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Title: Feelings as a tool to reveal the connection between experiences of light color and instruments' sound

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Abstract:

This master's thesis investigates the emotional impact of light colors on the perception of instrumental music, examining how varying sounds from different instruments create a connection to specific light colors. Inspired by the author's light installation 'Hypnotic Chandelier' made for Copenhagen's 'Distortion' festival and further explored during an internship at BOA Light Studio in Paris and Iannis Xenakis "Polytopes", this research examines how sensory stimuli influence human emotions and perceptions.

Using a triangular framework to visualize relationships between light color, sound, and feelings, the study hypothesizes that warm colors evoke energetic responses, while cool colors induce calmer states. The analysis includes a literature review of Kandinsky's use of colors to evoke musical feelings, Vivaldi's "Four Seasons" as a translation of colors into music, and Van Gogh's expression of emotional states through color in his artworks are examined. The concept of synesthesia, where one sensory input involuntarily triggers another, provides a framework for understanding these associations. and three interconnected experiments: Assessing feelings perceived by light colors (red, yellow, blue); Evaluating feelings perceived by light colors in combination with instrumental sounds (violin, piano, trombone); Determining the color perceived by instrumental sounds.

These experiments aim to understand how light affects the experience of sound and vice versa. The findings will offer insights into the complex interplay between light and music, enhancing the design of future multisensory environments.

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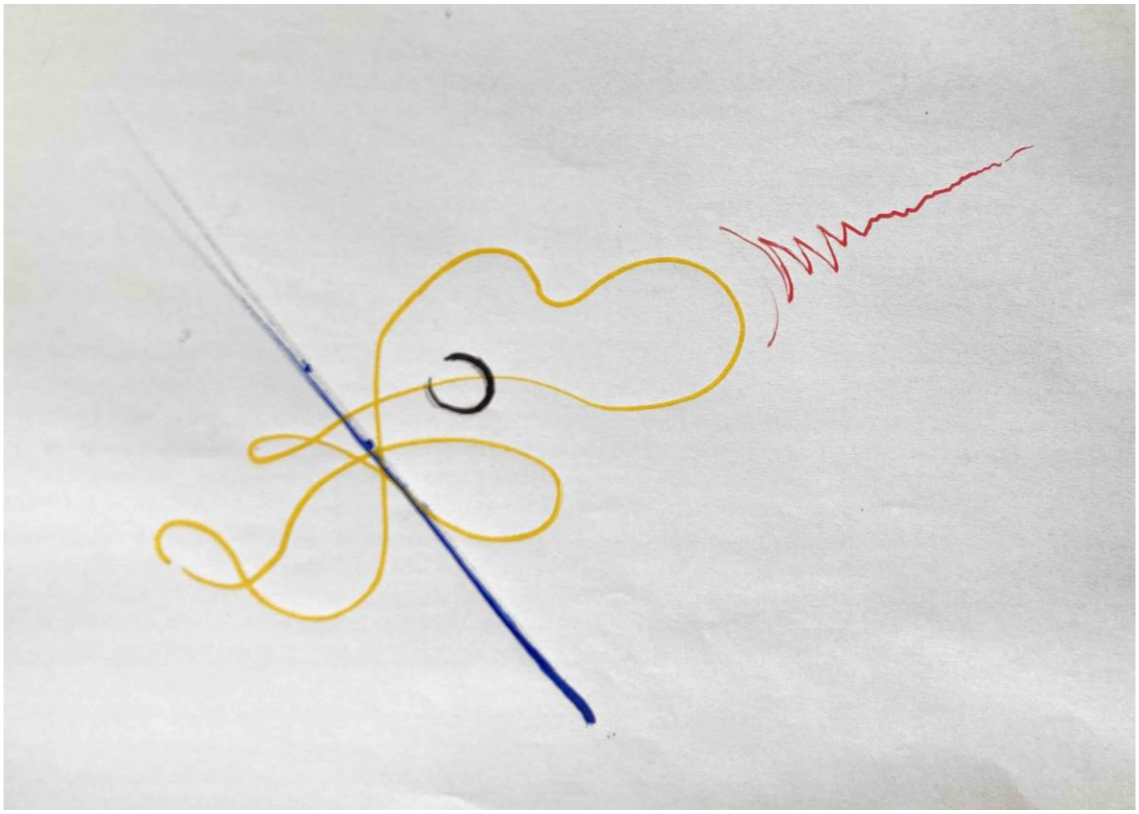
FEELINGS AS A TOOL TO REVEAL THE CONNECTION BETWEEN EXPERIENCES OF LIGHT COLOR AND INSTRUMENTS' SOUND



The drawing is created by a participant in Experiment three. It illustrates the colors and imagery the participant visualized while listening to violin music.

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Contents:

1. BACKGROUND CHAPTER

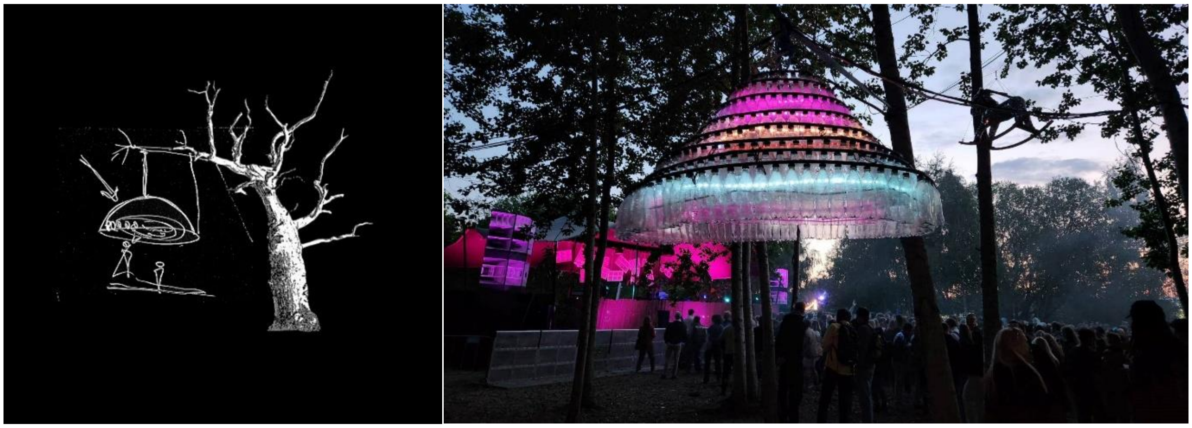


Figure 1, Distortion festival, photos, and images by the author

In June 2023, at Copenhagen's 'Distortion' music festival, my colleague Rezvan Shahrabifarahani and I introduced 'The Hypnotic Chandelier' (Figure 1). Crafted from 600 recycled bottles, adorned with LED lights, the installation hypnotizes visitors with synchronized movements to music. Our fascination with the fusion of light and sound sparked from this immersive experience, where attendees were drawn to dance beneath its pulsating glow. Despite the absence of direct programming, the installation appeared to harmonize with the music, illustrating the connection between sound and light. This became a crucial moment that triggered my curiosity, prompting a deeper exploration into the relationship between auditory and visual stimuli.

On my LID9 semester report I worked on this topic during my internship in BOA Light studio in Paris. BOA works, among others, with projects that combine light and sound.

Our design in the "Hypnotic Chandelier" experiment aroused my curiosity about the relationship between light and sound. This curiosity persisted as I interned at the BOA Light studio in Paris. In BOA I got intrigued by the "Pulsation" project, which was a collaboration with Nuit Noires collective, which I analyze more as a case study later in the report. I realized the importance of integrating both elements of light and sound in early design stages. This approach highlighted the value of simultaneous sound and light co-design, enhancing visitor experiences by harmonizing sensory perceptions.

2. INTRODUCTION

Light and sound both are forms of energy traveling as waves. When sound encounters objects, it bounces back to our ears, akin to light bouncing back to our eyes upon hitting a surface. Consequently, both are sensory experiences, impacting human perception.

According to Caivano the juxtaposition between sound and color perception reveals a foundational link, where pitch and hue are shaped by the undulatory nature of their respective wavelengths. This synergy between auditory and visual stimuli unfolds a harmonious interplay, inviting exploration at the crossroads of physics, neuroscience, and psychology. "The classical comparison relies on the fact that the stimuli for the sensations of pitch in sound, and hue in color, are mainly determined by the wavelength of the auditory energy and the visible energy, both taken as undulatory phenomena". (Caivano, 1994). According to BOA and Nuits Noires, the integration between light and sound evokes a more majestic experience, since feelings take part in the process.

More specifically, according to an interview conducted by the author during LID9 with Jeremie Nicolas, CEO of Nuits Noires: "*In music, the connection between sound and light often comes into play in visualizations or synesthetic experiences. Synesthesia is a condition where one sensory input can trigger an experience in another sense. Some people experience a form of synesthesia where they perceive colors or shapes in response to certain sounds or music. There are also visualizers that respond to music by creating patterns, colors, and movements that synchronize with the sound's rhythm and frequency. These visual representations of sound can be affected by the intensity, pitch, and tempo of the music.*

Additionally, in performances, concerts, or shows, lighting effects are used to enhance the auditory experience. Light shows, lasers, and visual effects are often synchronized with the music to create a more immersive and engaging atmosphere for the audience. Changes in light intensity, color, and movement can complement or contrast the mood and tempo of the music, impacting the overall emotional impact of the performance." (Nicolas, 2023)

Every moment of seeing, hearing, and feeling an object or environment generates emotions, which appear intuitively and immediately upon receiving sensory stimulation. Sensibility is thus closely related to the five senses, of which the visual and auditory are most important. Among sighted, hearing people, information from the outside is accepted in the proportions of 60% visual; 20% auditory; and 20% touch, taste, and smell together. (Cho, 2002) Emotional ratings of the colours and the musical excerpts showed a correlation between the emotional state and the musical excerpts, and emotional state to the colours, suggesting that music to colour associations might be mediated by emotion in the general population (Curwen, 2018).

To sum up, this master's thesis seeking the connection between light colors – sound and feeling -trying to prove different hues can evoke distinct emotions, which in turn can shape an individual's experience and preference towards the music.

3. VISION

Imagine if we can find a connection between experiences of light and sound through feelings.

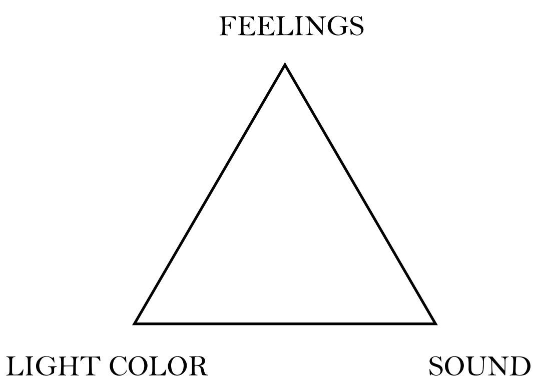


Figure 2, Triangle vision shape, image by the author

Visualizing the interplay between light color, sound, and feelings as a triangle offers a clear framework. In this triangular framework, each edge represents one of the three variables—feelings, light color, and sound—while the connections between them illustrate the relationships being explored (Figure 2).

At one corner of the triangle, we have feelings, representing the emotional responses and subjective experiences of individuals. This corner connects to both light color and sound, indicating that both visual and auditory stimuli influence emotions.

The second corner represents light color, illustrating how different colors of light impact emotional responses. This corner connects to feelings, as light color affects emotions directly, and to sound, suggesting an interaction between visual and auditory stimuli in shaping emotional experiences.

The third corner represents sound, indicating how instrumental music influences emotional responses and preferences. Like light color, sound connects to both feelings and light color, highlighting the intricate relationship between auditory and visual stimuli in evoking emotions.

Overall, this triangular visualization helps illustrate the complex interplay between light color, sound, and emotions, emphasizing how each variable influences and is influenced by the others in shaping individuals' subjective experiences and preferences.

According to Böhme, acoustics and music, key elements in the design of built environment, shaping the acoustic atmosphere, that can be described and characterized by expressions for sensitivities, such as “cheerful”, “grave”, “strident”, and “soft”, etc (Böhme, 2016). According to Merleau-Ponty, color is considered a way to present an object. According to Merleau-Ponty, color was not originally used to show the properties of known objects, but to express different feelings suddenly emerging from objects (Merleau-Ponty, 2004).

4. AIM AND RESEARCH QUESTION

This thesis examines the impact of varying light colors on emotional responses to instrumental music and its influence on individual preferences. By probing this correlation, the study aims to reveal how sensory stimuli (light color) interact with auditory experiences (instrumental music), shaping human emotions and perceptions. Through this exploration, valuable insights into the intricate interplay between light color and music on emotional and perceptual levels can be gleaned, offering a deeper understanding of their combined effect on individuals' preferences and experiences.

This thesis tests the following research question:

"What is the emotional impact of varying light colors on the perception and interpretation of instrumental music, and how does this influence individuals' subjective experiences and preferences?"

