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Article

Biomechanical insights into the regulatory effect of light on residents' emotions and physiological rhythms in human living environment

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Abstract: In the field of modern biomedical science, biomechanics focuses on the mechanical properties and interactions of molecules, cells, tissues, and organs, which is crucial for a deeper understanding of how the human body perceives and adapts to changes in the external environment. As an important environmental factor, light's impact on the human body not only involves psychological and physiological aspects, but is also closely related to biomechanical mechanisms. Therefore, this study aims to explore the regulatory effects of light on residents' emotions and physiological rhythms from a biomechanical perspective, providing a new perspective for revealing the mysteries of the interaction between light and the human body. By measuring physiological parameters such as heart rate, respiration, and skin conductance response, investigate whether there is a certain resonance between exposure to light of different wavelengths (red, green, blue) or color temperatures (3000 K, 6000 K) and hearing. The results indicate that auditory or visual environmental stimuli can indeed cause changes in human physiological parameters and emotions; The dynamic lighting environment has a stronger impact on emotional perception; Revealed the feasibility of using physiological parameters as the basis for acousto-optic fusion perception and judgment. Understanding the relationship between color and psychology is crucial for creating a living environment that meets people's psychological needs. Finally, summarize the principles of human living environment lighting design based on color psychology, providing guidance for future design practices. This study reveals the intrinsic relationship between light and human biomechanical response by measuring a series of biomechanical related indicators, providing scientific basis for optimizing human living environment design.

Keywords: biomechanics; light; physiological rhythms; living environment; resident emotions

1. Introduction

In the lighting design of living environments, the appropriate use of red can create a lively and joyful atmosphere, attract people's attention, and increase the vitality of the living environment. On the contrary, blue gives people a sense of calmness and tranquility, which helps to relieve tension and promote physical and mental relaxation. In the lighting design of leisure places such as parks and squares, using blue toned lights can create a peaceful and comfortable environment, allowing people to find a peaceful world in busy urban life. Besides red and blue, other colors also have their own unique psychological effects. For example, yellow can stimulate people's optimism and creativity, while green has the effect of soothing nerves and reducing stress. In residential lighting design, designers can choose appropriate colors to create the corresponding atmosphere based on specific scenes and needs. Reasonable application of color psychology principles is crucial in the lighting design of human living environments. Designers need to have a deep understanding of the relationship between color and psychology, and choose appropriate colors for lighting design based on people's psychological needs and behavioral habits. Scientific color matching and application can create lighting environments that meet both visual aesthetics and people's psychological needs, adding more charm and vitality to the living environment.

A persistent question in cognitive neuroscience is how the physical properties of the world are represented in the brain, leading to conscious perception. Among the five human senses—vision, hearing, touch, taste, and smell—vision is the one most relied upon by people. In fact, over 87% of the information humans obtain from their environment or objects comes through vision, with approximately 70%–80% of this being acquired through color. This highlights the importance of color perception for humans, as we are psychologically and physiologically affected by our surrounding color environment. Therefore, using appropriate color adjustments in work or daily life can improve efficiency and alleviate fatigue [1]. In recent years, the symbolic meanings and therapeutic uses of certain colors have been extensively studied, and many doctors, psychologists, and neurologists have demonstrated the importance of color in life [2].

1.1. Research background and significance

The psychological suggestion effect of color in human living environment lighting is one of its most significant features. Color can directly affect people's psychological feelings, thus creating different atmospheres. For example, in the lighting design of commercial areas, warm toned lights such as orange, yellow, etc. are often used because these colors can create a warm and enthusiastic atmosphere, attract customers to stop and stay, and increase the activity of commercial activities. In leisure places such as parks and squares, cool toned lights such as blue and green are more common because these colors can create a peaceful and comfortable atmosphere, help people relax and enjoy leisure time. However, some studies indicate that while color can affect one's own emotions, one's current emotions do not affect the usual identification of colors [3]. Recent research on the emotional perception of color is shown in **Table 1** and **Figure 1**.

