, thus, "there is no reason not to use any lexeme as a colour designation, especially with cosmetics" (Wyler, 2007, p.142). Consequently, this colour terminology deserves close attention to determine which trends constitute the current verbal identity (Allen and Simmons, 2003) of, in our case, Maybelline, and the potential intention behind such linguistic strategies.

2. The cosmetic industry: An overview

The cosmetic industry is an extremely competitive market that has thrived even through global economic crisis both during the 20th and the 21st century (see Merskin, 2007; Hill et al., 2012; Netchaeva and Rees, 2016). In Merskin's (2007, p. 592) words, "lipstick sales have an inverse relationship with economic downturns and national calamity". As a matter of fact, there is an economic indicator, what is known as "the lipstick effect", which is described as the tendency to acquire relatively inexpensive beauty items or "affordable luxury" (see Euromonitor International, 2013) during troublesome economic times due to psychological motives. Namely, an instant gratification feeling after purchase, an improvement in consumer's mood and an appearance enhancement that leads to an increase in positive self-esteem and social expression. According to Kestenbaum (2017, para. 13), there is a generalised growth in beauty items expenditure, regardless of the product category. In fact, this economic sector is expected to grow in spite of the setbacks produced by the Covid-19 crisis, with a shift towards hair dyes, skin care, nail care and others, that are ideal for at home pamper routines (see Sedlmayr, 2022; McKinsey & Company, 2021).

Regarding the different types of cosmetic brands, these could be organised according to their CEO or creator, like celebrity make-up brands and multinational corporations; their price point, such as drugstore, high-end or luxury brands (see Espinosa-Zaragoza, 2022); or depending on whether or not they are solely digital, like "digital brands" or Digitally Native Vertical Brands (DNVB), as opposed to those with traditional physical stores. The wide variety of brands currently available increases the competitiveness in the market and any detail like, for instance, the shade name in coloured products, is of paramount importance. These companies offer lipsticks in different formulas, finishes, colour ranges, prices, packaging and others. This has resulted in the production of countless similar lip products offering almost identical results and whose only difference may be the name given to the colour.

Concerning the name elements in cosmetics, these have their particular structure and consist of different constituent elements or parts. Following Tuna and Freitas (2015, p. 136), cosmetic names are often made of three constituent elements: (1) the brand name, that identifies the company; (2) the product line, also called range or collection; (3) and the generic product name or function expressed by means of a description. For example, the "Maybelline Super Stay 24® 2-Step Liquid Lipstick Makeup", consists of the brand name (e.g. Maybelline), the product line (e.g. Super Stay 24) and the generic name (e.g. Liquid Lipstick) also indicating its dual application stages (e.g. 2-Step). To this structure or these already mentioned parts, others could be added, like the (4) colour name and the (5) descriptions (see Espinosa-Zaragoza, 2022). More specifically, the name given to identify the shade within the collection (and the brand), which is precisely the object of this study, and the optional description provided by the company in case the name is semantically opaque (e.g. *Milan, Natalie*) or if the brand wants to provide more information about an already transparent colour name (e.g. *pink, berry*).

3. Colour terminology and verbal identity

Colour terminology may be divided into basic colour terms, henceforth BCTs, (see Berlin and Kay, 1969) and secondary colour terms (see Casson, 1994). On the one hand, BCTs —*black, white, red, green, yellow, blue, brown, purple, pink, orange* and *grey* in English— are not usually resorted to in cosmetic colour terminology owing to their basic nature and lack of attention-grabbing properties (see Wyler 2007, p. 116-117). These are, therefore, normally accompanied by diverse linguistic information referring to and describing its dimensions, like saturation and lightness (e.g. *light, dark, deep*), yielding compositional non-basic colour terminology (see Anishchanka, Speelman and Geeraerts, 2014). On the other hand, secondary colour terms (see Casson, 1994), also known as "non-compositional non-basic names" (see Anishchanka, Speelman and Geeraerts, 2014) or "logical terms" (see Biggam, 2012, p. 50), are denominations where the "entity stands for entity's color". Like in, for instance, *chocolate* to name a brown shade that resembles chocolate. These are very prevalent in marketing, although they could be felt as insufficient to stand out among the myriad of alternatives in this highly competitive market. As a consequence, more linguistic information is often included to produce original evocative terms (Biggam, 2012, p. 50).

Additionally, different "nominal architectures" (see Martín, 2009, p. 283; Wheeler, 2009, p. 22), that is, the identifiable patterns and relations in the naming of products, subproducts and services in a company, are applied to devise not only a coherent and homogeneous in-brand colour range organisation but also to increase the company's appeal power as a means to stand out from the rest of competitors. Thus, the creation of a brand identity helps in differentiating similar products. This advertising language is in search for attention value, readability, memorability and selling power which may be reached through a carefully considered verbal identity, more exactly, by the ideation of thought-out collections. Among the different nomenclatures put forward by Martín (2009), the most important for our purpose are the semantic and syntactic ones. In addition, phonetic-phonological aspects like alliteration and assonance, linguistic devices very much used in both poetry and marketing (see Vasiloaia, 2009), are often applied rigorously, and, in turn, could be considered as another type of nomenclature (see Espinosa-Zaragoza, 2022). Accordingly, a consistent and homogeneous brand image is apparent in the selected Maybelline ranges, which contributes to memorability, both in terms of retention and recall power as well as in product differentiation (see Skorupa and Dubovičienė, 2015).

4. Objectives and methodology

This paper focuses on the verbal identity selected for the lipstick shade names by the cosmetic brand Maybelline, paying attention to how these names are formed (i.e. word-formation processes), their themes and imagery exploited to appeal the consumer and other phonetic-phonological aspects present in them. Consequently, the main objective is to identify and describe the different verbal identity traits in Maybelline's lip product lines.

Collection	**Nomenclature**	**n**
Color Sensational® Made for All Lipstick	Syntactic	7
Color Sensational Ultimatte, Slim Lipstick Makeup	Syntactic	10
Super Stay 24® 2-Step Liquid Lipstick Makeup	Semantic	44
Color Sensational® Shine Compulsion Lipstick Makeup	Semantic	15
Total		76

Table 1. Sample information

For our purpose, a sample of seventy-six colour names by the cosmetic brand Maybelline (www.maybelline.com) was manually collected during March 2021. These shades belong to the four collections specified in Table 1. It must be pointed out that no additional colour description was provided by Maybelline at the time of the compilation, only a visual colour representation (i.e. picture and colour swatch).