This question investigates the emotional effects of different light colors when paired with instrumental music and how these pairing influences people's reactions. Essentially, it seeks to understand how the visual stimulus of light interacts with the auditory stimulus of music to shape our emotional responses and interpretations. By exploring this relationship, the study aims to uncover gap knowledge into how sensory cues combine to influence human emotions and perceptions, exploring how experiences could be ideally shaped in multisensory environments.

5. METHODOLOGY

The methodology of the master's thesis introduces the following components: Synesthesia, Literature review and case studies, design method of the experiments and the testing. Below there is a more detailed description of these methodological elements.

Chromesthesia and Auditory Synesthesia

The analysis chapter introduces chromesthesia, a subtype of synesthesia, involves automatic and involuntary associations between sounds and colors, while auditory synesthesia refers to synesthetic responses triggered by auditory stimuli. The literature review covers various studies and case reports on synesthesia, highlighting the dominant colors and instruments. High-pitched sounds are frequently associated with bright colors such as yellow, whereas low-pitched sounds are often linked to darker hues like blue or purple. The review also examines the influence of timbre and pitch on color perception. Instruments like the violin, piano, and trombone are commonly mentioned due to their distinct tonal qualities, and the review analyzes how these instruments elicit specific color responses in synesthetes.

Literature Review

Kandinsky's theories on the relationship between color and sound, and his belief in their synesthetic connections, are examined. His artworks, where he often used musical terms to describe visual compositions, are analyzed to understand his synesthetic perspective.

The review includes an exploration of Vivaldi's compositions and the historical context of synesthetic experiences in his music. It evaluates how synesthetes perceive Vivaldi's music in terms of color and emotion, providing insights into the interplay between auditory and visual stimuli.

Van Gogh's letters and artworks are studied for evidence of synesthetic experiences. The review assesses the impact of his mental health on his perception of colors and sounds, providing a nuanced understanding of his sensory experiences.

Case Studies

The BOA Light Studio's "Pulsation" project is described and analyzed, focusing on its use of light and sound to create a synesthetic experience. User experiences and feedback from the project are evaluated to understand its impact. Additionally, Iannis Xenakis' Polytopes, known for their immersive synesthetic environments, are examined. The review assesses the influence of Xenakis' architectural and musical backgrounds on his synesthetic creations, highlighting the interdisciplinary nature of his work.

Design Method

The design method outlines the process of creating the experimental setup. A section categorizing the different emotions that participants may experience in response to the experimental stimuli is included in the study. It includes the selection of colors (red, yellow, and blue) and instruments (violin, piano, and trombone), and explains the rationale behind these choices. The method ensures a systematic approach to exploring the relationship between auditory and visual stimuli.

Nielsen et al., in their study titled "Beyond Vision: Moving and Feeling in Colour Illuminated Space," conducted an experiment to investigate the impact of four selected light spectra, each illuminating a space in different colors, on observed body movements and reported sensory experiences. The primary objective was to explore how these specific light spectra influence participants' movements and sensory perceptions. Additionally, the study aimed to determine whether these effects were observable solely when the light was visually perceived by the eye. They utilize an experimental methodology, which involves exposing participants to various auditory and visual stimuli, serves as an inspiration for this research. Her approach is adapted to explore the interplay between color and sound in eliciting emotional responses. (Nielsen et al., 2021)

Nielsen et al. play a vital role in the way the experiments are conducted in this master's thesis, as the author creates a similar laboratory environment with different light scenarios.

Testing Method

The testing method involves lab experiments designed to gather both quantitative and qualitative data. The first experiment utilizes quantitative measures based on the literature review and emerges to answer what feelings are created by specific light colors. In the second and third experiments the author incorporates qualitative assessments from earlier experiments. Basically, the author reviews the emotional impact of the above light colors in combination with specific instruments' sounds – collected from the literature review and finally validates the above findings with the last experiment by answering on what hues are seen in the same instruments' sounds. The third experiment, in particular, builds on the first two experiments and also uses visual ethnography to provide a comprehensive understanding of the synesthetic experiences. This mixed-methods approach ensures a thorough exploration of the research question.

To sum up, this methodology integrates a detailed literature review, a structured design process, and a strong testing method to investigate the complex correlation between color and sound in synesthetic experiences. The approach is informed by existing research and made to address the specific objectives of this study.

By following this structured methodology, the thesis aims to provide a response to how do different light colors affect the emotional response and understanding of instrumental music, and how does this impact individuals' subjective experiences and preferences.

6. ANALYSIS

This section of the master's report examines the concepts of synesthesia, focusing on chromesthesia and auditory synesthesia. In the literature review the author isolates three cases of established artists Kandinsky, Vivaldi and Van Gogh who criticize the emotional impact of colors, especially red, yellow and blue and add how instruments' sound affect the whole experience. Moreover, research is done for two case studies of light and sound installations by BOA Light studio in collaboration with sound designers Nuits Noires and the analysis of installation "Polytope" Iannis Xenakis. The aim is to conduct a literature review to identify the most prevalent colors and instruments associated with these phenomena in current research.

As described by Böhme, illumination evokes sensations such as "cold," "warm," "gloomy," and "welcoming," shaping the atmosphere and ambiance of architectural environments. By manipulating light and its effects, architects can create immersive spaces that resonate with occupants on both a visual and emotional level, enhancing their overall experience within the built environment. (Böhme, 2016) The concept of illumination in architectural design extends beyond mere visibility, encompassing visual experience and bodily movement to alter the overall color impression of a space. This modification contributes to the space's visible emotional quality, influencing how individuals feel within it.

6.1. Synesthesia: The Intersection of Color, Sound, and Emotion

Historical Context

Auditory synesthesia, the tendency to associate sounds with colors, can be traced back to ancient Greek antiquity. During this era, philosophers explored the notion of the color of music, particularly focusing on "timbre," which they conceptualized as a quantifiable physical quality. Notably, Pythagoras contemplated the potential existence of a unified sensory experience. In 1735, French priest Louis

Bertrand Castel crafted the first instrument of colors, a harpsichord with colored tapes affixed to each key, projecting colors onto a screen when the keys were played (Caivano, 1994).

A significant milestone in the intersection of music and visual elements occurred in 1911 with Alexander Scriabin's composition "Prometheus," which integrated both auditory components and light, thus giving rise to a synesthetic phenomenon. The comprehensive elucidation of synesthetic experiences emerged in the 1920s, based on the recollections of individuals for whom every external stimulus evoked vivid and distinct images (Nielsen, Friberg, & Hansen, 2018).

Synesthesia: Definition and Mechanisms

Synesthesia is derived from the Greek words syn and aisthes, and represents a perceptual phenomenon. Audio-visual synesthesia refers to the imagination, association, reproduction, and creation of various visual situations and musical emotions in the mind (Wang et al., 2023). Mossbridge et al. discovered the influence of music changes on the visual-spatial attention of the subjects (Mossbridge et al., 2011). Santini confirmed the impact of audio-visual synesthesia on improving the usability of software by exploring the relationship between color and sound (Santini, 2019). Zhu conducted research on the application of audiovisual synesthesia in the design of interactive devices and proved that it can promote interactive cognition (Zhu, 2004).

Based on “Touching tastes, seeing smells–and shaking up brain science”, by Cytowic, synesthesia can be acquired via epilepsy or the ingestion of hallucinogens such as mescaline or LSD, but idiopathic (or developmental) synesthesia arises naturally without an external agent or brain abnormality. There is nothing in need of medical treatment. The subjective, ineffable, and idiosyncratic nature of this kind of synesthesia does make it an easy target for dismissal. Even the term “synesthesia” has been used imprecisely over time, referring to everything from metaphor (loud tie, sharp cheese, sweet voice) to deliberate contrivances such as son et lumière theatrical performances and “smell a vision.” (Cytowic, 2002). This form of synesthesia is defined by five clinical findings: it is involuntary and automatic, spatially extended, consistent and generic, memorable, and affect-laden (Krpan & O'Connor, 2017).

Color and Senses

Küller and colleagues carried out several studies on the influence of colours on brain activity, mood and performance (Küller, Ballal, Laike & Mikellides, 2006; Küller, Mikellides & Janssens, 2009). For example, these studies found that the light level in work environments impacted workers' level of mood, that strong colours could cause increased arousal of the central nervous system and that especially red colours put the brain into a more excited state, sometimes to such an extent as to cause a paradoxical slowing of the heartrate. (Nielsen et al., 2021) Anter and Klarén wrote at SYN-TES that "in a human context it is necessary to regard colour and light as related and functional parts of a comprehensive, coordinated and dynamic processes that influence our experience of the world as a whole. This includes both physical and mental aspects." (Anter, Klarén, 2010) According to them, colour and light are not used effectively to create positive experiences, but rather tend to give poorly integrated spaces creating disrupting experiences.

Color and Sound

The exploration of the color of light and its effects remains an evolving field. Goethe noted that specific colors excite particular states of feeling (Goethe, 1970), and Küller et al. found that colors and light levels influence brain activity, mood, and performance (Küller et al., 2006). Strong colors can increase arousal in the central nervous system, with red colors sometimes causing a paradoxical slowing of the heart rate.

According to Kandinsky, colors resonate with each other, creating visual 'chords' that influence the soul (Kandinsky, 1912). Caivano found that about 80% of people associate pure sounds with saturated colors and noise with gray or achromatic colors, suggesting a physical correlation between sound purity and color saturation (Caivano, 1994).

Synesthesia and Modern Research

Recent research explores the "non-visual" effects of light, initiated by the discovery of ipRGCs in the retina, which contribute to mood regulation, alertness, and circadian clock entrainment (Berson, Dunn, & Takao, 2002; Hattar et al., 2003). These effects extend beyond vision, affecting physiological processes such as melatonin suppression and cognitive performance (Brown, 2020; Lockely et al., 2006).

In the PhD by Nielsen "Beyond Vision. Moving and Feeling in Colour Illuminated Space", 26 participants were exposed to different light spectra—white, blue, amber, and red—in a controlled environment. The results indicated that different colors of light influenced body movements and sensory experiences. White light induced feelings of stress and sharp movements; blue light created sensations of chill and emotional responses; amber light led to welcoming, supportive, and dancing movements; and red light evoked grounding, elastic, and organic movements. (Nielsen et al., 2021)

To conclude, synesthesia reveals the intricate interplay between auditory and visual stimuli, highlighting the harmonious relationship between sound and color. This phenomenon underscores the significance of sensory experiences in shaping human perception and emotion, inviting further exploration at the crossroads of physics, neuroscience, and psychology.

6.2. Literature review

Color serves as a means of presenting objects, according to Merleau-Ponty, who suggests that its primary function is to convey the emergent feelings associated with those objects rather than merely representing their properties (Merleau-Ponty, 2004). Cho's research explores whether sight is necessary for perceiving color, aligning with the theory that viewers attribute meaning to colors based on their individual experiences. Color perception is subjective and varies based on personal preferences and past encounters, indicating that emotional responses to color are deeply rooted in individual histories (Cho, 2021). Artists like Van Gogh, Kandinsky, and Vivaldi integrate color and sound in their works, reflecting the interconnectedness of sensory experiences in art (Cho, 2021).

6.2.1. Vasily Kandinsky

In Kandinsky's paintings, the concept of music permeates throughout. He posited that colors resonate with each other akin to producing visual 'chords,' exerting an influence on the soul (Kandinsky, 1912).


Figure 3, Lyrical (Lyrisches) from Klänge (Sounds) by Vasily Kandinsky (1913). Source MoMA

Vasily Kandinsky's "Klänge" (Sounds), often referred to as his "musical album," aimed for an artistic synthesis, blending text with image, sound with meaning, and mark with blank space. (Figure 3) In this innovative work, Kandinsky explored the interaction between different art forms, seeking to create meaning through their dynamic interplay and the spaces they inhabit. Through "Klänge," he pushed the boundaries of traditional artistic expression, envisioning a harmonious fusion where various elements converged to evoke deeper emotional and aesthetic experiences. (MoMA, 2024) The painting was selected for its title, “Sounds”. This name captures the essence of the artwork, suggesting a visual representation of auditory sensations.

Colours through sounds

As a synesthete, Kandinsky perceived colors corresponding to the sounds of different instruments, integrating these synesthetic experiences into his paintings. He believed in the inherent musicality of his art, asserting that painting possessed the ability to evoke energy akin to music. Kandinsky likened the process of painting to composing music, emphasizing the rhythmic interplay between form and color. Just as musicians convey emotions through rhythm, timbre, and melody, Kandinsky contended that artists could express inner experiences using color and form arrangements. He associated specific emotions with colors and forms, drawing parallels between visual and musical elements, and sought to articulate these subjective experiences through coherent and universal principles. Kandinsky famously assigned meanings to colors, such as **yellow representing stimulus, red symbolizing energy, blue evoking infinite sensibility, and green embodying calmness.** (Kandinsky, 2012).