Table 1. Affective perception representation of color.

Colors	Color Emotions
Red	Excitement, Anger, Aggression, Speed, Danger, Aggression, Love, Anger, Passion, Courage.
Blue	Pleasure, comfort, calm, relaxation, sadness, trust, safety, coldness, joy, happiness
Green	Forest, safety, hope, indifference, calm, relaxation, happiness, balance, nature, freshness
Yellow	Cheerful, hopeful, optimistic, pleasant, warm, happy.
White	Youth, pleasure, innocence, peace, hope, purity, simplicity, and cleanliness.
Black	Sadness, depression, fear, severity, anger, death, mourning, powerful, formal, mysterious, modern.
Gray	Loneliness, sadness, depression, boredom, fatigue, anger, fear, confusion, and bad weather.

In the design of human living environment lighting, the design concept of people-oriented should always be adhered to. This means a deep understanding and attention to people's psychological needs and behavioral habits, as well as how color affects these needs and behaviors. For example, in the design of residential areas, the needs of residents for a comfortable and peaceful environment should be fully considered, and soft and warm colors such as light blue, light yellow, etc. should be used to create a pleasant living environment. In the design of commercial streets, bright and lively colors such as bright red and orange can be used to attract customers and stimulate consumption, creating a vibrant and attractive atmosphere.

The dosage of specific spectra in the light environment and the duration of exposure can affect a person's circadian rhythm and psychological health. For example, studies have found that prolonged exposure to blue-light-enriched environments at night can lead to circadian rhythm disorders [4]. Conversely, the right spectral light environment can have a positive effect on reducing stress, anxiety, and improving mood. Numerous clinical trials have shown that bright-light therapy has a significant therapeutic effect on seasonal affective disorder (SAD) [5]. Additionally, there is evidence suggesting that bright-light therapy has a positive therapeutic effect on non-seasonal depression (chronic depression, prenatal depression, and bipolar disorder) [6].

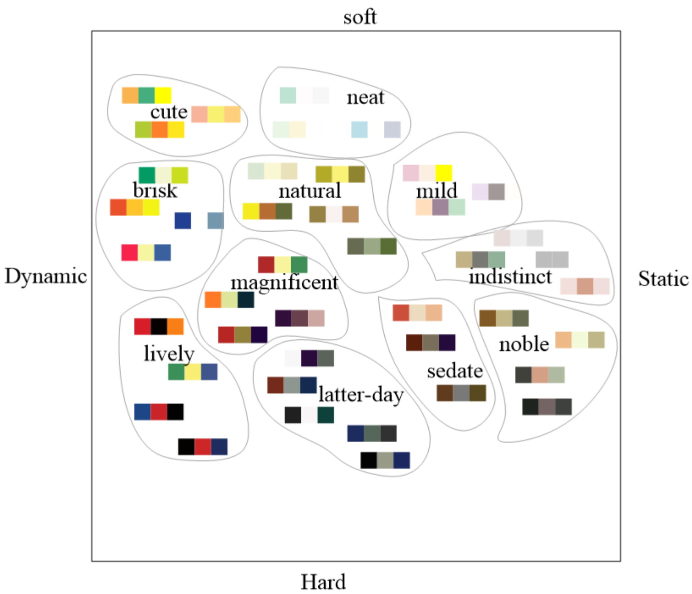


Figure 1. Emotions-color 2D map.

The creation of rural landscapes should start from improving the architectural style, enhancing the level of greening, and creating public spaces. It is necessary to improve the overall quality of rural building facades and carry out overall restoration and improvement of some endangered buildings; Attention should be paid to the level of rural greening, improving the overall quality of rural greening, and creating distinctive rural landscapes; In terms of creating public spaces, we should actively explore the long-term abandoned public spaces and some buildings within the village. Through consultation and communication with local residents, and on the basis of fully respecting their opinions, we can turn them into cultural squares that conform to the local cultural atmosphere, so as to facilitate local villagers' leisure and recreation.