5. Analysis and discussion

The analysis reveals the homogeneous utilisation of nomenclatures across collections based on (1) structure repetition which replicates patterns (i.e. morphosyntactic nomenclature) and (2) a consistent theme or topic in which every colour is part of a semantic field belonging to either colour longevity or romance (i.e. sematic nomenclature). Moreover, some phonetic-phonological aspects are also intentionally exploited (i.e. assonance and consonance) so as to further appeal to the consumer with fancy sounding colour names.

5.1. *Morphosyntactic nomenclature*

Concerning structure repetition in colour naming, two different word formation processes are consistently applied in two of Maybelline's lip colour ranges. On the one hand, in the "Color Sensational Made for All Lipstick" collection (1), hyphenated expressions are selected to reinforce the collection's claim made in the collection name (i.e. Made for All) and the general appropriateness of this particular colour for the customer (e.g. *red-for-me, pink-for-me; mauve-for-me, fuchsia-for-me; plum-for-me, spice-for-me; ruby-for-me*). In this way, the colour name is addressing the person, indicating that this specific colour is perfect, appropriate and suitable for the consumer. This structural pattern (i.e. "colour term-for-me") is a compound phrase with a colour term as Head and a prepositional phrase complement (see Bauer and Renouf, 2001, p. 103). Not only does this work as a mantra in each product application by stressing that this particular colour belongs to the consumer, but it also links and identifies those shades as part of the "Made for All" collection.

(1) Color Sensational® Made for All Lipstick:

a) *pink-for-me*
b) *red-for-me*
c) *ruby-for-me*
d) *mauve-for-me*
e) *fuchsia-for-me*
f) *spice-for-me*
g) *plum-for-me*

(2) Color Sensational Ultimatte, Slim Lipstick Makeup

a) *more berry*
b) *more ruby*
c) *more scarlet*
d) *more magenta*
e) *more blush*
f) *more mauve*
g) *more buff*
h) *more taupe*
i) *more rust*
j) *more truffle*

On the other hand, the "Color Sensational Ultimatte, Slim Lipstick Makeup" collection (2) utilises a determiner (e.g. *more*) and a secondary colour term to convey that there is more of something, in this case, a secondary colour term (i.e. "entity stands for entity's colour"). The secondary colour terms preceded by *more* belong to different semantic fields like flowers and plants (e.g. *more mauve*), food and beverages (e.g. *more berry, more truffle*), minerals and pigments (e.g. *more ruby, more rust, more scarlet, more magenta*) and animals and its fur, skin or feathers (e.g. *more taupe, more buff, more blush*).

5.2. *Semantic nomenclature*

According to Martín (2009), a semantic nomenclature entails thematic consistency, in other words, following an identifiable conceptual pattern across all the products or services in a brand or, in our case, the colour names in a lipstick collection. There are two collections that follow a semantic nomenclature in our sample. Firstly, the "Super Stay 24® 2-Step Liquid Lipstick Makeup" collection (3) heavily exploits the concept of product longevity: not only is it mentioned in the collection name (i.e. Super Stay 24), which claims to last up to 24 hours, but also in the colour name of the products. This is done in order to emphasise the long-lasting nature of these liquid lipsticks intended to stay on your lips for hours. To yield nameables including this homogeneous and constant reference to longevity across all shades, the structural pattern usually consists of either adjectives (e.g. *everlasting, eternal, endless, infinite, unlimited, boundless, constant*), adverbs (e.g. *all day, 24/7, all night, forever*) and a colour term, either basic (e.g. *pink, red*) or secondary (e.g. *wine, cherry, chestnut* and others). Some examples are gathered in (3) below. In addition, there are some instances of sentences, like *pink goes on* or *keep up the flame,* that also indicate that the shade is long-lasting and even one instance of "colour term + noun", *merlot armour*. In the latter, the colour is presented as a firm and enduring shield. As can be seen from the examples provided below, the notion of colour durability is maintained throughout all the collection shade names by using different adjectives and adverbs which highlight the high staying power of these lip products.

(3) Super Stay 24® 2-Step Liquid Lipstick Makeup:

a) *never ending pearl*
b) *absolute taupe*
c) *constant toast*
d) *all night apricot*
e) *frosted mauve*
f) *infinite petal*
g) *always heather*
h) *forever chestnut*
i) *blush on*
j) *crisp magenta*
k) *frozen rose*
l) *24/7 fuschia*
m) *all day cherry*
n) *eternal cherry*
o) *everlasting wine*
p) *optic ruby*
q) *unlimited raisin*
r) *all day plum*
s) *boundless ruby*
t) *endless expresso*
u) *pink goes on*
v) *on and on orchid*
w) *keep up the flame*
x) *keep it red*
y) *merlot armour*

(4) Color Sensational® Shine Compulsion Lipstick Makeup:

a) *baddest beige*
b) *undressed pink*
c) *secret blush*
d) *spicy sangria*
e) *spicy mauve*
f) *risky berry*
g) *steamy orchid*
h) *arousing orange*
i) *pink fetish*
j) *taupe seduction*
k) *chocolate lust*
l) *scarlet flame*
m) *magenta affair*
n) *berry blackmail*
o) *plum oasis*

Secondly, the "Color Sensational® Shine Compulsion Lipstick Makeup" collection (4) focuses on love and romance (see Merskin, 2007; Radzi and Musa, 2017; Espinosa-Zaragoza, 2022), especially on compulsion which is mentioned in the collection name. Thus, this theme is resorted to with a two-fold aim: seducing the consumer so as to purchase these colours and, in turn, s/he also becoming the object of seduction.

On the one hand, the semantic nomenclature is mainly carried out via compound adjectives (4a-4h) whose Head is a colour term, either basic or secondary, and the modifier is an adjective related to sex and romance. Thus, the sex-related information is conveyed with the left element in the compound, such as in, *undressed pink, spicy sangria, spicy mauve, steamy orchid, risky berry, baddest beige, arousing orange* and *secret blush*.