6.2.2. Vivaldi's Four Seasons

Figure 4, Antonio Vivaldi Four Seasons cover, Source: eclassical.com

According to Cho, In Vivaldi's Four Seasons, the use of color symbolism extends to the instrumentation. **Red, representing warmth, is embodied by the passionate tones of string instruments, particularly the violin and cello**. **Yellow bursts, signifying energy and brightness, are evoked by a group of brass instruments, such as the trumpet and trombone**. Orange, combining warmth and vigor, finds expression in the acoustic guitar lively yet inviting tones. Green, representing stability and comfort, is mirrored in the soft and reassuring sounds of woodwind instruments like the clarinet and bassoon. **Blue, symbolizing coldness is embodied by the dense and refreshing tones of the piano.** Lastly, purple, blending warm red and cold blue, resonates through the majestic brass tones of the pipe organ. (Cho, 2021).

6.2.3. Van Gogh

Cho describes "Van Gogh also started playing the piano in 1885, but he had a hard time holding the instrument. He declared that the playing experience was overwhelming, as each note evokes a different color". (Cho, 2023)

Van Gogh's experience with playing the piano and associating musical notes with colors is well-documented in various biographies and letters written by the artist himself. One notable reference can be found in a letter he wrote to his brother Theo in September 1885:

"I want to tell you that I am beginning to learn to play the piano. Music makes me melancholy; it brings out the devil in me. Every time I play the piano, I understand more and more that each note evokes a different color, and it's overwhelming. It's as if I'm painting with sound, but in a way that I can't control." (Pickstone,1990)

This excerpt reflects Van Gogh's deep emotional and synesthetic connection to music, where he perceives auditory stimuli as visual experiences. His struggle to physically hold and play the piano contrasts with the intensity of his emotional response to the music, suggesting a profound inner world where sensory perceptions intertwine. Van Gogh's synesthesia, a condition where stimulation of one sensory pathway leads to involuntary experiences in another, likely influenced his unique artistic style and color choices in his paintings.

Van Gogh **described the experience of playing the piano as overwhelming** due to the synesthetic perception he had, where each note evoked a different color. However, he didn't explicitly mention the specific feelings associated with playing the piano. Given his deep connection to color and emotion in his artwork, it's possible that the colors he perceived while playing influenced his emotional state. For example, certain colors may have evoked **feelings of joy, sadness, or excitement**, contributing to his overall emotional experience while playing the piano. Unfortunately, he didn't provide detailed descriptions of these emotional responses in his writings. (Gogh, 1885)

6.2.3. Other references

Nielsen et al., "Beyond Vision: Moving and Feeling in Colour Illuminated Space,"

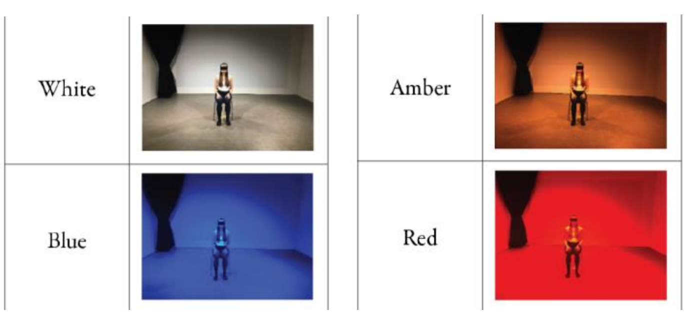


Figure 5, Four experimental light scenarios (Nielsen et al., 2021)

In the controlled environment of their light lab, 26 participants were engaged in the experiment. The participants were exposed to four distinct light spectra, representing white, blue, amber, and red illumination. The study incorporated both blindfolded and non-blindfolded conditions to assess whether the observed effects were dependent on visual perception. During these conditions, participants were prompted to move around within the illuminated space. (Figure 5)

The results showed that white light scenario, occurred feelings of stress, awaking, sharp and squared movements. **The blue light scenario created chill, dizzy, unbalanced, coldness, emotional. The amber light scenario caused welcoming, supporting, natural, dancing bodily movements, while the red, grounding, elastic, animalistic, organic sense of moving.** (Nielsen et al., 2021)

Bresin, R., "What is the color of that music performance?"

The representation of expressivity in music remains an underexplored area. One potential solution is a graphical, non-verbal representation of musical expressivity using color to index emotions. This method could be beneficial for providing feedback on emotional expression in music, such as in real-time tools for music education or in the display of large music databases. To determine which colors are most suitable for representing emotional expressions, an experiment was conducted. Subjects rated how well each of 8 colors and their 3 nuances corresponded to 12 music performances expressing different emotions. **These performances were played by professional musicians using three instruments: saxophone, guitar, and piano**. Results showed that subjects associated different hues with different emotions. **Dark colors were associated with music in minor tonality, while light colors were linked to music in major tonality. The correspondence between spectrum energy and color hue is preliminarily discussed.** (Bresin, 2005)

The experiment confirmed that different colors are associated with different emotional expressions in music. This finding suggests that color could be a useful tool for representing expressivity in music performance, potentially benefiting music education, and enhancing the display of music databases. (more information in Appendices a)

The gap in the above research is the hues of colors that are used to distinguish the instruments' sound, for saxophone, guitar and piano.

6.3. CASE STUDIES; LIGHT AND SOUND ART

In this chapter I introduce two case studies which integrate light and sound experiences. The first one is the project "Pulsation" by my internship studio, in Paris and the second describes the great Iannis Xenakis' light and sound "Polytopes". They show how different light colors emotionally impact the perception and interpretation of instrumental music, and how these effects influence individual preferences.

6.3.1. "Pulsation", BOA Light Sudio and Nuits Noires Sound designers, Paris 2022

Figure 6, Simulation of the atmosphere of the lighting design (BOA, 2022)

Video: (boa.fr)

The project "Pulsation", crafted by BOA Light Studio and Nuits Noires, is a sensory experience intertwining light and sound (Figure 6). Initiated amidst the COVID-19 outbreak, its innovative lighting design for the newspaper's "Le Monde" facade remained underappreciated until it was transformed for La Nuit Blanche. The concept of pulsation, symbolizing heightened physical performance and adrenaline, guided the design. Red hues, stroboscopic lights, and intense sounds were utilized to evoke a synchronized rush akin to athletes' exertion. Collaborating with Nuits Noires, a diverse array of metallic and techno sounds, coupled with immersive lighting, enveloped participants. Although sound and light were not directly synchronized, their harmonious interplay created a captivating atmosphere. Participants, lying on the floor, immersed themselves in the experience, becoming active participants. This innovative approach, diverging from traditional synchronicity, enhanced audience engagement and left a lasting impression. Through "Pulsation," the lighting design studio of BOA and the sound designers of Nuits Noires showcased the transformative potential of merging sound and light, amplifying the human experience in immersive environments.

Fabienne Maman, the artistic director of BOA, emphasizes that light operates on a distinct scale from architecture, encompassing time, space, and rhythm. BOA's lighting designs aim to infuse spaces with a human element, eliciting sensations and emotions. Whether evoking the intense mood of a cloudy sky or the organic movement of tree leaves swaying in the wind, their designs transcend mechanical precision to evoke tangible human experiences. Through light, BOA creates atmospheres where visitors can deeply connect with their surroundings, fostering an immersive and emotive interaction with the environment. (Maman, 2023)

Moreover, Jeremie Nicolas, CEO sound designer of Nuits Noires, was interviewed for further exploration of the question how light and sound work together:

"In art, particularly in visual arts, the relationship between sound and light can be explored in various ways. Some artists experiment with incorporating sound elements into their visual artworks or installations. For example, an artwork might include elements that produce sound when activated or interacted with by viewers.

Light itself is a fundamental element in visual art. Artists use light to create depth, highlight specific areas, evoke emotions, and manipulate the perception of color. The way light falls on a subject can dramatically alter its appearance, texture, and mood within a piece of art. Think of how a sunset's warm, golden light can evoke different feelings compared to the cool, harsh light of midday.

Moreover, certain art forms, like kinetic art or light art installations, directly utilize light as a medium to create visual experiences. These artworks often involve movement, changes in color, or interactions with the audience, creating immersive environments that engage both sight and sometimes sound.

Overall, the interplay between sound and light in both music and art provides avenues for creative exploration, offering opportunities to enhance, complement, or even intertwine sensory experiences in unique and captivating ways.

Anyway, sound and light is like salt and pepper, black and white, Minth and chocolate, it's not inseparable, one can work without the other, but together, they can create more unique and immersive experience."

(Nicolas, 2023)

Drawing on Böhme's concept of 'The Aesthetics of Atmospheres,' architecture plays a pivotal role in defining spatial experiences. It regulates spatial dynamics by opening and closing spaces, establishing focal points, and guiding movement. Ultimately, the design aims to create environments where people feel comfortable and engaged, enabling seamless navigation, and fostering a sense of connection with the surroundings. Böhme's perspective underscores the importance of considering human experience and movement patterns in architectural design, highlighting the impact of spatial arrangements on individuals' perceptions and interactions within built environments (Böhme, 2016).

In summary, the project "Pulsation" by BOA Light Studio and Nuits Noires explored the dynamic interplay between light and sound to evoke emotional responses and sensory experiences. **By incorporating red hues, and metallic sounds, the designers aimed to stimulate sensations of**

adrenaline and intensity reminiscent of physical exertion and urban environments. The unconventional venue and immersive elements positioned participants as active participants, heightening their engagement and leaving a lasting impression. Through the synergy of light and sound, the project created a captivating atmosphere that transcended traditional boundaries, inviting participants to explore the depths of their emotions and preferences.

In relation to the research question on the emotional impact of varying light colors on the perception of instrument's sound, the focus on **red as a color** associated with **adrenaline** and **metallic sounds, as "software instrument"** demonstrates how sensory stimuli can elicit specific emotional responses. By leveraging these elements, "Pulsation" aimed to influence individuals' subjective experiences and preferences, showcasing the power of multisensory experiences to evoke feelings and shape perceptions. Through this innovative approach, the project provided valuable insights into the intricate relationship between light, sound, and emotions, paving the way for further exploration in the field of sensory design.

6.3.2. Polytopes, Iannis Xenakis

Figure 7, Polytope de Cluny (Xenakis, 1972).

Polytopes : 'Poly' = a lot, 'topos' = space, Greek

Video : Polytope de Cluny Documentary Iannis Xenakis

Polytopes is the collective name of a series of multimedia installations, including sound, light and architecture, conceived by Iannis Xenakis during 1960s and 1970s. (Sterken, 2001)

Xenakis's Polytope de Cluny invites visitors to immerse themselves in a contemporary opera or musical experience at the Festival d'Automne à Paris. Within the installation, visitors enter an interior space with the freedom to position themselves as they please—standing, sitting, or lying down. They are enveloped by laser blades emitting colors Red, Yellow and Blue, varying in intensity and direction throughout the space (Figure 7). These laser blades are synchronized with a sound composition, creating a multisensory experience where visitors perceive the sound through the interplay of light. Despite not seeing the source of the sound, the synchronized light and sound stimulate the senses, transporting visitors into an immersive sonic and visual environment. Xenakis's Polytope de Cluny blurs the boundaries between auditory and visual perception, inviting participants to explore the intersection of sound, light, and space in a dynamic and engaging manner. (Xenakis, 1972)

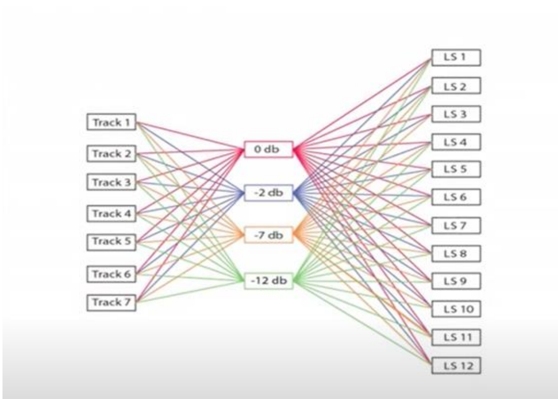


Figure 8, Polytope de Cluny (CIX, 2011)

A metallic grid was constructed like a web lining, on which all the light and sound apparatus was attached. The piece included a 7-channel music composition, distributed over 12 speakers and a computer generated light score realized by using six hundred white flashes, three laser beams colored in red, blue and yellow, three rotating arrays of mirrors as well as 100 fixed mirrors, to create light paths and geometrical figures. Each luminous event described in the score was either played by a specifically designed software "instrument" or it was data-coded directly from the score. The distribution of the 7 tracks of music among the 12 speakers was also controlled by this program, as well as the volume of each routed track at 0db, -2db, -7db or -12db. With 7 tracks of music, 12 speakers and 4 possible different volume settings, Xenakis had 336 possibilities to mix the music for the space at any time. (Figure 8) By inventing new technology, Xenakis was able to compose a very precise light and music score, enabling movements in light and sound. The 12 speakers were arranged in group of two and at two different heights as seen in the drawing. (Figure 6) (CIX, 2011) A Symphony recorded by four separate "orchestras" of identical instrumentation was transmitted via four sets of loudspeakers, one each quadrant of the hall (Lovelace, 2010).