1.2. The impact of lighting environments on the human body

The widespread adoption of LEDs and the development of lighting control technology have led to the emergence of colored lights such as red, blue, and green. Colorful lighting often attracts more attention and provides a wider range of psychological and physiological effects. As reported in recent literature, the impact of lighting goes beyond the comfort and safety of rural living environments. Light level and environmental color seem to have different effects on perceptual and physiological parameters [7]. In current research, lighting conditions and lighting levels interact with objective and subjective parameters [8]. In the field of modern biomedical science, biomechanics focuses on the mechanical properties and interactions of molecules, cells, tissues, and organs, which is crucial for a deeper understanding of how the human body perceives and adapts to changes in the external environment. As an important environmental factor, light's impact on the human body not only involves psychological and physiological aspects, but is also closely related to biomechanical mechanisms. Therefore, this study aims to explore the regulatory effects of light on residents' emotions and physiological rhythms from a biomechanical perspective, providing a new perspective for revealing the mysteries of the interaction between light and the human body. In human living environments, light is not only a source of visual information, but its physical properties can also affect the structure and function of the human body through biomechanical pathways. The wavelength, intensity, and color of light may alter the mechanical stimuli received by human tissues and cells, thereby affecting the physiological and psychological state of the human body. However, there is currently relatively little research on how light regulates residents' emotions and physiological rhythms at the biomechanical level. This study aims to fill this gap.

1.2.1. Current status of research abroad

Christian Cajochen and colleagues from the University of Basel in Switzerland conducted an experiment to detect changes in various physiological parameters such as heart rate, body temperature, and melatonin levels by exposing human subjects to light of different wavelengths in rural living environments. The results indicate that human body temperature is more sensitive to light with a wavelength of 460 nm and can rapidly increase body temperature; Other wavelengths have no effect on body temperature. Similarly, light with a wavelength of 460 nm has a greater impact on heart rate, significantly increasing it after 1.5 h of exposure, while other wavelengths have no significant effect [9].

Tsutsumi attempted to measure the effects of fluorescent lamps with different rural living environment color temperatures in the bedroom on heart rate variability and blood pressure. The results showed that compared with fluorescent lamps with color temperatures of 3000 K and 5000 K, the light source with a color temperature of 6700 K had a more significant impact on these two physiological parameters [10].

Aseel Al Ayash and colleagues manipulated six colors of rural living environment (bright red, bright blue, bright yellow, light red, light blue, and light yellow) in a simulated research environment to determine their effects on college students' academic performance, emotions, and heart rate. Assuming that different colors of rural living environments can affect students' learning, physiological, and emotional states. The results showed that although participants felt more relaxed, calm, and happy in light colored environments, their reading scores were significantly higher in light colored environments. In addition, the results indicate that regardless of whiteness, color tone significantly affects participants' emotions; Compared to other colors, blue enhances a sense of relaxation and calmness.

Watchara Sroykham conducted a study on five participants, measuring their arterial oxygen saturation (SpO_2), pulse rate, and quantitative electroencephalography (QEEG) for five minutes under six different colors (white, blue, green, yellow, red, black) in rural living environments. Then, the participants completed an emotional questionnaire. The results showed that compared to blue, green, white, and black, red and yellow had higher high beta wave brain activity in the lower frontal and temporal lobes. Red has a significant impact on anger ($F = 4.966$, $p = 0.002$) and confusion ($F = 3.853$, $p = 0.008$). Both red and green have a high impact on vitality. Green has no effect on depression. Blue has a moderate impact on orientation disorders, tension, and fatigue. White and black have a relatively small impact on any emotion, while black has no effect on vitality. In addition, there was no significant change in pulse rate and blood oxygen saturation for each color [11].

Giorgia Chinazzo analyzed the effect of sunlight passing through different color filters on people's thermal acceptance and found that at an ambient temperature of 24 °C, people's thermal acceptance is affected by the color of sunlight. Orange sunlight can lead to a deterioration of environmental thermal acceptability, while neutral colors are the most comfortable [12].