On the other hand, it is also done by means of a colour term as a modifier in a compound noun (4i-4o) whose Head carries the meanings related to passion, desire and a risky and forbidden love. Examples of these types of shade names are *pink fetish, taupe seduction, scarlet flame, chocolate lust, magenta affair, berry blackmail* and *plum oasis*, as shown above in (4).

5.3. *Phonetic-phonological aspects*

Apart from the previously mentioned consistent and homogeneous nomenclatures, there are some apparent phonetic-phonological aspects in these ranges, although not in every single shade name. Therefore, it is not a nomenclature in this particular case, even though it could be considered another type of nomenclature as posed in Espinosa-Zaragoza (2022).

These phonetic-phonological aspects are found in the "Super Stay 24® 2-Step Liquid Lipstick Makeup" collection (5) which, apart from being based on the notion of colour endurance, is also combined with consonantal alliteration in almost 40% of the collection. The objective here is boosting the attractiveness of this product, where the initial consonant sounds in both elements of the compound coincide. This can be observed in the repetition of consonantal sounds (5a-5m), especially of the voiceless plosive stops such as /p/ in *so pearly pink* and *perpetual plum*, /t/ in *timeless toffee* and /k/ in *committed coral, constant cocoa* and *continuous coral* or in the voiced plosive stop /b/ *boundless-berry*. The different approximants consonantal sounds are also repeated in compounds, like the voiced alveolar approximant /l/ in *loaded latte* and *lasting lilac*, the voiced post-alveolar approximant /r/ in *reliable raspberry* and *relentless ruby* and the voiced bilabial velar /w/ in *wear on wildberry*. Lastly, the voiced bilabial nasal /m/ is also repeated in *more & more mocha*, as well as the voiceless alveolar fricative /s/ in *stay scarlet*.

(5) Super Stay 24® 2-Step Liquid Lipstick Makeup:

a) *so pearly pink*
b) *perpetual plum*
c) *timeless toffee*
d) *committed coral*
e) *constant cocoa*
f) *continuous coral*
g) *boundless-berry*
h) *loaded late*
i) *lasting lilac*
j) *reliable raspberry*
k) *wear on wildberry*
l) *more & more mocha*
m) *stay scarlet*
n) *extreme aubergine*
o) *non-stop orange*
p) *steady red-y*
q) *very cranberry*

Nevertheless, this initial sound repetition in the elements of the compounds, although mainly employed through consonantal sounds, is not exclusively relegated to them. In fact, there are also some instances of vowel sound reiteration (5n-5q), in other words, assonance, with repetition of /iː/ in *extreme aubergine* (/ɪkˈstriːm ˈəʊbərʒiːn/) or /ɒ/ in *non-stop orange* (/ˌnɒnˈstɒp ˈɒrɪndʒ/). Furthermore, longer sound clusters like /ɛdi/ in *steady red-y* (/ˈstɛdi ˈrɛdi/) and /ri/ *very cranberry* (/ˈvɛri ˈkrænbəri/) include the repetition of several consonantal and vowel sounds. It must be noted that the wordplay *red-y* coincides with the homophone "ready" but yielding a colour at the same time.

6. Conclusions and final remarks

This study highlights the importance of colour terminology in the cosmetic industry as part of the verbal identity of a company. Thus, cosmetic colour names in general, but specially in lipsticks, do much more than simply describe or designate hues: these "constructed nameables" instil lip products with a distinctive touch that helps relating them to their brand and also serve as an organising tool where all the colours in a collection are named in a coherent and homogeneous way in hopes of capturing customer attention. These cutting-edge linguistic trends that currently dominate cosmetic colour denomination are worth analysing so as to know what has already been done and the possibilities still available for captivating and original colour terminology curation.

On the one hand, with a repetition of structure patterns, the intention behind this verbal identity is to surprise the consumer by diverting customer expectations of finding a selection of conventional monolexemic colour terminology —either BCTs (Berlin and Kay, 1969) or secondary colour terms (Casson, 1994)—. In this way, eye-catching syntactic structures are searched for, which further contribute to collection memorability and homogenisation.

On the other hand, the thematic consistency across ranges (e.g. longevity or romance) reinforces information that is already stated in the collection name.

In this way, everything is connected and information which might influence a purchase is reinforced. On the subject of the use of romance as a theme in cosmetic colour names (see Espinosa-Zaragoza, 2002), there is a patent ambivalence with the customer both seducing and being seduced. That is, it is utilised with a two-fold intention: (1) the consumer is captivated by the colour range and, thus, seduced and/or enamoured by it and/or (2) the person that wears the shade is able to seduce others owing to the application of that particular colour to their lips.

Additionally, and in sum, alliterative compound colour names add to this experience as they are pleasing to the ear. Some phonetic-phonological aspects, namely consonance and assonance, are also found in the sample. These are helpful rhetorical devices in an advertising context due to their fancy-sounding qualities and ability to increase memorability (see Skorupa and Dubovičienė, 2015) and also, in some cases, even constitute nomenclatures (see Espinosa-Zaragoza, 2022).

This analysis further complements and expands on previous cosmetic advertising studies and on the language of cosmetics (see Merskin 2007; Ringrow 2016; Radzi and Musa 2017). These results are based on a reduced selection that does not capture the wide variety of colour naming strategies used in the cosmetic industry. This could be counteracted by adding other Maybelline collections and even other brands to enlarge the colour name sample. Nonetheless, the results and conclusions point to the crucial importance of verbal identity in cosmetic companies. The ideation of marketing-driven colour terminology is part of the verbal identity of a brand, which combined with other advertising elements, like PR packaging design, colour palette selection, brand ambassadors and social media (re)presentation and interaction, create an entire personality that differentiates the company from its competitors. We actively encourage the continuation of studies focused on colour terminology in advertising, not only in the cosmetic industry but also in other industries and economic sectors.

7. Conflict of interest declaration

The author of this piece of research declares no known conflict of interest with other people and/or organisations.

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10. Short biography

Isabel Espinosa-Zaragoza – holds a PhD in Linguistic Studies from the University of Alicante. Her main research interests lie primarily in the field of colour names in marketing, paying attention to their (non)transparency and potential effects on consumers. She has participated in different national and international conferences (e.g. PICS 2022, AIC 2021) and published articles mainly covering the naming of colour in cosmetics.