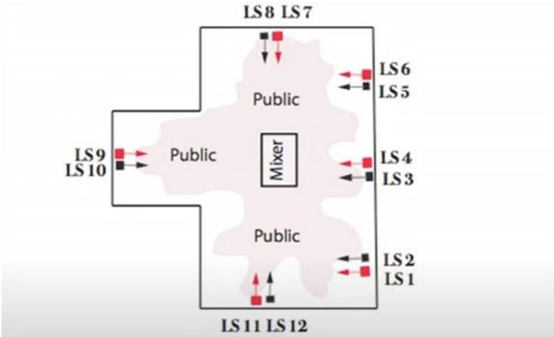


Figure 9, Polytope de Cluny (CIX, 2011)

As with his other polytopes to date, Xenakis chose to compose music that was independent from the visual spectacle. However, for Polytope de Cluny, he mixed computer-generated sounds with some purely instrumental elements on tape. **His observation that light occupies time, for its effects depend on rhythm and duration, while music shapes space was borne out. In contrast to the light program the tape-music is very simple, providing modulating timbres, varying pulses which are heard in counterpoint to the rate and density of lights constantly going on and off, while the sound moves in space around the spectators changing the climate of events.** (CIX, 2011)

Featuring vibrant forms projecting into space within drawing's two dimensions, they are the way he imagined *sound* (Xenakis, 1972). Xenakis's Polytope de Cluny demonstrates how varying light colors can profoundly influence the perception and interpretation of instrumental music, shaping individuals' subjective experiences and preferences by creating immersive and emotionally resonant environments. **Xenakis's observation that light occupies time, while music shapes space, highlights the complex relationship between light, sound, and perception. The interplay between computer-generated sounds and instrumental elements on tape, along with the modulation of timbres and varying pulses, contributed to a rich auditory experience that complemented the visual spectacle of the light installation.**

Further experimentation follows up, by designing the experiment to discover a connection between the experiences of light and sound through emotions.

7. DESIGNING THE EXPERIMENT

The use of primary colors (red, yellow, and blue) is justified based on their fundamental role in color theory and their distinct visual impact. The selection of the violin, piano, and trombone is based on their diverse tonal qualities. Both choices are frequently mentioned in literature review and case studies. These choices are intended to provide a broad range of auditory stimuli for the experiments.

This section, furthermore, categorizes the different emotions that participants may experience in response to the experimental stimuli. Typology is developed based on existing psychological frameworks and is tailored to the context of synesthetic experiences.

7.1. Typology of emotions

Emotions play an undeniably important role in human lives. They are involved in a plethora of cognitive processes such as decision-making, perception, social interactions and intelligence (Alarcão quoted in Galvão, 2021). Identifying a person's emotional state has become increasingly essential. Imagine a scenario where we aim to determine the emotional state of individuals based on their EEG signals[1]. However, the goal extends beyond merely classifying these states as simply positive or negative, or identifying specific discrete emotions like happiness or disgust. The aim is to acquire more detailed information by pinpointing the exact valence and arousal levels the individual is experiencing. This approach provides a broader spectrum of emotional states and allows for the conversion into discrete emotions if desired. (Galvão, 2021).

Emotions are triggered by the perception of significant changes in the environment or the physical body. Two main scientific approaches explain the nature of emotions. The cognitive appraisal theory

[1] Electroencephalogram (EEG) signals refer to the electrical activity of the brain that is recorded through electrodes placed on the scalp. These signals capture the synchronous firing of neurons, offering crucial insights into brain function and cognitive states (Niedermeyer & da Silva, 2004).

posits that emotions are judgments about how well the current situation aligns with our goals or enhances our personal well-being (Smith quoted in Galvão, 2021).

For the first experiment, there is a range of diverse emotions gathered from the literature review that help the participants' acclimation and comfort in the laboratory environment. This list serves as a quantitative tool in the experiment, aiding the participants expressing their emotional state. (Figure 10)

- ❑ Energetic
- ❑ Grounding
- ❑ Welcoming
- ❑ Chill
- ❑ Dizzy
- ❑ Adrenaline
- ❑ Supporting
- ❑ Friendship
- ❑ Purity
- ❑ Stimulus
- ❑ Excited
- ❑ Happiness
- ❑ Love
- ❑ Anger
- ❑ Fear
- ❑ Jealously
- ❑ Pride

Figure 10, List of emotions given for experiment 1, image by the author

For the second experiment, the participants have established comfort, thus are encouraged to express their emotional state by describing, through qualitative descriptions.

7.2. Color Light parameters

RYB (Red, Yellow, Blue) and RGB (Red, Green, Blue) are both sets of primary colors, but they serve different purposes and have different origins. In the realm of color theory, RYB (Red, Yellow, Blue) and RGB (Red, Green, Blue) represent two sets of primary colors with distinct applications and historical backgrounds.

RYB, plays a significant role in artistic color mixing, dates to the 18th century and finds its basis in the observation of pigments commonly utilized in painting (Itten, 1961). In RYB color theory, these three colors are considered primary as they are combined to produce a broad spectrum of secondary and tertiary colors, with equal parts of two primary colors yielding secondary hues, such as orange resulting from the mixture of red and yellow (Gage, 1999). (Figure 11)

Conversely, RGB primary colors are integral to additive color mixing, predominantly employed in digital displays like computer monitors and televisions (Poynton, 2003). Rooted in the trichromatic theory of human vision, RGB theory posits that the human eye possesses receptors sensitive to red, green, and blue light, with the brain perceiving various colors through the stimulation of these receptors in varying combinations.

Both RYB and RGB play significant roles within their respective contexts, with RYB established in traditional artistic practices and RGB fundamental to digital color representation and perception.

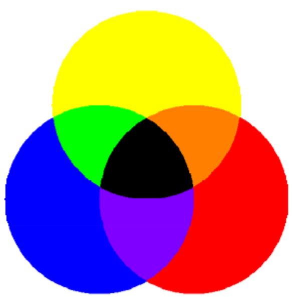


Figure 11, RYB primary colors and their combinations, (Sugita & Takahashi, 2015)

Iannis Xenakis, in Polytope de Cluny, ulitise laser blades emitting Red, Yellow, and Blue colors envelop them, varying in intensity and direction throughout the space (Xenakis, 1972), BOA use the light color Red (BOA, 2023), Vivaldi use red, yellow, blue, orange, green, purple (Cho, 2021), Van Gogh talks about color blue (Gogh, 1885). Kandinsky use red, yellow and blue to describe feelings, Nielsen in her experiments use red, amber, blue and white (Nielsen et al., 2021).

Dominant light colors from analysis and literature review: red yellow blue.

In this report, the colors that are used for the experimental face, are eventually the RYB. These colors give a better comprehension to the participants, in analog terms, for the third experiment, where they use colors of pens to describe the intruments sounds.

7.3. Sound parameters

Drawing from Vivaldi, notes that Red, symbolizing warmth, finds expression through the passionate tones of string instruments, particularly the violin and cello. Similarly, Yellow bursts, representing energy and brightness, are summoned by a group of brass instruments, such as the trumpet and trombone. On the other hand, Blue, symbolizing coldness, resonates with the dense and refreshing tones of the piano. (Cho, 2021) Van Gogh, vividly described the experience of playing the piano as overwhelming, evoking a range of emotions such as joy, sadness, or excitement (Gogh, 1885). Iannis Xenakis creates a composition of electronic sounds, but describes it as intrumental synthesis (Xenakis, 1972). BOA with Nuits Noires sound designer originate metallic sound to mimic the urban sounds, which are described like “trombone synth sounds” (Nicolas, 2023). In Bresin, R., “What is the color of that music performance?” the acts that were played by musicians in the experimental part, use three instruments: saxophone, guitar, and piano (Bresin, 2005).

In this report, the intruments that are used for the experimental face are the violin, the piano and the trombone. These instruments are familiar and easily recognizable to the participants, as they are common in everyday background noises. Furthermore, there is frequent use of them in the study’s literature review, which will provide further insights and comparisons.

8. Hypothesis

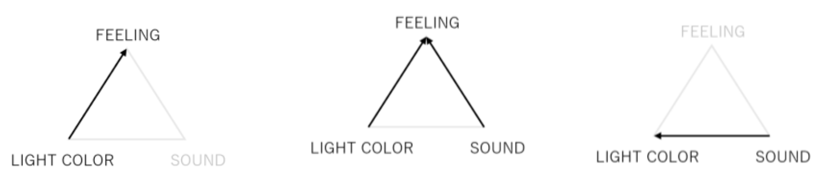
The emotional impact of varying light colors on the perception and interpretation of instrumental music differs based on the psychological associations of the light colors. Specifically, it is hypothesized that warm colors like red and yellow will evoke more energetic and passionate emotional responses, enhancing the perception of dynamic or intense musical passages. In contrast, cool colors like blue may elicit calmer and more contemplative emotional states, influencing the interpretation of softer or more melodic musical elements. These emotional responses to the combined stimuli of light color and instrumental music will subsequently influence individuals' subjective experiences and preferences, shaping their overall response to multisensory environments.

The primary light colors red, yellow, and blue evoke distinct and consistent emotional responses in participants, with each color being associated with specific emotions.

This hypothesis posits that exposure to the primary light colors will elicit identifiable and consistent emotional reactions from participants, allowing for a quantitative measure of the emotional impact of each color. By examining these responses, the experiment aims to establish a baseline understanding of how these primary colors influence emotional states, in line with the principles outlined by the triangle of vision.

9. TEST

There are conducted three series of experiments according to the above diagrams. The first experiment to explain the feelings evoked by light colors red, yellow and blue (Figure 12 (a)), the second experiment to explain the feelings evoked by light colors red, yellow and blue combined with instruments violin, piano and trombone equally (Figure 12 (b)) and the third experiment to explain the colors evoked by the instruments' violin, piano, and trombone (Figure 12 (c)).



(a) (b) (c)

Figure 12, Triangle shape, image by the author

Experiment 1:

This first experiment is a quantitative experiment, conducted within the environment of a built-in laboratory. It is based in the above literature review on the subject. Participants are exposed to Red, Yellow, and Blue (RYB) color light and afterwards are asked to express their emotional responses. This step aims to create a standard baseline for realizing of participants' emotional reactions to RYB light colors.

Experiment 2:

Based on the findings from Experiment 1 and the literature review, the second phase is a qualitative experiment also conducted in the same setting. Participants are exposed to RYB light combined with the sounds of violin, piano, or trombone. Then they are asked to provide descriptions of their emotional experiences. This phase the author emerges to investigate deeper into the emotional responses prompted by RYB colors when combined with different instrument sounds.

Experiment 3:

The final experiment is a qualitative investigation conducted in the laboratory area, incorporating elements of visual ethnography. Informed by the results of Experiments 1 and 2, participants are motivated to visualize sound as colors. Specifically, they are asked to identify the hues they associate with the sounds of the above three instruments-violin, piano, trombone. This last experiment aims to explore potential auditory synesthesia and further explanation of the relationship between sound and color perception. Also, it aims to answer to the research question, of how light color and instrument sound are related, without the medium of feelings, thus it is a way to validate the above research.

9.1. Participants and equipment

Three experiments were conducted with a total of 16 participants aged between 22 and 64 years old. The participants' background was diverse: artist, architecture student, electrical engineering students, management student, music producer, mechanical engineer, leather designer, researcher, professor of medicine, mathematician, therapist, scenographer, social worker, gardener.

The light fixture used was the Philips Hue G93 globe with an E27 LED bulb, which was programmed in four light scenarios, Red, Yellow and Blue for experiments one and two and amber white for experiment three.

The sound fixture employed was the Sony SRS - XB13 speaker. In experiments two and three, participants are exposed to music sounds made by three different instruments: the violin, piano, and trombone.

Throughout all three experiments, the consistent duration of 5 minutes per scenario ensures uniformity in participant exposure and allows for effective data collection.

For the last experiment the participants can visualize the instrument sounds they hear in the given colors: red, yellow, blue, and their combinations, orange, green and purple.

9.2. Parameters for the experiment

As mentioned in the analysis chapter of the literature review and the case studies, there were gathered all the emotions there were used. These emotions are: Energetic, Grounding, Welcoming, Chill, Dizzy, Adrenaline, Supporting, Friendship, Purity, Stimulus, Excited, Happiness, Love, Anger, Fear, Jealously, Pride.
According to the literature review, red color represents adrenaline (BOA, 2023), yellow representing stimulus, red symbolizing energy, blue evoking infinite sensibility, and green embodying calmness (Kandinsky, 2012), Nielsen in her experiments describes blue light as chill and dizzy, amber as welcoming and supporting, and red as grounding (Nielsen et al., 2021).

These exact emotions are used as answers for the participants, in experiment number one, based on the literature review, as quantitative experiment. They are used in order to create a warm-up feeling so they can connect better with the environment of the lab test.
The remaining two experiments will be qualitative, drawing from the literature review and insights gained from experiment 1. Following the warm-up provided by experiment 1, participants will have the opportunity to describe their feelings more openly and freely.

9.3. Scenarios and simulations

Experiment 1

RYB Light color vs feelings

Figure 13, Triangle vision shape visualizing feelings through light color, image by the author

The first experiment aims to explore the feelings evoked by the primary light colors red, yellow, and blue, following the principles drawn by the triangle vision shape (Figure 13). Participants are exposed to light in these colors, specifically red, yellow, and blue (RYB), and subsequently asked to express their emotional responses.