1.2.2. Current status of domestic research

Lin Yandan and his colleagues from Fudan University conducted a comprehensive analysis of the current research status of phototherapy in controlling bipolar disorder, emotional disorders, and other related diseases. The results showed that the dose-response of different treatment durations, illumination levels, and durations varied depending on the type and individual characteristics of emotional disorders. Compared to drug therapy, phototherapy is easier to control and has fewer side effects. In addition, it provides an alternative therapy for emotional disorders, significantly alleviating symptoms. At present, the non visual effects of light indicate that short wave blue light, especially blue light around 480 nm, stimulates 5-HT neurons through ipRGCs, affects neurotransmitter secretion, and thus affects the prefrontal cortex, striatum, and amygdala, thereby affecting emotions [13].

Hao Luo and his colleagues from Tongji University reviewed the history of research on healthy lighting for rural living environments, analyzed the basic elements of people-oriented lighting, summarized the biological safety issues and treatment effects of light, and proposed future directions for research, design, and application of healthy lighting for rural living environments. They also predicted the inevitable trend of cutting-edge science and evidence-based design in the field of photon health in rural living environments. This article provides a comprehensive review of healthy lighting in rural living environments. This indicates that the interaction and influence between vision, visual tasks, and rural living environment are the core of human factor lighting.

Light usually affects people's emotions and circadian rhythms, and an appropriate light environment can even have a therapeutic effect. By integrating light from different dimensions, a healthy lighting environment can be created. With the deepening of research on light, emotions, and circadian rhythms, the therapeutic effects of light will become a new approach and direction for future research on light and health [14].

As an important foundation of lighting, the color of light has been widely studied and applied. Various studies have shown that different light colors have different physiological and psychological effects in various rural living environments. Properly adjusting and combining light colors or gradient frequencies can improve circadian health, affect emotions, soothe emotions, and provide a certain degree of adjuvant therapy [15].

We will study from the perspective of biomechanics how light affects the mechanical properties of the human musculoskeletal system, the mechanical microenvironment of cells, and the mechanical balance of physiological systems. This will reveal the regulatory mechanism of light on residents' emotions and physiological rhythms, providing a scientific basis based on biomechanical principles for lighting design in human living environments

1.3. The impact of audio-visual synesthesia on the human body

There is a strong cross modal matching between music and color, regulated by emotional associations [16]. Researchers are attempting to identify the systematic connection between music and color. Perhaps the most direct connection comes from the fascinating phenomenon of color synesthesia in music. A small group of people, including some famous artists and musicians, have different cross modal color experiences when hearing music sounds. Scientific research initially failed to establish a universal connection because the sound color mapping in synesthesia seemed very specific. The current research results indicate a clear and strong connection between music and color, which is widely present in rural living environments [17].

1.3.1. Current status of research abroad

Kosuke Itoh and colleagues pointed out that there are two forms of tone-induced color synesthesia: pitch height-color synesthesia and pitch category-color synesthesia, with pitch height-color synaesthesia being a well-known cross-modal link between pitch and brightness-luminance. By studying the reaction times of 10 participants to 10 tonal color pairs, they investigated whether audio-visual synesthesia occurs automatically. The study confirmed the consistency of pitch-color sensation over time, even when unnecessary, thus verifying the authenticity of pitch category-color synesthesia. Multiple objective criteria established pitch category-color synesthesia as a new form of true synesthesia [18].

Mark Reybrouck indicates that the formation of musical meaning arises from the mediation of cognitive events through sensorimotor interactions with the physical world, which may be multimodal. Adding the visual modality to the auditory modality allows listeners to become aware of previously hidden auditory information, thereby altering their perceptual experience. Using similar terminology to explain synesthesia challenges the popular view that music-color synesthesia is a form of cross-sensory imagery with a neurological origin [19].