Licensing terms

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The promise of color in marketing: use, applications, tips and neuromarketing

Alessandro Bortolotti[1,2], Loreta Cannito[2,3], Stefano Anzani[1,2] and Riccardo Palumbo[1,2]

[1]Department of Neuroscience, Imaging and Clinical Sciences, University Gabriele d'Annunzio Chieti-Pescara. alessandro.bortolotti@uinich.it, stefano.anzani@uinich.it, riccardo.palumbo@unich.it.

[2]Center for Advanced Studies and Technology (CAST), University "G. D'Annunzio" of Chieti-Pescara.

[3]Department of Psychology, University of Campania, 81100 Caserta, Italy. loreta.cannito@unicampania.it

Corresponding author: Alessandro Bortolotti (alessandro.bortolotti@uinich.it)

ABSTRACT

In our daily lives, we are constantly exposed to many stimuli, some of which influence our behavior without full awareness. One of these stimuli is color. In particular, our purchasing decisions are guided by individual color preferences. Color preferences influence various daily tasks. For example, people make decisions within 90 s of their first interaction with products, and approximately 60-90% of the evaluation of a product is based solely on its color properties. However, these types of behavior often escape consumer awareness, so marketing may need the help of neuroscience. Thus, it is necessary to place color preferences at the center of marketing strategies. However, few attempts have been made to unify the literature on the contribution of different color characteristics and the role of consumer characteristics. This article reviews scholarly articles that focus on the use of color in marketing, identifying salient features and highlighting limitations. Practical implications and future directions for this area of research are outlined, with a particular interest in neuromarketing. The results obtained will be useful for both basic research and companies that want to operate consciously in the use of color.

KEYWORDS Color, Marketing, Psychology, Context

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1.Introduction

It is now known that people make decisions within 90 s of their first interaction with a product. Approximately 62-90% of the evaluation is based on color alone (Singh, 2006); some of these decisions are emotion-driven and, therefore, escape consumer awareness (Alsharif et al., 2021). In this particular case, one needs neuromarketing techniques, defined as the application of neuroscientific methods to analyze and understand human behavior in relation to markets and marketing exchanges (Lee et al., 2007). Optimizing the use of color in marketing is of paramount importance today, and several techniques have been employed to more accurately investigate the influence of color on consumer choices (Shaw & Bagozzi, 2018). To date, defining the term "color," giving it a definition acceptable to all stakeholders, is a very difficult challenge. Over time, color has been defined in a myriad of ways, and it is fair to say that no universal and definitive definition has yet emerged (Kuehni, 2012). To fully define or understand the phenomenon of color, it is important to distinguish two characteristics: the first relates to the physical nature of the stimulus encountered and the second relates to the response of the individual encountering the color (Hunt, 1978). In the latter case, color can be described as a perceptual phenomenon present in everyday life, capable of influencing mood and behavior based on the emotions it arouses (Babin et al., 2003; Yildirim et al., 2011). At this point, the study of color preferences is crucial for the vast majority of "social subjects" (Plack & Shick, 1974). For example, the influence of color on purchasing behavior has been extensively studied (Bellizzi & Hite 1992). Most research to date has focused on psychophysical descriptions, thus trying to describe how we perceive a given color by explaining its preference through wavelengths (Camgöz et al., 2002). In addition, the lack of scientific publications on the use of color in marketing is related to the fact that research and results in this field have retained the preservation of individual companies to gain an economic advantage over competitors (Bellizzi & Hite, 1992). More recently, several studies have sought to investigate individual differences in color preferences based on gender (Wilms & Oberfeld, 2018) and context (Palmer & Schloss, 2010). Therefore, it is of paramount importance to know the color variables well, because in marketing, an inappropriate choice of product or packaging color can lead to strategic failure (Czinkota & Ricks, 1983), in which context and target culture play an important role (Elliot & Mayer, 2012). However, to date, there have been mixed results on the contribution of color preference in marketing.

The objective of this paper is to review the available literature and classify items according to color and consumer characteristics used as independent variables, as well as according to the area of application (e.g., branding, packaging, etc.). The goal of this study is to show how consumer color preference is a key factor in marketing strategies, as we believe it is one of the most influential variables to be considered in this field, showing how in discussions such as marketing alone as a survey tool is not enough to identify all kinds of purchase decisions, which is because neuromarketing has often been discussed recently.

2.Theoretical Background on Color Preference

In the past, studies on color preference, or theories derived from them, have been described as confusing and contradictory (McManus et al., 1981). One of the first theories on the argument was proposed by Humphrey (1976) who claimed that color preferences derive from signals that colors transmit to organisms in nature and that their preferences come from signals that we define as "approaching" (for example, the colors of a flower attracting pollinating insects) or "avoiding" (for example, the colors of a poisonous toad that discourages predators) (Humphrey, 1976). Then, color preference is expressed through the mechanism of "natural selection". Hurlbert and Ling (2007) reinterpreted the theory proposed by Humphrey (1976), adding that color preference is based on innate behavioral adaptations (Hurlbert & Ling, 2007). They proposed an "innatistic" theory, suggesting that color preference is related to the human visual system as weightings on cone-opponent neural responses arising from evolutionary selection. According to the authors, the color vision system was adapted to improve performance on an evolutionarily important behavioral task, specifically highlighting gender differences in color preference (Ling et al., 2006). Ou et al. (2004) proposed an account based on the relationship between color and emotions, which they defined as "feelings evoked by both colors or color combinations' (Ou et al., 2004). Color emotions can be causally linked to color preferences if colors are preferred to the extent that the visualization of colored objects produces emotions (positive or negative) in the observer. The proposed theory considers gender differences in color preferences. The so-called ecological valence theory (EVT) is a coherent and complete theory of human color preferences (Palmer & Schloss, 2010). EVT incorporates previously cited theories but with some differences. Consistent with Humphrey 's (1976) and Hurlbert and Ling's (2007) ideas, EVT is based on the premise that human color preferences are fundamentally adaptive. This ecological heuristic is adaptable to the concept of survival, where the color provides a good/bad index of a given object, which makes the survival of the individual easier. While Hurlbert and Ling (2007) refer to an evolutionary timescale (where genetic adaptations are inherited through generations), EVT seeks to incorporate the proposed theories, extending the range of potentially adaptive mechanisms to include individual organisms learning color preferences on an ontogenetic timescale. EVT also connects to emotion-based theory (Ou et al., 2004) by showing how environmental feedback is necessary for learning-based heuristics, and that color preferences are provided by the emotional results of color-relevant experiences throughout a person's life. EVT implies that the average preference for any color on a representative sample of people should be largely determined by their average effective responses to their corresponding colored objects. The more enjoyment and positive the effect that an individual receives from experiences with objects of a given color, the more the person will tend to appreciate that color. Therefore, people should be attracted by colors associated with salient objects that generally elicit positive emotional reactions, and should reject colors associated with salient objects that generally elicit negative reactions. To date, although different theories have been proposed to explain human color preferences, as well as the impact of a specific color on individual preferences and choices, existing controversies in the literature prevent the efficient application of knowledge about color preferences in marketing strategies (Schloss & Palmer, 2011).