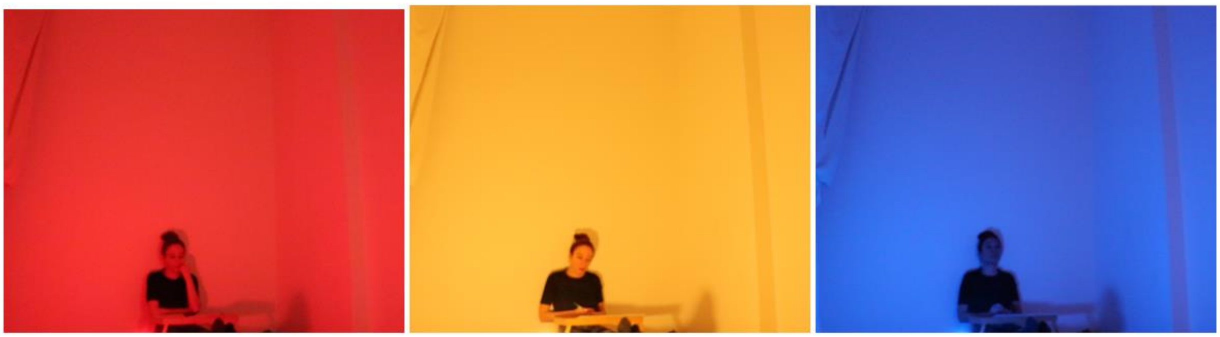


Figure 14, Three light scenarios for the first experiment RYB, image by the author

To establish a standard baseline, participants are given a list of emotions and are asked to check the emotions they experience in response to each light color. This method allows for a quantitative measure of the emotional impact of each color of light. By doing so, the experiment seeks to understand the participants' emotional reactions to RYB light colors, providing a foundational understanding of how these primary colors influence emotional states.

Experiment 2

RYB Light color and instrument sound vs feelings

Figure 15, Triangle vision shape visualizing feelings through light color combined with instrument sound, image by the author

Experiment number 2 focuses on identifying the emotions experienced by participants when exposed to red, yellow, and blue light colors in combination with the sounds of a violin, piano, or trombone.

Building on the findings from Experiment 1 and the literature review, the second phase involves a qualitative experiment conducted in the same setting as experiment 1. This phase aims to investigate the emotional responses created by each RYB light colors with combination of a different instrumental sound. The baseline is explained by using the triangle of vision shape, where the combination of light color and sound leads to specific emotions. (Figure 15)

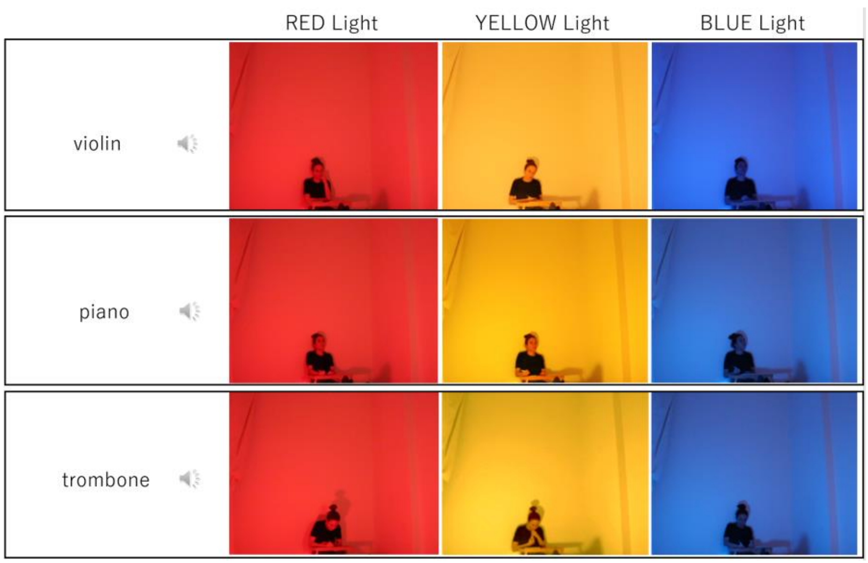


Figure 16, Three light scenarios for the second experiment RYB combined with three instrument sounds, image by the author

Participants are exposed to red, yellow, and blue (RYB) light colors in combination with the sounds of a violin, piano, or trombone. There are nine sets of experiments in total, with three experiments for each instrument, corresponding to each of the RYB light colors. (Figure 16) Following these exposures, participants are asked to provide descriptions of their emotional experiences.

This qualitative approach allows for a deeper investigation into how the combination of RYB colors with different instrument sounds affects emotional responses, providing more valuable insights into the interplay between visual and auditory stimuli in evoking emotions.

Experiment 3

Light color vs instruments' sound

Figure 17, Triangle vision shape visualizing the color that arises from the instrument sound, image by the author

Experiment number 3 focuses on recognizing the participants' emotions elicited by the RYB light colors (red, yellow, and blue) in combination with the instrumental sounds of a violin, piano, or trombone. By translating the triangle vision of this scenario is in what color the participants perceive the sound. (Figure 17) This experiment is a way to validate the hypothesis of the auditory chromatesthesia.

The light color in this scenario is amber white, in order to be easier for the participants to feel like they are in a natural environment. (Figure 18)

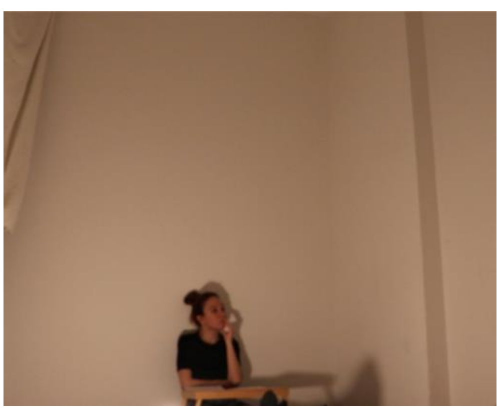


Figure 18, Amber white light scenario for the third experiment, image by the author

The participants can visualize the instrument sounds they hear in the given colors: red, yellow, blue, and their combinations—orange, green, and purple. (Figure 19).

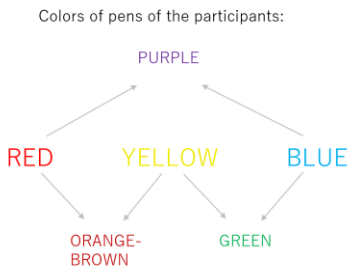


Figure 19, colors of pens given to participants of experiment 3, image by the author

9.4. Results

Experiment 1

For the results the author calculated the answers of the participants and made charts visualizing the emotional responses to each color hue.

RYB Light color vs feelings

Figure 20, Triangle vision shape visualizing feelings through light color, image by the author

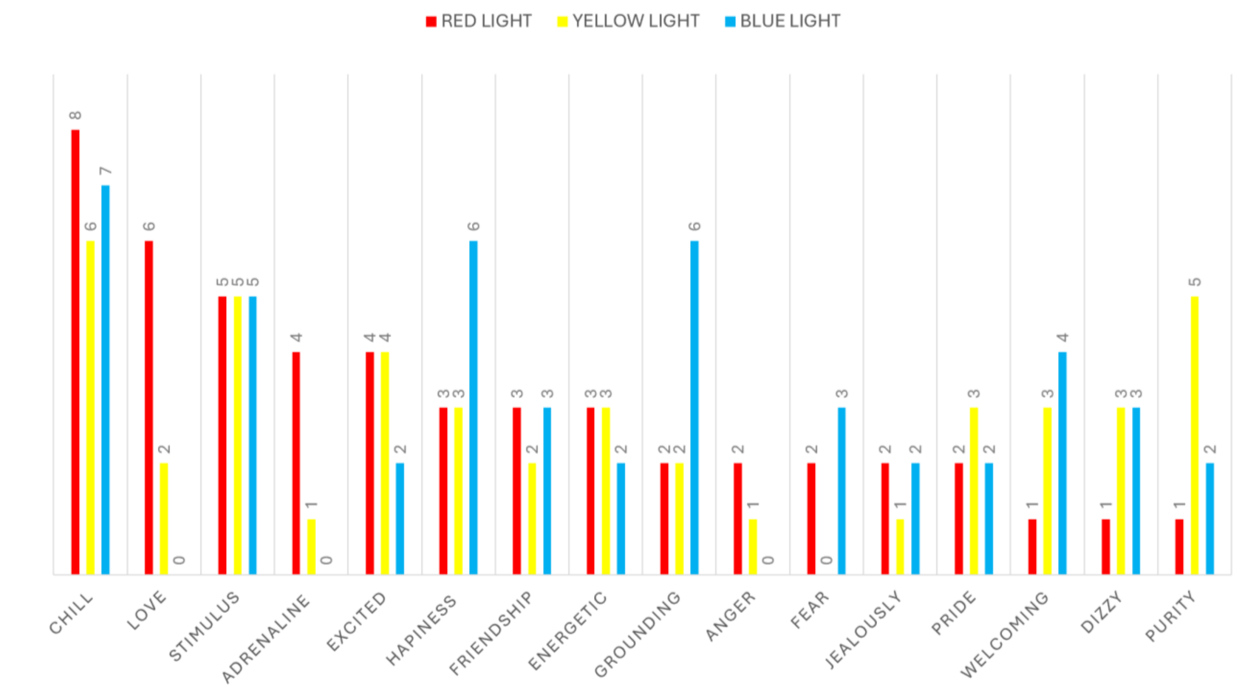


Figure 21, Chart visualizing feelings through light color, image by the author

The results of the first experiment are the feelings that occur from light color red, yellow and blue. In red light color the feelings chill, love and stimulus are in high percentage, while the welcoming, dizzy and purity are in very low rates. In yellow light color the dominant feelings are chill, stimulus and purity, and the less dominant fear, anger, and adrenaline. In blue light color we find in higher range the emotions of chillness, happiness, and grounding while in lower love, adrenaline and anger. (Figure 21)

Experiment 2

Figure 22, Triangle vision shape visualizing feelings through light color combined with instrument sound, image by the author

RYB Light color and violin vs feelings

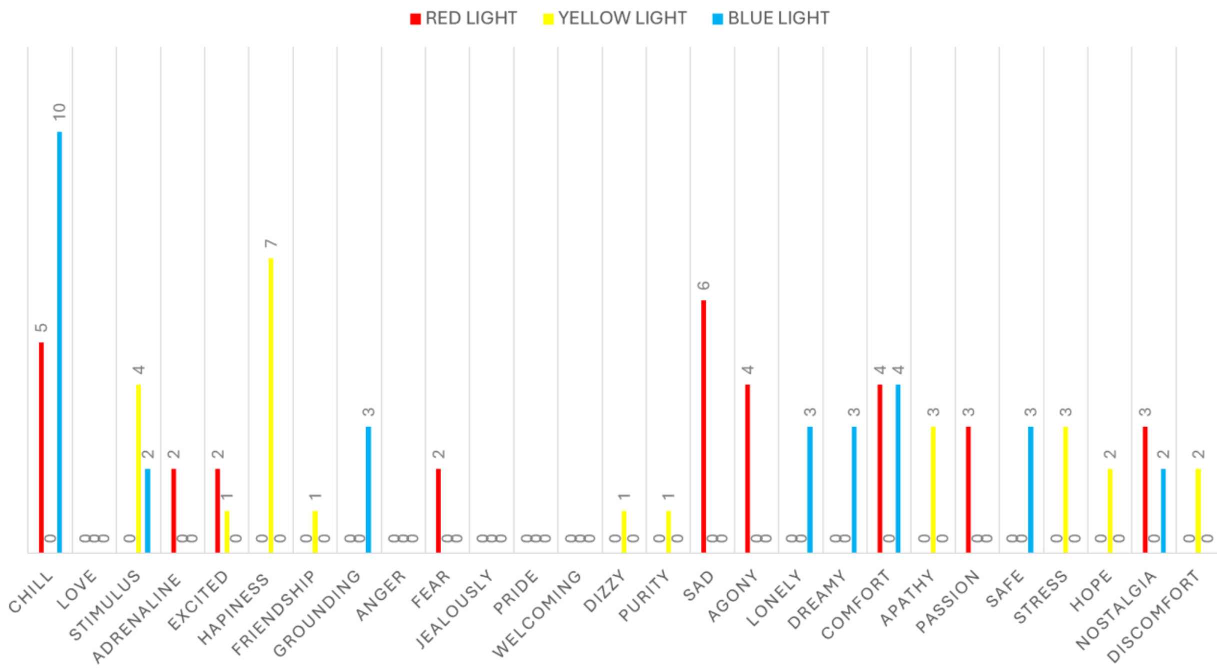


Figure 23, Chart visualizing feelings through light color combined with violin, image by the author

When the violin starts playing the emotional impact in the participants starts to change. It is observed that in red light color the chill feelings lowered from eight to five and the sadness elevated to six, while they remain the more distinguished feelings in this hue color. In yellow light color the happiness increased from three to seven answers out of sixteen and the stimulus remained almost similar to four responses. In blue light color in combination with the violin the most dominant feeling is chillness which has a value of ten answers, slighlty higher that the previous experiment with seven answers. Positive answers of comfort, grounding and dreamy are also seen in the chart. (Figure 23)