Kelly L. Whiteford and colleagues studied the relationship between 37 colors and 34 musical genres by playing each music clip for 15 seconds and then selecting appropriate and inappropriate colors. They conducted emotional preference scales for each color and each piece of music, ultimately finding systematic associations between the perceptual features of the music and the selected best/worst colors (for example, loud, powerful, distorted music is usually associated with darker, redder, more saturated colors). However, these associations are also consistent with emotional regulation, such as exciting music being related to seemingly exciting colors [20].

1.3.2. Current status of domestic research

Wang Jingmei and colleagues found through brain wave monitoring under musical stimulation that different music has a significant impact on emotions, which is closely related to the EEG activity of the frontal lobe, temporal lobe, and parietal lobe, with changes in brain waves more concentrated in the frontal region. The effects of different types of music on emotions vary, and the brain's responses are also different [21].

Lu Wei and colleagues investigated the impact of audio-visual synesthesia on emotions and found that using self-report analysis methods and quantitative EEG techniques can accurately determine emotional changes. The results showed that major scale, palace mode music, and green lighting environments can trigger positive emotions, while minor scale, feather mode music, and red lighting environments can trigger negative emotions. When music and lighting dual environmental factors simultaneously stimulate emotions, they have an interactive effect. Positive correlations strengthen the influence of dual environmental factors on emotions, while negative correlations weaken it. The findings indicate that self-report analysis methods and EEG can accurately describe the triggering and fluctuation of people's emotions, and the valence-arousal two-dimensional framework is very clear and straightforward for constructing and expressing emotions [22].

1.4. Purpose and innovation of the paper

In short, both lighting and music can evoke emotions, and the appropriate combination of lighting colors and music tones can produce similar emotional effects. There seems to be some physiological connection between light color and music. In order to explore the combined effects of lighting color and music on emotions in rural landscape living environments, this paper uses a quantitative valence awakening framework and physiological parameter measurements to study the synesthesia between lighting color and music in rural landscape living environments. The valence awakening framework can represent emotional differences through visual data analysis charts. Usually, physiological parameters such as heart rate, skin conductance response, and respiratory rate can effectively quantify emotional responses.

This study is based on the profound achievements of sensory synesthesia research at home and abroad, as well as relatively complete research in the field of physiological parameter collection. Based on relevant research at home and abroad, a comparison was made between visual and auditory synesthesia, exploring how various combinations of lighting colors and music in rural landscape living environments can bring people a better sensory experience. The existing arguments only measure the psychological or physiological factors of rural landscape living environment lighting or audio-visual perception. Our research introduced cross modal matching of rural landscape living environment, conducted dual factor combination tests on lighting and music, and analyzed and discussed single factor and dual factor factors. By combining changes in physiological parameters with subjective scales, and based on the two-dimensional emotional coordinates formed by these parameters, we search for corresponding resonance points for each sensation. On this basis, we further explored the dynamic lighting and music matching of rural landscape living environment, attempting to find the best mode to combine the lighting environment of rural landscape living environment with music. This aims to provide theoretical support for future human centered intelligent sensing environments, with the hope that it can be applied to places with certain needs such as rural landscapes and living environments.

2. Methods of measuring emotional responses

People's perception of rural landscape living environment is based on visual and other sensory information, as their interaction with rural landscape living environment mainly relies on visual stimuli. However, they are not only necessary for sensory experience, but also essential for the processing and integration of specific experiences and knowledge. Perception essentially reflects the entire rural landscape living environment. Generally speaking, people's overall perception of objects goes through three main processes (see **Figure 2**):

1) Sensory registration, involving the discovery and perception of reliable information provided by rural landscape living environment;

2) Pattern recognition, which involves extracting feature information from the perceived rural landscape living environment and distinguishing between the whole and parts;

3) Perception processing, which synthesizes and analyzes previously obtained information to derive specific visual images of the perceived rural landscape living environment.