The controversies in this field of studies are mainly due to the complexity of two aspects: the color and its properties on one hand (Bortolotti et al., 2022; Cohen, 2004) and the characteristics of the human being (Schloss 2015), such as demographic differences (gender and age) and cultural differences, little considered until a few years ago, on the other hand (Madden et al., 2000). As previous reviews have shown (Labrecque et al., 2010), for a long time, studies in this field have focused only on color hue, excluding other physical characteristics such as lightness. As seen in another review paper (Elliot, 2015), there are different difficulties and limitations in studies on color and psychological functioning, especially for the manipulation of color stimuli. The objective of this review is to demonstrate the importance of color research in marketing and consumer behavior, providing a new perspective by integrating previous theories regarding color preference. As a starting point, the extant literature is reviewed to generate a better understanding of how consumers perceive color and its influence on decision-making. Given many processes and the number of characteristics related to color, it is not difficult to believe that there is a huge variance in the types of experimental protocols and variables considered. To better understand how to use color in marketing it is necessary to consider different variables, both individual and color-related characteristics; these variables must be considered because they significantly influence the preference for a given color. The variables that influence this process are described in detail below.

2.1.*Physiology of Color perception*

The perceptual process involves the subjective processing of a stimulus; in short, color exists only in the mind; that is, it is a highly subjective experience that creates strong individual differences (Helm & Tucker, 1962). This can be described as a perceptive, highly subjective response to light entering the eye directly from self-luminous light sources, or indirectly from light reflected by illuminated objects (Brainard & Maloney, 2011). Without going into too much detail, color vision requires the presence of at least two types of photoreceptors (cones and rods) with different spectral sensitivities; more precisely, cones, which are photoreceptors that distinguish in three categories, S (short) cones that are particularly sensitive to short wavelengths, M (medium) cones that are particularly sensitive to wavelength averages, and L (long) cones, sensitive to long wavelengths. Each color can be described in terms of three main attributes: hue, saturation, and lightness (Wong 2010). Hue is identified as the color family or name of the color (e.g., red, green, purple), which is a measure of a color's purity or the intensity or weakness of the color, and lightness is the tint (darkness) or hue (clarity) of a perceived color (Jagnow, 2010). The perceptual process, in all its complexities, influences affect, cognition, and behavior, but the reverse is also true; that is, affective, cognitive, and behavioral states can influence the perception of color (Elliot & Maier, 2012).

2.2. *Color and culture*

One of the variables that strongly influences the preference for a given color, also modulating the meanings it carries, is culture of reference (Taylor et al., 2013). Culture is the foundation of our lives and lifestyles. The behavior of human beings has a direct impact and reflects their cultural aspects of human beings. Asian, Middle Eastern, European, and American cultures have rich values that make people living in those counties unique to each other. These cultures retain their beliefs and associations with colors to show the value of each culture individually, which makes the preference for color a culture-dependent factor and not a universal factor (Taylor et al., 2013), although there may be some similarities (Yokosawa et al., 2016). In some cultures, religion plays a significant role as a factor influencing culture (Soma and Saito 1997). It can be concluded that, currently, the use of color in marketing is not universal because of the individual variables underlying culture and color preference. To better understand the cultural "macro-category" we should study in detail other individual characteristics, such as age and gender because within the same culture there are individual differences related to color preference and make it a highly subjective process.

2.2 *Color and gender*

In marketing, attention must be paid to gender differences in preferences for certain colors. In this regard, several studies have been carried out that have found empirical evidence, albeit with some differences between them (Silver et al., 1988; Ellis & Ficek, 2001). In this field, one of the first major discoveries was that females showed a greater preference for warm colors (red, pink, yellow, etc.) than males, and males showed a greater preference for cold colors (blue, green, etc.) than females (Helson & Lansford, 1970). More recent works by Hurlbert and Ling (2007) showed that females prefer reddish shades and do not like greenish-yellow tones significantly more than males do. These gender differences in shade preference could be explained by cultural differences (Al-Rasheed 2015). A very relevant study has obtained differences related to the gender of the participants in their experiment, but more importantly, note that they tried to identify differences in color preference in sexual orientation, and did not find significant differences between heterosexual and homosexual/bisexual of both sexes. In other words, homosexual/bisexual males and females essentially showed the same color preference configuration as their heterosexual counterparts. These studies support the idea of Ling and Hurlbert's (2007) claim of a universal sex difference, which means that women universally prefer redder shades than the background. However, today, there is still a long way to define a universal color preference and apply it to marketing without damaging the company.

2.3 *Color and age*

Contextual factors significantly influence older consumers' decision-making (Yoon et al., 2009). In this field, different studies have confirmed a change in color preference during aging (Gaines & Little, 1975). Different results suggest that color preference changes during adulthood (Dittmar, 2001). These changes seem to be a reversal of the trend reported in literature for children. The change in color preference in the elderly could be attributed to alterations in color discrimination and visual images, yellowing of the lens, and decreased function of the blue cone mechanism with aging. Other results. Jain et al. (2010) showed that the color preference of an older person is different from that a of younger person. The determinants of color preference were the attributes of chroma and lightness in the older and younger groups, respectively. In this field of study, marketing strategies should be targeted at a specific age, given the difference in color preferences throughout life.