RYB Light color and piano vs feelings

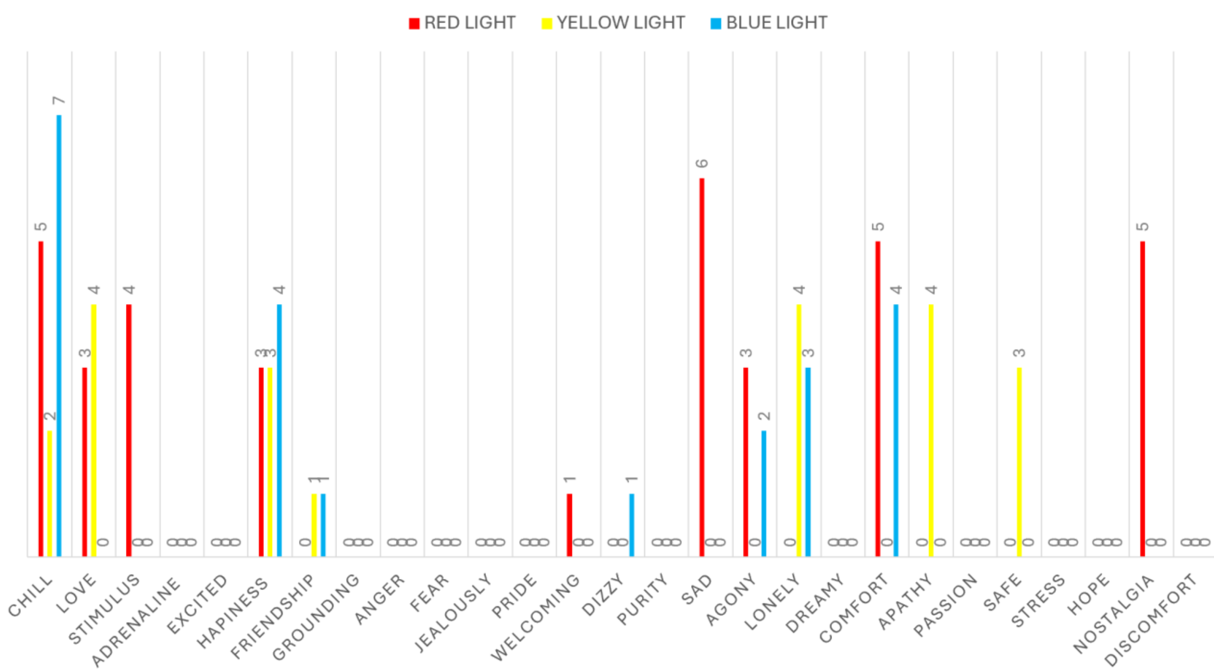


Figure 24, Chart visualizing feelings through light color combined with piano, image by the author

When the piano starts playing in the red light, the sadness emotions remain still high, in the same percentage as in the violin. The chillness also stays constant at five points, while the comfort and nostalgia goes higher at five points as well, unlikely to the previous sound. In yellow light color, the love, lonely and apathy equalize in four responses. The responses of chillness under the blue light remains unchanged with a value of seven, indicating that the insertion of the instrument had no impact on the outcome in any of the above experiments. (Figure 24)

RYB Light color and trombone vs feelings

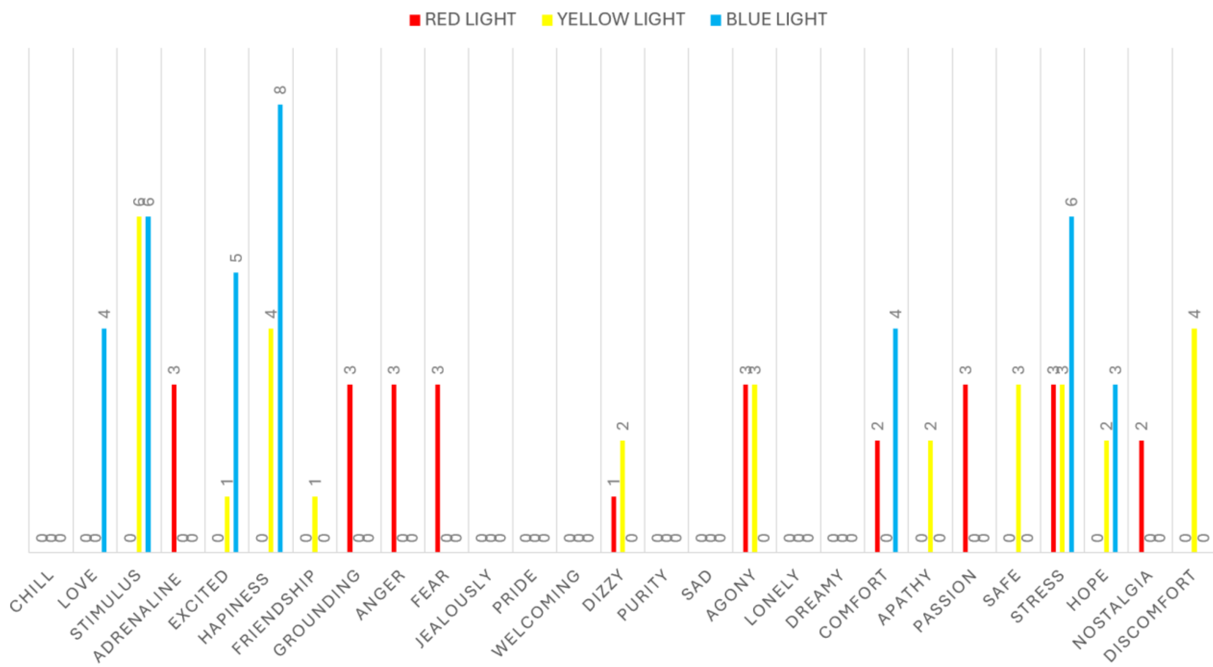


Figure 25, Chart visualizing feelings through light color combined with trombone, image by the author

In the trombone sounds the participants do not describe a lot of feelings. There is a tie in emotions of adrenaline, grounding, anger, fear, agony, passion and stress. In yellow light the stimulus remains high enough, while in blue light the responses are very high in happiness, stimulus, stress and excitement. (Figure 25)

Experiment 3

Instruments' sound vs color

Figure 26, Triangle vision shape visualizing the color that arises from the instrument sound, image by the author

Violin vs color

Several of the drawings that the participants created during experiment 3, while violin intrument was playing were perceived to calculate the color they see through each intrument (Figure 27).

Figure 27, Drawings made by the participants in violin, image by the author

By assigning a higher value of >1< to each dominant color and a value of >0.5< to each secondary or tertiary color, the calculated predominant color used in violin music is yellow. (Appendices b)

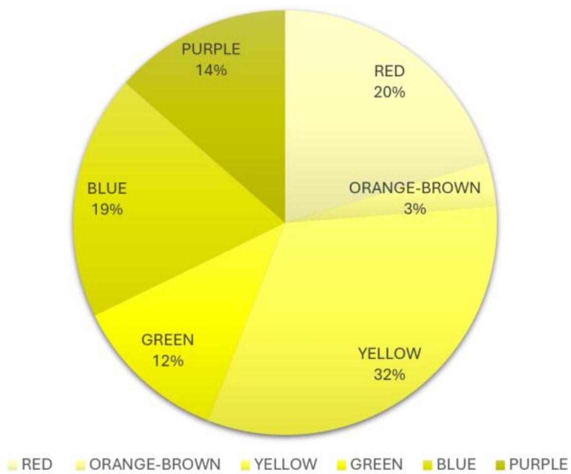


Figure 28, Chart visualizing color arising from violin, image by the author

Piano vs color

Figure 29, Drawings made by the participants in piano, image by the author

Respectively the calculated eminent color used in violin music is blue.

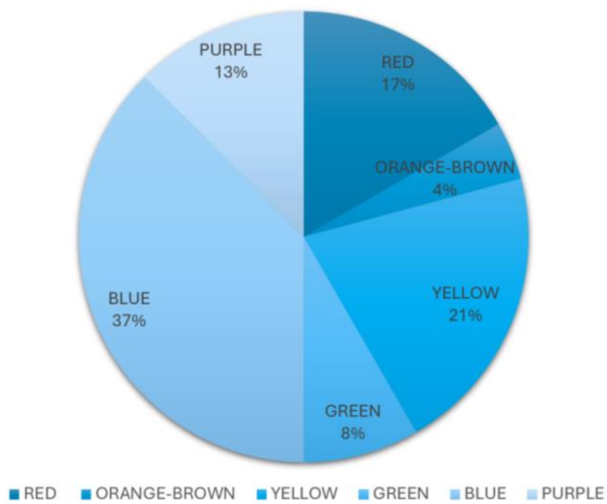


Figure 30, Chart visualizing color arising from piano, image by the author

Trombone vs color

Figure 31, Drawings made by the participants in trombone, image by the author

In the trombone sound the dominant color will be the red and the yellow, which if combined would result to orange-brown color.

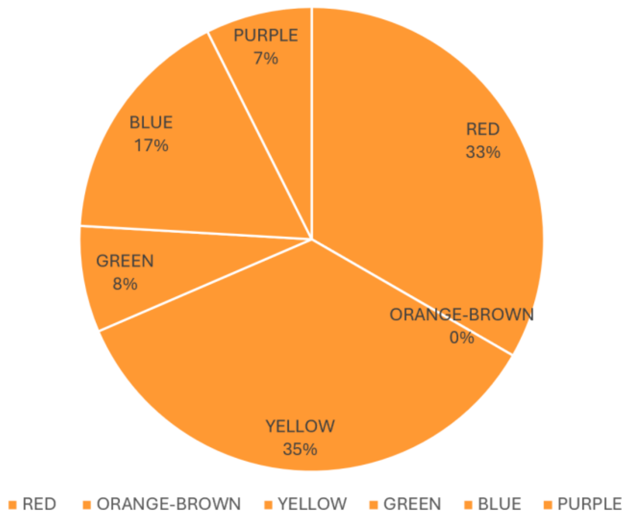


Figure 32, Chart visualizing color arising from trombone, image by the author

10. FINDINGS

10.1. Arousal and Valence diagram of the results of experiment 1 and 2

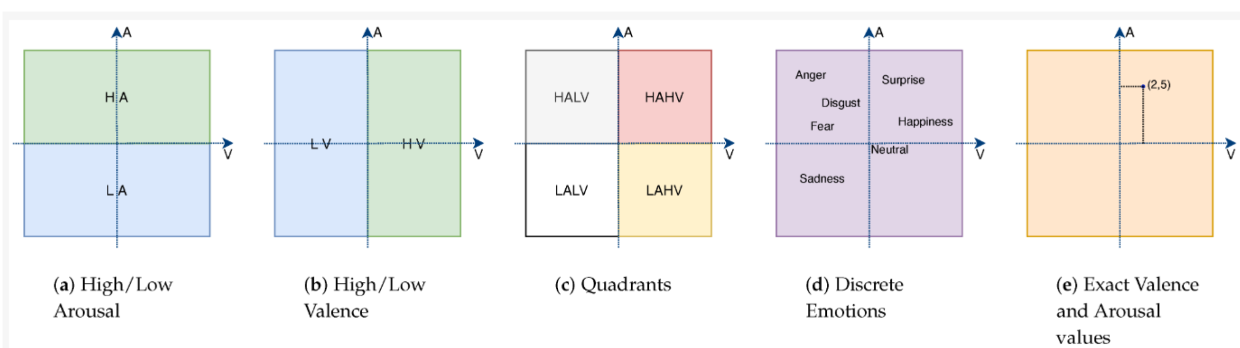


Figure 33, The typical set of emotions recognized in the literature (a–d) and what we want to achieve with our work (e). A: arousal; V: valence. (Galvão, 2021)

According to the above diagram, there are two perspectives to represent emotions: discrete and dimensional. In the discrete perspective, all humans are thought to have an innate set of basic emotions that are cross-culturally recognizable. A popular example is Ekman's six basic emotions (anger, disgust, fear, happiness, sadness and surprise) (Ekman quoted in Galvão, 2021). In the dimensional perspective, emotions are represented by the valence, arousal and dominance dimensions (Mehrabian quoted in Galvão, 2021). Valence, as used in psychology, means the intrinsic attractiveness or aversion of an event, object or situation, varying from negative to positive. Arousal is the physiological and psychological state of being awake or having the sensory organs stimulated to a point of perception, ranging from sleepy to excited. Dominance corresponds to the strength of the emotion (Gunes & Schuller quoted in Galvão, 2021).