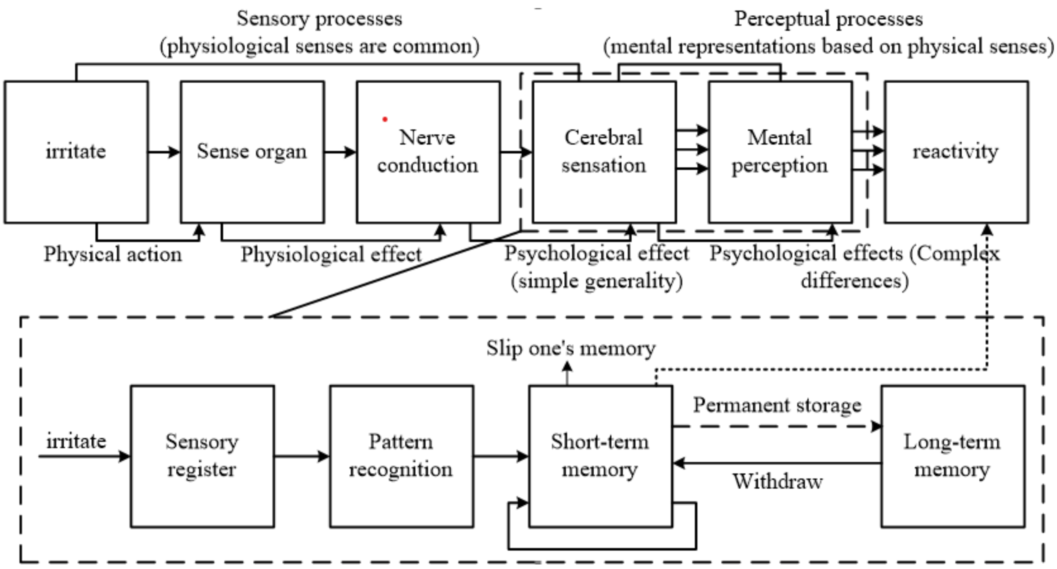


Figure 2. Sensation, perceptual processes, and perceptual models.

People mainly perceive and psychologically evaluate their rural landscape living environment through perception. In order to scientifically and accurately quantify the impact of light on human health in rural landscape living environments, this study improved the method of using only subjective or objective emotional measurements. By combining these two, it adopts a dual measurement of subjective evaluation and physiological parameters. This includes quantitative detection of heart rate, respiratory rate, and skin conductance response, as well as qualitative subjective emotion questionnaire surveys. Using the method of "simultaneous measurement and mutual verification of multiple methods", collect human performance data from multiple complex physiological and psychological processes in a rural landscape living environment with audio-visual integration.

2.1. Subjective measurement—Emotional assessment methods

Emotion is central to life. It occurs over relatively short periods and typically involves changes in motivational stances and three types of emotional responses: experience, expressiveness, and physiological arousal. In 1935, Hevner conducted experiments and constructed an emotion ring model with eight major categories of emotions, as shown in **Figure 3**. The eight categories include a total of 67 emotional adjectives, and adjacent pairs have mutually progressive emotional dimensions. This means that within this circular structure, adjacent emotional categories share similarities but differ in degree, thus achieving a smoother transition between the eight categories of emotions [23]. Subsequently, Hevner verified the accuracy of the emotion ring by asking participants to select their emotional responses from the ring while listening to Debussy's classic work "Reflets dans l'eau". The results showed that the emotional responses to the piece were mainly divided into two types: tender and lively.