2.4 *Color and context*

In this case "context" means the entire space, place, and combination with which the color is associated. What is interesting in the field of marketing is how to use the color in the most "universal" way possible to obtain a purchase, as it is well known that when the same color is used in different contexts, the perception of that color can change radically. This aspect has been studied very carefully by psychologists, as in the case of the "theory of color in context" (Elliot, 2015; Elliot & Maier, 2014), which is designed to be a broad model of color and psychological functioning that can be used to explain and predict the relationships between color, cognition, and behavior (Elliot & Maier, 2007). The theory of color in context is based on six main assumptions: (1) color has a meaning, (2) color vision influences psychological functioning, (3) color effects are automatic, (4) color meanings (and related responses) have two sources: learning and biology, (5) the relationship between perception and color influences cognition and behavior that are reciprocally interrelated, and (6) color meanings and effects are context-specific. This is the most accredited and comprehensive theory that can be applied to marketing.

2.5 *Color association*

Color and its association with products act on human bodies, minds, and emotions, influence mood and feelings, trigger deep and subtle responses at the subconscious level of the consumer, trigger both top-down and bottom-up attention processes, influence thinking, stimulate action, and provoke reactions (Park & Smith, 1989). Color can irritate or soothe, increase blood flow pressure or suppress appetite, and suppress appetite. It has been found that satisfying consumers' color expectations are beneficial to brand quality by increasing processing fluidity and facilitating product category identification (Labrecque & Milne, 2012). This creates color-product expectations in the consumer's mind, which I would dare to index as "congruent category" and "incongruous category". The colors in packaging can conform to the intuitive meaning that color has for a given product category. According to the theory of categorization, individuals tend to organize their external environment based on their previous experiences (Knapp & Anderson, 1984; Rehder, 1986). That is, based on knowledge accumulated within a given conceptual domain, people form cognitive categories over time or sets of expectations, which are then used to determine how future experiences will be learned (Sujan & Bettman, 1989).

2.6 *Color in Marketing*

As we now know, color preference is an automatic mechanism (Kareklas et al., 2014), even if it is very complex to explain, especially when all the variables involved are taken into account, or more simply when several colors are used in opposition to each other (Deng et al., 2010). Colors and their use seem to be very controversial and certainly not universal (Elliot, 2015; Taylor et al., 2013). On these points, various authors have tried to devise a theory, starting from Newton and Gothe, who were among the first to propose the "chromatic circle" (Vendler, 1995). Since then, chromatic circles have been used as a tool to understand chromatic relations and create harmonious combinations of colors. The chromatic circle, which has been the basis of various studies (Camgöz et al., 2002), clearly shows the distinction between warm and cold colors, which are complementary and similar. This is useful nowadays in the world of marketing, as will both color preference and the color used in different fields of marketing applications. The lack of scientific results related to color in the context of marketing has given rise to several speculations, including the private use of results that are not disclosed by many companies (Bellizzi & Hite, 1992). There have been some advances in research, although from companies in the color consulting industry, although in recent years there has been an increase in research in this field. Although the nature of the experiments is not entirely scientific, the results seem to be generally shared by marketing professionals, which makes them applicable. Some applications of color in marketing have been reviewed according to the guidelines of the PRISMA model (Page et al., 2020). Different inclusion and exclusion criteria were used for article selection (Figure 1).

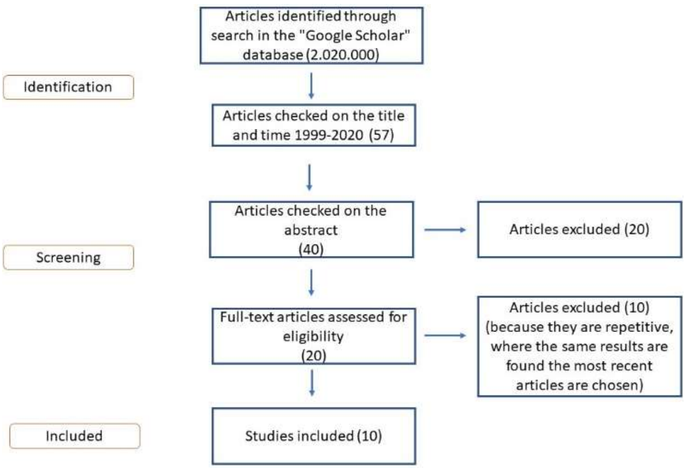

Figure 1. Inclusion and exclusion criteria

The selection of the articles was made by Google Scholar, being the source with the most results obtained, the selected articles have passed three phases; the first phase "Identification," where the articles containing the keywords "Color in Marketing" are selected, a search that is refined by selecting the keywords in the title and narrowing the publication period from 1999 to 2021. The second phase of "Screening," provides for the selection of articles based on the relevance of the work to the proposed review, in two ways, first, by reading the abstract of the reviewed work, articles that do not meet these parameters or that are unclear are excluded, second, all articles that have passed the first phase are read and will be discussed later (Table 1.); older articles that had a common result obtained from more recent work, articles with repetitions, or unclear were excluded.

Summary Review of major "Color in the Marketing", literature Organized by Area.

Citation	*Area*	*Independent Variables*	*Dependent Variables*	*Major Findings*
(Chattopadhyay et al., 2002)	Color and Culture	Hue	Products choice	The results of the work suggest that most aspects of color preference are likely to be culturally universal and applicable across cultural groups and marketing contexts.
(Farzan & Alamtalab Poshtiri, 2016)	Color Packaging	Hue	Products choice	The results show that color is the main factor influencing consumer perception and understanding of the concept and effect of colour in consumer behaviour.
(Hunjet & Glogar, 2016)	Color and Brand	Hue	Brand	The results show how the combination of color and distinct corporations and brands influences their perceived wealth, authority, social influence and recognition.
(Kauppinen-Räisänen, 2013)	Color and Brand; Packaging	Hue	Color choice	The study contributes to the field in terms of summarizing the existing knowledge and highlights aspects for marketers and managers to consider in their attempts to develop brand identity, and the brand-color correlation.
(Labrecque & Milne, 2012)	Color and Brand	Hue, saturation, value	Brand	The results of the work show how color properties influenced brand personality, the colour matching of the package and the brand personality profile increased purchase intention.
(Lee & Rao, 2010)	Color in store	Hue	Store choice	The results show the difference in trust associated with blue and green, and that store choice is highly correlated with the difference in trust.
(Mohebbi, 2014)	Color and Brand; Packaging	Hue	Products choice	The results are additional evidence that graphics and color play a key role in promoting product sales.
(Park et al., 2017)	Color and Brand	Hue	Brand awareness	The results suggest that the use of colors have a positive effect on consumer purchase intentions if consumers are able to develop familiarity and affection for stores.
(Paulsen, 2020)	Color and Brand	Hue	Brand-emotion	Survey results, show how to determine exactly what emotions consumers feel with each color associated with a brand. Although the sample size was large.
(Tamba-berehoiu et al., 2010)	Color Packaging	Hue	Products choice	The results show that companies with higher sales used fewer blue-based colors in the color composition of their packaging, and also smaller amounts of green. The colors that were least affected by turnover value were red-based colors.