More specifically, arousal refers to the level of alertness or stimulation, ranging from calm to excited. Valence measures the intrinsic attractiveness (positive valence) or averseness (negative valence) of an event, object, or situation. (Figure 33)

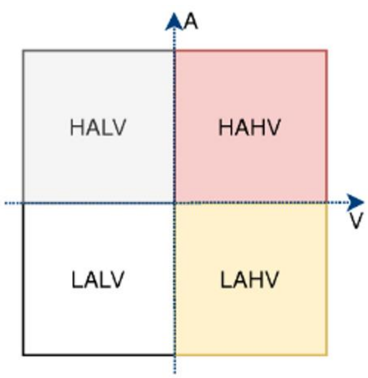


Figure 34, A: arousal; V: valence. (Galvão, 2021)

Starting from the top left HALV is High Arousal feelings and Low Valence, which means negative emotions, though more inciting. On the other hand on the bottom right corner, there are the LAHV, which are the low stimulation but positive emotions. The HAHV is the most ideal state required, High Arousal and High Valence, positive and inciting emotion, while bottom left corner will be the LALV, Low Arousal and Low Valence, which is the less wanted results, since it means low excitation and negative feelings. (Figure 34)

Utilizing Galvão's diagram as a foundational framework, diagrams have been constructed to depict the results of the master thesis experiments, which effectively classify emotions with greater specificity.

Experiment 1

RYB Light color vs feelings

Figure 35, Triangle vision shape visualizing feelings through light color, image by the author

Experiment number 1 is focused on identifying the participants' emotions created by the RYB light color spectrum. (Figure 35)

Based on the diagram by Galvão depicting Arousal and Valence values, the following representation has been constructed. This diagram illustrates the relationship between Arousal and Valence, providing a visual interpretation of emotional states of the participants. As stated beforehand, arousal reflects the intensity of emotion, while Valence indicates the positivity or negativity of the emotion.

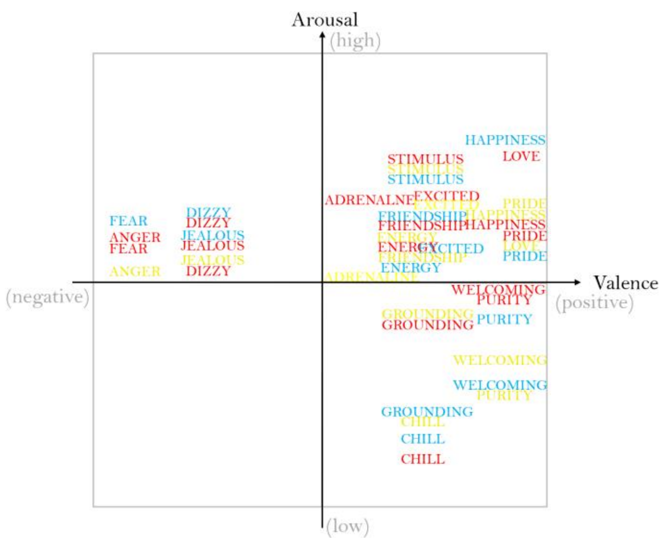


Figure 36, RYB Light color vs feelings in arousal and valence diagram, created by the author

Under red light, participants dominantly feel chill, comfort, loneliness, and stress. Yellow light shows feelings of chill, pride, and purity, while blue light is mosty associated with happiness, fear, and chill. (Figure 36).

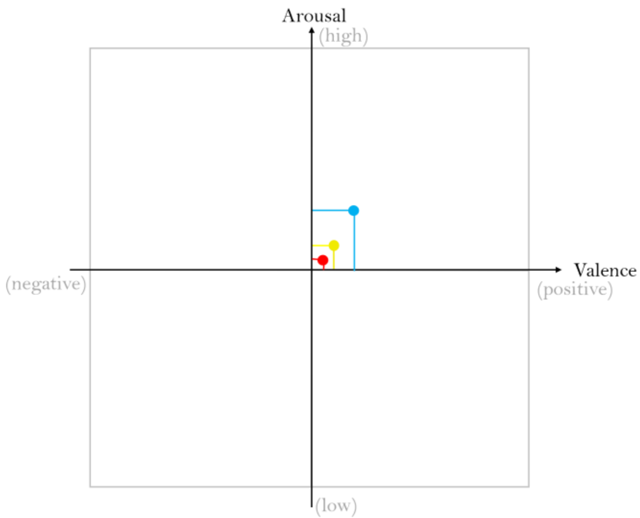


Figure 37, RYB Light color vs feelings in arousal and valence values, created by the author

We see in the value chart, that the BLUE light color dominates, while in Blue light color the HAHV is higher (Figure 37).

Experiment 2

Experiment number 2 is focused on recognizing the participants' emotions created by the RYB light color in combination with instrument sound of violin or piano or trombone.

Figure 38, Triangle vision shape visualizing feelings through light color combined with instrument sound, image by the author

According to the figure of Galvão of Arousal and Valence values, there are created the following diagrams, depicting feelings through RYB light color combined with instrument sound:

RYB Light color and violin vs feelings

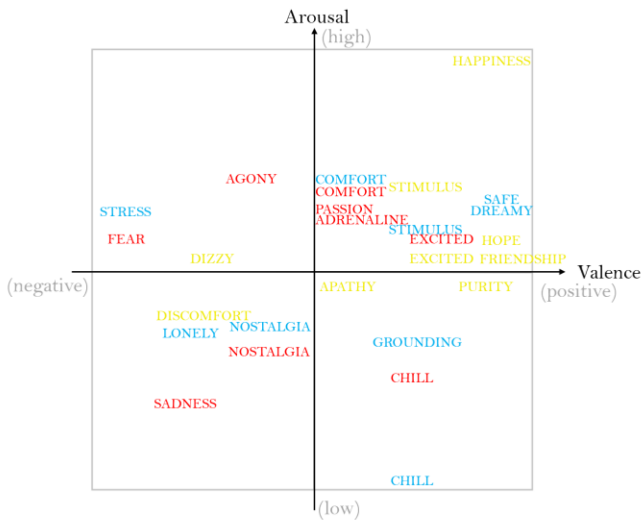


Figure 39, RYB Light color and violin vs feelings in arousal and valence diagram, created by the author

In Red light color combined with violin, the feelings that stand out are sadness, chill, agony and comfort. In Yellow light color combined with violin, the more dominant feelings are happiness and stimulus. In Blue light color combined with violin the prevailing feelings would be chill, comfort, lonely and stress. (Figure 39).

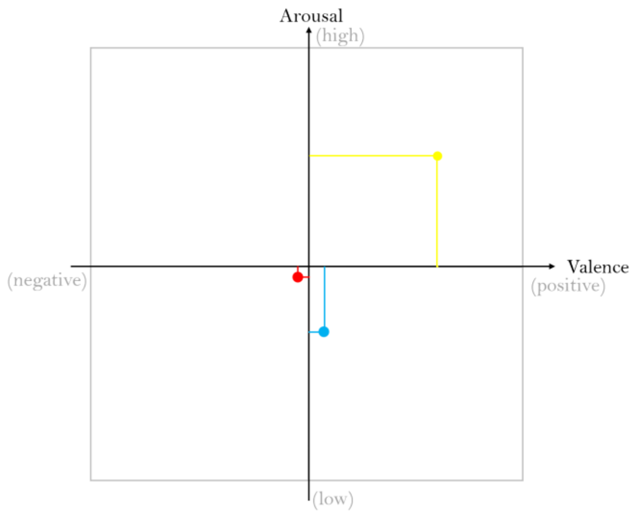


Figure 40, RYB Light color and violin vs feelings in arousal and valence values, created by the author

We see in the value chart, that the YELLOW light color dominates, while in Yellow light color combined with violin we have higher HAHV (Figure 40).

RYB Light color and piano vs feelings

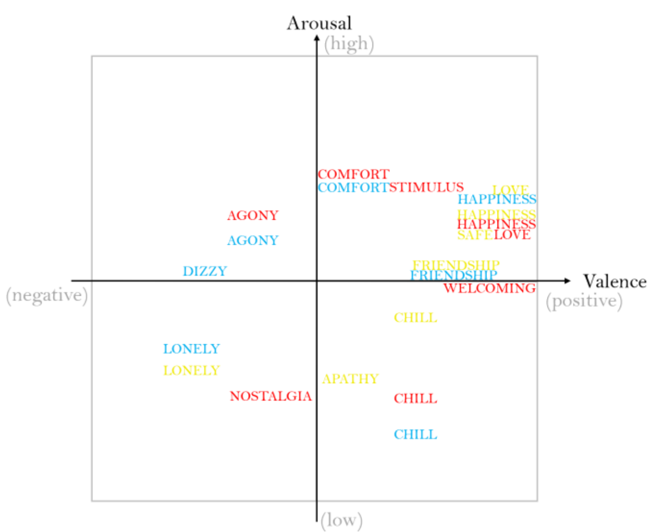


Figure 41, RYB Light color and piano vs feelings in arousal and valence diagram, created by the author

In Red light color combined with piano, the standing out emotions are comfort, stimulus, nostalgia and chill. In Yellow light color combined with piano, the more dominant feelings are love, lonely and apathy. In Blue light color combined with piano the distinguished feelings would be chill, comfort and lonely. (Figure 41).

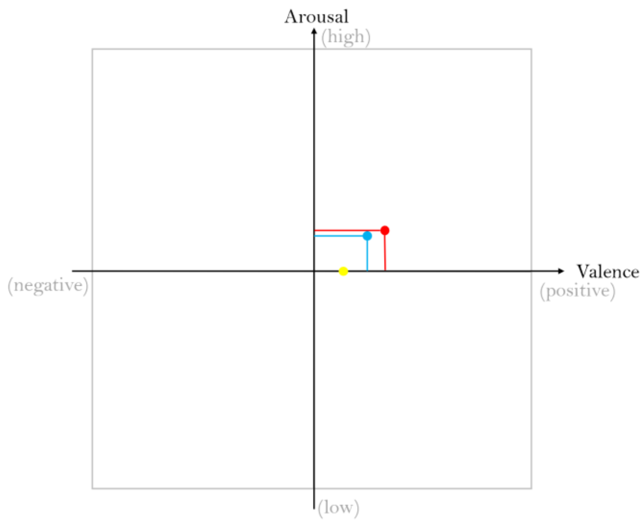


Figure 42, RYB Light color and piano vs feelings in arousal and valence values, created by the author

It is noticeable in the above value chart, that the RED and BLUE light color distinguish, as in there is higher HAHV (Figure 42). PURPLE would be the dominant color, as it is the combination of blue and red color.

RYB Light color and trombone vs feelings

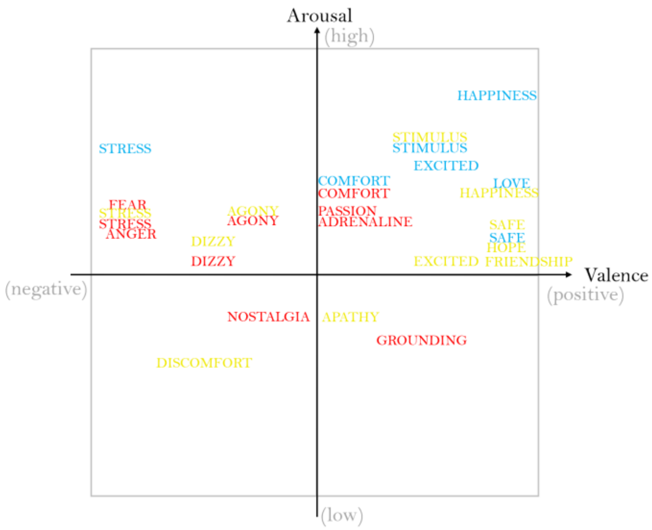


Figure 43, RYB Light color and trombone vs feelings in arousal and valence diagram, created by the author

In Red light color combined with trombone, the standing out emotions are comfort, fear and grounding. In Yellow light color combined with trombone, the more dominant feelings are stimulus and discomfort. In Blue light color combined with trombone the distinguished feelings would be happiness, stimulus and stress. (Figure 43).

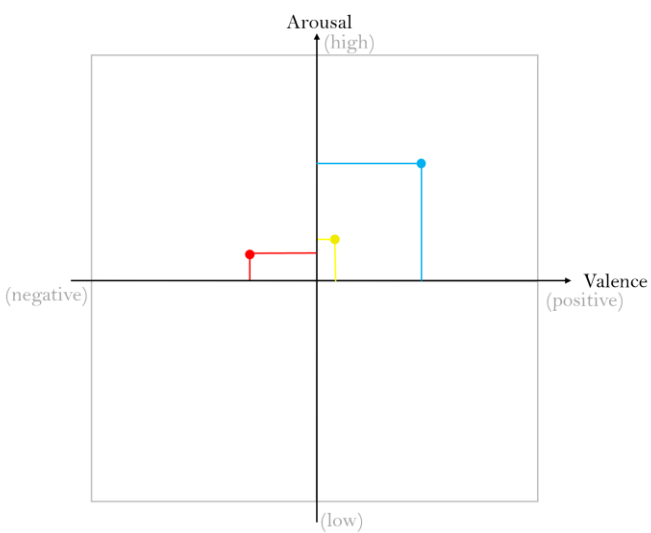


Figure 44, RYB Light color and trombone vs feelings in arousal and valence values, created by the author

In the value chart the BLUE light color dominates, because in Blue light color combined with trombone the HAHV is higher (Figure 44).

10.2. Comparison of findings

In summary, if we assume that HAHV is the optimal mental state that the individual reaches during a subjective experience, the anticipated outcomes would be the following:

In the presence of light colors alone, without any accompanying instruments' sound, the color blue evokes feelings of happiness and relaxation.