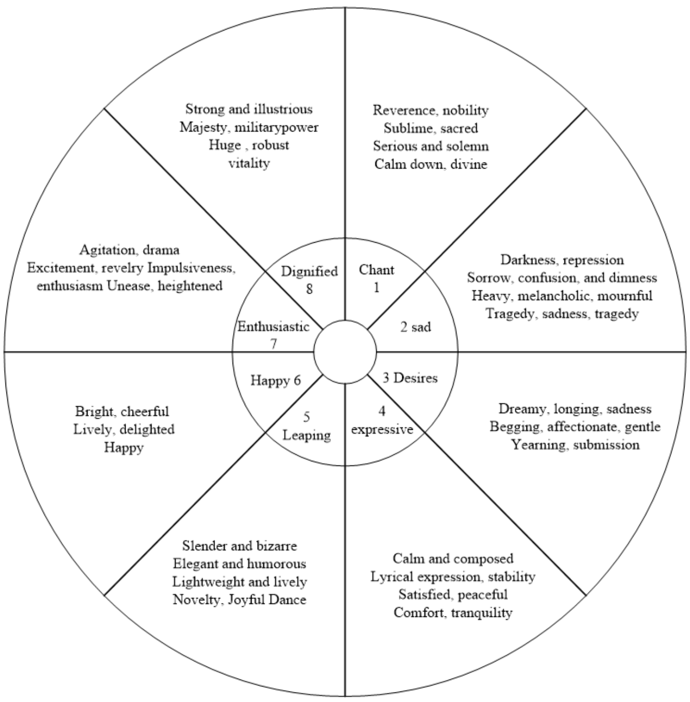


Figure 3. Henver emotional circle.

To associate the emotions of music with the colors of lighting, the study adopted a group of 5-dimensional emotional space adjectives based on Hevner's model [24], including sadness (encompassing depression, pain, loneliness, solitude), consolation (including laziness, recovery, warmth, nostalgia, lyrical), happiness (including joy, romance, freshness, sweetness, relaxation), bravery (including passion, atmosphere, inspiring), and excitement. Since mainstream music typically does not evoke overly exaggerated emotions such as fear or panic [25], the excitement option was changed to fear (including panic, terror, unease, tension) for the sake of completeness in triggering emotions through lighting [26]. The emotion survey record is shown in **Table 2**.

Table 2. Screenshot of subjective emotion record sheet.

Stimulus Variables	Fear	Sadness	Comfort	Happiness	Courage
	Panic	**Depression**	**Laziness**	**Joy**	**Passion**
	Terror	**Pain**	**Warmth**	**Romance**	**Ambiance**
	Panic	**Loneliness**	**Nostalgia**	**Freshness**	**Inspiration**
	Tension	**Solitude**	**Lyricism**	**Relaxation**	**Motivation**
Song 1	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5
Song 2	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5
Red Light	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5
Green Light	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5
Blue Light	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5
White Light (3000 K)	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5
White Light (6000 K)	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5	1-2-3-4-5

Emotions (such as happiness, sadness) are constructed from varying degrees of activation along core emotional dimensions, typically marked as arousal (i.e., energy continuum) and valence (i.e., pleasure/displeasure continuum) [27]. Emotional valence is divided into five discrete emotional scales from negative to positive, with each emotional degree ranging from weak to strong in five gradations marked as arousal levels. The emotional valence-arousal two-dimensional diagram used is shown in **Figure 4**.

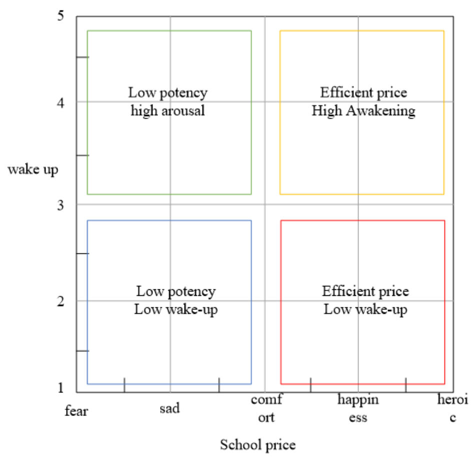


Figure 4. Emotional valence-arousal 2D map.