Note: this table and related discussion in the text summarizes research in which color is considered the focal variable. This table and discussion are not meant to be exhaustive of all research that may include color as a minor variable of interest.

Table 1. Summary Review of major "Color in the Marketing", literature organized by area.

2.7 *Color used in store*

For "color used in-store" refers to two categories of approaches related to marketing, the first is packaging and the second is the colors used in-store design. The color of packaging attracts consumers' attention, creates aesthetic experiences, and gives symbolic value to a brand (Garber et al., 2000; Kauppinen-Räisänen & Luomala, 2010; Labrecque & Milne, 2012). Product packaging is an essential component for communicating the meaning of the brand to consumers. Especially at the time of purchase, packaging has been identified as the most important vehicle for communication (Underwood & Klein, 2002; Van Rompay et al., 2014). Many researchers in the field (Veryzer & Hutchinson, 1998) argue that color is an essential feature of packaging design and a prominent component of the visual identity of the product (Garber et al., 2000; Labrecque & Milne, 2012). Similarly, the literature indicates that consumer categories' perceptions incorporate specific expectations about the color options that branded packages typically employ within a given category (Bottomley & Doyle, 2006; Labrecque & Milne, 2012). This trend towards categorization creates a norm for the use of color in packaging. For the use of colors in-store design several studies have examined the use of color in a store and identified how it can affect the customer's stay in the store and the purchase of products. Babin et al. (2003) suggested that color and lighting are important factors in purchasing intention. They applied two colors, blue (450 nm) and orange (590 nm), and two light sources (soft and bright). A blue interior was associated with more favorable ratings and greater purchasing intentions, but the use of soft lights with an orange interior canceled out its negative effects, and perceived price equity was higher. Changes in the physical characteristics of a store are related to consumers' mood, perceptions, and buying time. Crowley (1993) stated that color affects both the affectivity and excitement of consumers. There is a U-shaped relationship between excitement and wavelength, where extreme wavelengths evoke greater excitement. Barli and colleagues show how color influences the time spent in a store and influences purchasing behavior; for example, green color influences the time spent in the store and has positive effects on the purchase of the product (Barli et al., 2012). We have just seen how color is widely used and studied these two aspects of "color used in-store," but the use of color in marketing is not limited to this.

2.8 *Color and brand*

According to Hsieh et al. (2004), a successful brand image allows consumers to identify the needs that the brand meets and differentiates the brand from its competitors, and consequently increases the likelihood that consumers will buy the brand". are important in the process of building a brand for the first time. Companies use a brand to create an experience and association, and color allows consumers to identify their corporate identities. Some companies now live off their colors; an important example is Coca-Cola, just thinking of Coca-Cola and we immediately think of red, or the opposite, if we think of red and we have to associate it with a brand in an almost automatic way we associate it with the famous brand mentioned above; this is just an example of how color can leave a positive memory on a brand (Caivano & López, 2007).

2.9 *Color and trend*

One of the most difficult aspects to predict for a company is certainly the fashion trend; it is often associated with colors that become boring or obsolete with the passage of time (Blumer, 2017). Predicting color preference for a specific product is crucial for companies dealing with trends or time-dependent consumer products. In this regard, different models have been proposed that attempt to anticipate a preference for a given color. The first model, "Autoregressive Integrated Moving Average" (ARIMA), is a method based on the integration of self-regression and moving averages (Makridakis & Hibon, 1997). Second, an artificial neural network (ANN) model is a computational model. It imitates the structure and function of biological neural networks (Gurney et al. 1997). Each ANN consists of an interconnected group of artificial neurons that can automatically adapt their structure and parameters to learn data such that the ANN can model sophisticated data relationships by mapping the input data to the output data. the last one The Extreme Learning Machine (ELM) (Huang et al., 2004) is a variation of ANN. In a typical three-layer feed-forward backpropagation ANN, the parameters in the structure are tuned in the learning process. This model (thanks to the creation of an algorithm) is believed to be much faster than ANN. Given the complexity and unpredictability of fashion trends in the preference for a given color, in this field, the data until now appear very confused.

3. Concluding Remarks

The results obtained from various studies in this field are very controversial; some authors believe that human responses to colors are stable (Amsteus et al., 2015). Therefore, they are applicable to everyone, while in reality, several individual differences make the use of color in marketing a very delicate point and not to be underestimated, and the responses and preferences to colors vary depending on culture, gender, and age (Elliot, 2015). The problem with research in the field of color in the context of marketing is that the results obtained from scientific work when applied in a more ecological and "real" context are often not confirmed or even denied. Any company before launching a product, opening a store, and proposing a new brand should implement and conclude research related to the choice of colors and analyze the preferences of its consumers according to age, gender, and culture of interest; this should be done before launching a product because the wrong choice of color can have a negative and disastrous impact on the image of the product and the company. Let us try to summarize all of these points in Figure.2 to make graphically clear and simple reactions between the various aspects of color and the various marketing contexts proposed.