When the sound of violin comes in the more higher and positive emotions come with yellow light, which are happiness and stimulus.
In piano sounds they stand out the comfort, stimulus, nostalgia and chill in red light color and chill and comfort in blue light. Thus, the standing out light color would be red and blue, eventually purple.
Finally, in trombone the distinguished emotional impact on participants are happiness and stimulus, which come in blue light color.

From the results of the experiment three, which focuses on synesthesia of participants, the color that occurs from violin is yellow, from piano is the blue and from trombone is orange – the combination of yellow and red hues.

10.3. Comparison of findings with the literature review

10.3.1. RYB Light color VS feelings

- **Literature Review**:
  - Red: Passion, warmth.
  - Yellow: Energy, brightness.
  - Blue: Coldness, refreshing tones, overwhelming emotions.
- **Master's Thesis findings**:

- Red: Comfort, stimulus, nostalgia, chill, fear, grounding, sadness, agony.
- Yellow: Love, loneliness, apathy, happiness, stimulus, discomfort.
- Blue: Chill, comfort, loneliness, stress, happiness, fear.

10.3.2. RYB Light color combined instrument's sound VS feelings

- **RED LIGHT**:
  - **Literature Review**:
    - BOA uses red, which is often associated with warmth and passion (Vivaldi, Cho, Xenakis, Nicolas).
    - In music, red is linked to the passionate tones of string instruments like the violin and cello (Cho, 2021).
  - **Master's Thesis findings**:
    - With violin: Red light evokes sadness, chill, agony, and comfort.
    - With piano: Red light evokes comfort, stimulus, nostalgia, and chill.
    - With trombone: Red light evokes comfort, fear, and grounding.

- **YELLOW LIGHT**:
  - **Literature Review**:
    - Yellow represents energy and brightness, associated with brass instruments like the trumpet and trombone (Cho, 2021).
  - **Master's Thesis findings**:
    - With violin: Yellow light evokes happiness and stimulus.
    - With piano: Yellow light evokes love, loneliness, and apathy.
    - With trombone: Yellow light evokes stimulus and discomfort.

- **BLUE LIGHT:**

- **Literature Review**:

- Blue symbolizes coldness and is often associated with the piano's dense and refreshing tones (Cho. 2021).

- Van Gogh associates blue with overwhelming emotions when playing the piano (Gogh, 1885).

- **Master's Thesis findings**:

- With violin: Blue light evokes chill, comfort, loneliness, and stress.

- With piano: Blue light evokes chill, comfort, and loneliness.

- With trombone: Blue light evokes happiness, stimulus, and stress.

Both the literature review and the master's thesis findings highlight the interplay between light color and sound in evoking emotions. Red and blue lights are particularly significant, consistently creating a range of emotions across different instruments, with red often correlated to comfort and passion, and blue to chill and happiness. Yellow light tends to evoke more energetic and stimulating emotions, although the specific emotional responses can vary depending on the instrument.

10.4. Triangle with feelings – light color – sound

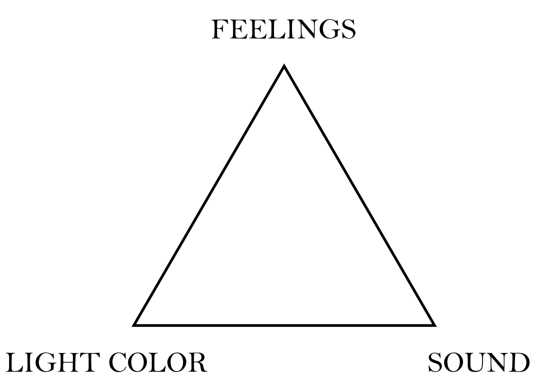


Figure 45, Triangle vision shape, image by the author

In this master's thesis, I introduced the triangle shape with the components of feelings, light color, and sound to create a clearer picture of the vision and the thesis structure. It is created to aid the vision, in finding a connection between experiences of light and sound through feelings. Visualizing the interplay between light color, sound, and feelings as a triangle offers a clear framework. In this triangular framework, each edge represents one of the three variables—feelings, light color, and sound—while the connections between them illustrate the relationships being explored.

11. DISCUSSION AND PRAXIS

Incorporating light color and instrument sound into everyday life to evoke feelings in individuals can be reached in various ways, by using principles of sensory design, psychology, and artistic expression.

Home Environment Enhancement: Utilize smart lighting systems that allow an individual to adjust the color and intensity of lights in your home environment. According to the findings, blue light with gentle piano music can promote relaxation in the evening.

Event Planning: Incorporate light color and live instrument sound into events to create a better ambiance. For instance, with dimmed, blue-toned lighting with the accompany of trombone or a festive celebration with vibrant orange hues could promote dance and stimulus emotions.

Therapeutic Practices: Incorporate light color and instrument sound into therapeutic and wellness practices such as meditation, yoga, and spa treatments to promote relaxation, stress reduction, and emotional well-being. Red light With violin evokes chill and comfort, while with piano, red light evokes comfort, stimulus, nostalgia, and chill

Educational and Learning Environments: Integrate light color and instrument sound into educational settings to stimulate creativity, engagement, and emotional expression among learners. For example, blue light combined with trombone creates feelings of happiness, stimulus, and stress. Yellow light with violin evokes happiness and stimulus to the knowledge seekers who ask for a break.

By creatively integrating light color and instrument sound into various aspects of everyday life, individuals can experience heightened sensory experiences, emotional connections, and overall well-being, enriching their daily routines and interactions with the environment.

12. CONCLUSION

This thesis researches the connection between light colors, instrumental music, and emotions. By examining how sensory stimuli interact, we gain valuable insights into their combined effects on human preferences and experiences. This research enhances our understanding of multisensory environments, by creating the way for applications in areas such as music education, therapeutic settings, and immersive entertainment. Through a series of carefully designed experiments, the author emerges to investigate how varying light colors impact emotional responses to instrumental music and how these responses influence individuals' subjective experiences and preferences.

Houser Jeffrey et al., explain that there are many non-photic ways in which physiological responses to light can be modulated. Alertness, for example, can be changed by signals from any of the five senses. An alerting response can be evoked by the smell of smoke in a building, the sound of a fire alarm, inappropriate touching or ingested substances such as caffeine. Houser et al. add that non-sensory factors also play a role, such as interest and mood state. On the surface, any of those things might be expected to cause a comparable or greater alerting effect than a small change in illuminance or CCT. It should also be noted that the longer the delay between the stimulus and the response, the greater the opportunity for other non-lighting factors to influence the response. (Houser et al., 2020)

Ultimately, the findings suggest that the emotional impact of the combination of light and sound can be utilized effectively to create more engaging and emotionally resonant experiences, emphasizes the influence of sensory interactions on individual's perception and emotion.

Is it the light that directs the visitor towards the sound or inversely to create a (collective) consciousness of the inhabited space?

13. LIMITATIONS AND FUTURE WORKS

13.1. Limitations

The experiments were conducted with a relatively small and similar group of participants. This limits the general responses and affects the quality of the findings.

In addition, the experiments were conducted in controlled lab environments that may not fully resonate real-world where music and light are experienced. Variations in lighting scenarios, sound quality, and environmental distractions could affect the outcomes.

Also, the study focused on a limited number of instruments (violin, piano, trombone). Exploring a broader range of instruments and electronic synth instrumental sounds, could provide a more comprehensive understanding of the connection between light and sound.

13.2. Future Works

By conducting larger-scale experiments, including controlled laboratory environments, will help to validate the findings and understand how they apply towards diverse contexts.

Another valuable insight would be to extend the experiments, by including a wider range of instruments and sound sources. This will help explore how different timbres and sound characteristics interact with various different light colors to create emotions. By developping interactive installations where participants can manipulate light and sound in real-time, can help explore the immediate effects of these changes on emotional and synesthetic responses of individuals.

Furthermore, collaborate with composers and performers would be a valuable idea, to create art pieces designed to explore the interaction of light and sound. This could involve by composing new synth music that integrates light changes or designing performances that include synchronized light displays. For instance, create proposals for integrating light and sound at festivals like the Berlin Festival or like the background study of Distortion Music Festival.

Finally, by involving a bigger number of colleagues from diverse fields such as music, visual arts, psychology, and technology, can provide deeper outcomes and more innovative methodologies.

By facing these limitations and investigating these future research ideas, this master's thesis could dig more into understanding the complex relationship between light, sound and feeling, and enhance the application of these findings in artistic and real-world contexts.

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Bresin, R. (2005). What is the color of that music performance?. In ICMC.

APPENDICES

a)

Bresin, R. What is the color of that music performance?

Studies on synesthetic experiences related to music perception have reported non-consistent associations between music events and colors (Hubbard & Ramachandran, 2005). This study investigates whether these differences can be explained in terms of the expressive content of music performances and whether color can serve as an indicator of expressivity in music performance. This research is part of a larger project, Feedback-learning of Musical Expressivity (Fee-Me), aimed at developing a computer system for teaching students to play expressively. An essential component of this system is a tool for the automatic extraction of acoustic cues crucial for analyzing performance expression. These cues include duration, sound level, articulation, and vibrato. For example, staccato articulation might be typical of a happy performance, while legato articulation could be characteristic of a tender performance. This tool was previously presented at ICMC 2002 in Gothenburg (Friberg et al., 2002).

Method

An experiment was designed to test how subjects associated different emotionally expressive performances with various colors. Performances of two melodies were used: Brahms' 1st theme of the Poco Allegretto 3rd movement Symphony Op.90 No.3 in C minor, and Haydn's theme from the first movement of Quartet in F major for strings, Op. 74 No. 2. In a prior experiment, these melodies were performed with piano, guitar, and saxophone by nine professional musicians, three for each instrument. The musicians performed the two melodies with twelve different emotional intentions: happiness, love, contentment, pride, curiosity, indifference, sadness, fear, shame, anger, jealousy, and disgust. A listening test asked subjects to rate these performances regarding their emotional character. The performances with the highest ratings for each instrument and each emotion were chosen for the current experiment, resulting in 72 performances. (Bresin, 2005)

Colors

Colors were rated using the Hue Saturation Brightness (HSB) scheme, including red, orange, yellow, green, cyan, blue, violet, and magenta, and their bright and dark versions, totaling 24 colors. Low saturation and brightness were coded as 50%, while high saturation and brightness were coded as 100%. The computer screens were calibrated to a luminance of about 90 cd/m^2. (Bresin, 2005)

Subjects and Procedure

Two groups of subjects participated in the experiment. Group 1 consisted of eleven psychology students, while Group 2 comprised researchers and students of speech and music acoustics. Subjects rated how well different colors fit a particular music performance using a computer program, COLORANCE (COLOR and performANCE perception test), which presented 8 colors at a time. Subjects rated each of the 72 performances using the color palettes shown on the screen. Each performance was rated with sliders on a scale from 0 to 10, and colors could be hidden if not suitable. (Bresin, 2005)

Results

The emotional intention of the performances significantly affected the listeners' ratings of hue, saturation, and brightness. There were significant correlations between brightness and expressive performances with love, pride, tenderness, contentment, sadness, and fear. Anger and shame correlated with saturation, while disgust correlated with hue. Detailed analysis showed that dark colors were preferred for minor tonalities and light colors for major tonalities. Additionally, saxophone and guitar had similar color profiles, while piano differed due to its lack of timbre control features like attack time and vibrato, essential for communicating emotions. (Bresin, 2005)

b)

Main: Yellow
Secondary: blue - red

Main: Yellow
Secondary: green

Main: white

Main: purple

Main: blue

Main: Yellow - red
Secondary: purple

Main: blue – black
Secondary: green – red
Third: yellow

Main: Yellow – blue

Main: red
Secondary: blue – yellow

Main: Yellow
Secondary: purple - blue

Main: Yellow – green

Main: bright orange transform to dark brown

Main: Yellow – red – green
Secondary: blue

Main: purple
Secondary: red - blue – yellow

Main: purple- Yellow – red

Main: orange- red
Secondary: yellow

Calculation of the colors used in violin, image by the author

Main: Yellow
Secondary: blue, black
Third: red, purple

Main: red

Main: brown

Main: blue

Main: red

Main: blue
Secondary: green

Main: blue
Secondary: yellow

Main: blue

Main: blue
Secondary: purple

Main: Yellow – purple

Main: Yellow

Main: black and white, green

Main: blue

Main: red – blue - purple

Main: blue
Secondary: red – yellow

Main: blue – Yellow
Secondary: green

Calculation of the colors used in piano, image by the author

Main: red - yellow

Main: yellow

Main: yellow

Main: grey

Main: blue

Main: black
Secondary: blue, purple

Main: blue
Secondary: red, green

Main: red - yellow

Main: red – yellow
Secondary: blue - green

Main: yellow
Secondary: purple – green

Main: red

Main: red - yellow

Main: yellow
Secondary: red

Main: red - blue
Secondary: purple

Main: red - yellow
Secondary: green

Main: red
Secondary: yellow, purple, blue

Calculation of the colors used in trombone, image by the author