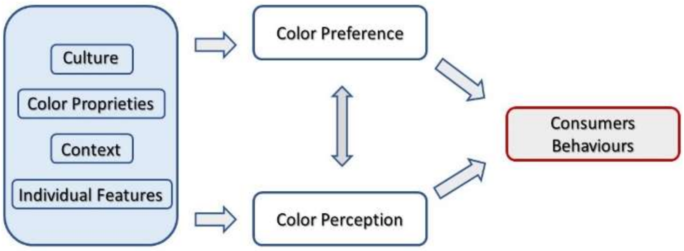

Figure 2. "Hypothetical model"

One could think of "universalization of color preferences" in global/international marketing strategies, in fact in the historical era in which we find ourselves with the reduction of territorial barriers and progress in communications, both through social networks and television programs, should facilitate the homogenization of the use of colors throughout the world; making it easier for companies to select the most effective color. This hypothesis could be a double-edged sword for companies by making color marketing strategies simpler globally on the one hand, but on the other hand, it would make all "competing" companies similar by depersonalizing them. As this is a hypothesis, the extent to which color can become standard for a given geographical point depends on how much companies are striving to adopt such strategies during this period, and to what extent. It is hoped that this general framework will clarify crucial points for future interventions in this field.

4. Neuromarketing and future research direction

Having shown the weaknesses regarding the difficulty of using color as a stimulus (especially in research on color and psychological functioning) we can see how applying them to marketing and the choices made by a potential consumer depends on many variables, and makes the whole thing very complex. The development of new technologies in the production and delivery of color (e.g., increasing of colors, digital color screens, and lower production costs) have altered the role that color plays in our lives, thanks to the variety of subjects and researchers from various fields, such as physicists, psychologists, and economists (just to name a few) are going to meet a more global vision of "color", which for now is still in its infancy but sees before it a great margin of development; this is also thanks to neuroimaging techniques that are very useful for the understanding of human behavior. Another interesting approach could be to use a multisensory approach, as shopping experiences are influenced by different senses in combination (Elder & Krishna, 2021). A "modern change" that must be examined with updated research. Undoubtedly, color research is critical to the advancement of marketing and presents a promising area of growth for marketing practices. From an innovative marketing perspective, the use of color in marketing strategies can be significantly improved and optimized with the help of neuromarketing. Neuromarketing is a relatively new and rapidly growing field of study that combines the disciplines of neuroscience, psychology, and marketing to understand how consumers process and respond to marketing stimuli. It uses various tools and techniques, such as functional magnetic resonance imaging (fMRI), electroencephalography (EEG), eye-tracking, and skin conductance response (SCR), to measure and analyze the neural and physiological responses of consumers to marketing messages. One of the key benefits of neuromarketing is that it provides insight into consumer behavior that goes beyond self-reported data and conscious responses, allowing marketers to gain a deeper understanding of the unconscious drivers of consumer behavior, such as emotions and motivations. This can help brands better understand the impact of color on consumer perception and decision-making, and make more informed decisions on color selection and placement in marketing campaigns. For example, neuromarketing research has shown that different colors can evoke different emotions and stimulate different parts of the brain, which can influence consumer perception and behavior. Red, for example, has been shown to stimulate the brain's attention center and evoke feelings of excitement and energy, while blue is often associated with calmness and stability. By understanding the emotional impact of different colors, brands can select the most appropriate colors for their marketing campaigns to create the desired emotional response in consumers.

In conclusion, neuromarketing offers a valuable tool for marketers looking to understand and optimize the impact of color in marketing. By utilizing the latest advancements in psychology and neuroscience, neuromarketing can provide a more comprehensive and in-depth understanding of consumer behavior, allowing brands to make informed decisions on color selection and placement, resulting in more effective and impactful marketing campaigns.

5. Conflict of interest declaration

Nothing to declare

6. Funding source declaration

Nothing to declare

7. Short biography of the authors

Alessandro Bortolotti - Psychologist and PhD student in Business and Behavioral Sciences at the University of Chieti-Pescara, where he studies neuromarketing and emotion using behavioral and neurophysiological methods.

Loreta Cannito - Psychologist and Psychotherapist in training, she obtained her doctorate in Business and Behavioral Sciences at the University of Chieti-Pescara, where she deals with decision making and neuroeconomics.

Stefano Anzani - Psychologist, he obtained his doctorate in Business and Behavioral Sciences at the University of Chieti-Pescara.

Riccardo Palumbo - Is Professor of Business and Behavioural Economics and Neuromarketing at the Department of Neuroscience Imaging and Clinical Sciences of the University of Chieti-Pescara. Coordinator of the section of Behavioural Economics and Neuroeconomics and the PhD in Business and Behavioural Sciences. Co-founder and CEO of Umana Analytics

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BOOK REVIEW: I colori sono di tutti? 22 domande curiose sul colore

Marcello Picollo

Lia Luzzatto e Renata Pompas: I colori sono di tutti? 22 domande curiose sul colore, Edizioni Mediterranee, 2022. [Italian Language]

Since the early years of the last century, color, and the world surrounding it, has attracted increasing interest of professionals from various fields. Scholars have explored its function and meaning, academics and color associations have organized conferences and workshops that have deepened and popularized this complex and fascinating world. The continued interest in exploring color and understanding its significance is clearly demonstrated by the number of new publications that have appeared nationally and internationally in recent years. These include the work "I colori sono di tutti? 22 domande curiose sul colore" by Lia Luzzatto and Renata Pompas (Edizioni Mediterranee, 2022, pp. 259), which is aimed at an audience of non-specialists with an innate desire to satisfy their curiosity and delve into a path of thinking outside the box. The book is, in fact, designed and structured in a simple and straightforward way, providing answers to basic questions, some not immediately obvious, concerning color and its meaning. The book, as the subtitle suggests, is divided into 22 chapters. It opens with a very brief but intriguing 'introduction' that unlocks the door to this colorful journey for the reader. Each of the subsequent chapters addresses a well-defined topic starting with a specific question related to color and its analysis. Among the many, and among the ones that most intrigued and fulfilled me personally, I would like to mention those related to such questions as 'Does everyone own color?', 'Is color tasty?' and 'Does marketing love color?' In these chapters, the authors guide the reader, albeit in just a few pages, through a succession of information, news, curiosities and considerations of their own that make for lively and extremely enjoyable reading.

The authors have an established and extensive experience in the world of color, both as writers of books and as journalists, having collaborated with prestigious magazines and weeklies, as well as teaching academic courses and seminars. In short, the newly published volume clearly reflects the authors' mastery of a range of themes and their overall expertise in the field of color. The volume sheds light on what color is and how it may operate in society.