2.2. Objective measurement—Physiological signals

The body is the foundation and primary stage of emotions, being the direct or expressed sensory structure. Human sensitivity to biological signals plays an important role in many emotional theories. Emotions originate from both the central and peripheral nervous systems, and research results indicate that psychological signals are influenced by emotions. According to various survey results, a variety of signals occurring within the body will not fail to manifest, nor can emotions be concealed or buried, such that when physiological biosignals occur, the individual's psychological load space can accurately and precisely accommodate and analyze these biosignals [28]. These biosignals include changes in blood pressure, brain waves, heart rate, respiratory rate, skin conductance, etc. [29]. Therefore, the reception and perception of internal biosignals play a decisive role in many emotional theories.

2.2.1. Heart rate

Electrocardiogram (ECG) is a key objective technique that reflects human health, using graphical and numerical changes to display the cycle of each heartbeat. This cycle comes from the electrical signal changes detected by the electrocardiograph. Abnormal heart rate is associated with various arrhythmias, atrial enlargement, myocardial infarction, myocardial ischemia, and other diseases [30]. The heart is located in the left chest and is a three-dimensional structure that requires comprehensive detection of its activity patterns and features. We use electrode sensors placed in different areas around the heart. Based on the biological laws and responses of heartbeat, these sensors convert biological features into electrical signals. By analyzing the patterns of these electrical signals, we can determine the electrical activity of different aspects of the heart. The main indicator in this experiment is heart rate (HR), expressed in beats per minute (BPM), as it is a physiological indicator used to control feedback signals. Many studies have shown that whenever our bodies are exposed to various colors of light in rural landscapes and living environments, the indicators of the heart undergo significant changes. Under the influence of different intensities and colors of light in rural landscape living environments, the novelty brought by new stimuli will significantly affect the heart. In the quiet living environment of rural landscapes, the maximum value of cardiac time activity increases absolutely, raising the peak limit. The changes in these periodic activities and rhythmic factors show a clear correlation. The greater the fluctuation of these periodic activities, the stronger the physiological impact of rural landscape living environment sound and different shades of light on the heart. Based on these factors, we can analyze the intensity of non audiovisual effects on the human body under different audiovisual environments in rural landscape living environments. In order to record ECG, we used three medical standard silver electrodes and disposable gel. One is placed about 5 cm below the left lower rib of the abdomen. The second electrode is placed along the midline directly below the right clavicle. The third electrode is used for grounding and is located directly below the left clavicle. Form different wires between two electrodes or one electrode and the central potential terminal, and connect them to the positive and negative poles of the electrocardiograph galvanometer through wires to record cardiac electrical activity. Heart rate variability is a potential indicator of emotional valence.

2.2.2. Respiratory rate

From a biomedical perspective, respiratory rate (RESP) describes the number of normal breaths an organism takes in a minute. Breathing is accompanied by lung activity; Therefore, the rise and fall of the human chest represent a single respiratory cycle, including inhalation and exhalation. Research has found that respiratory rate can vary and is significantly influenced by various rural landscape and living environment stimuli. Changes in relaxation levels can be observed through respiratory rate: under relaxed conditions, respiratory rate slows down, while irregular rural landscape living environments can cause significant fluctuations in respiratory rate due to external stimuli. The stages of inhalation and exhalation for measuring respiratory rate. Due to the voluntary control of breathing by participants, we have decided to include this measurement and may use it as a direct strategy to influence heart rate (HR). In this study, respiratory rate was measured in units of minutes. The respiratory rate of participants is processed offline using software to automatically detect individual respiratory cycles, and then manually corrected to eliminate false positive and false negative cycles. The breathing belt is used to collect chest breathing records and is placed directly below the chest.

2.2.3. Skin conductance response

Skin electrical response (GSR) (measured in microsiemens); μ S) is a method of activating participants' sweat glands when triggering emotions, which can measure skin conductivity. When the phase response of participants exceeds the baseline conductance, a GSR peak occurs. Skin electrical activity (EDA), also known as the "electrical phenomenon on the skin," reflects the psychological state of the human body and affects the secretion of sweat. In this case, the skin undergoes autonomous changes. EDA measurement can be used to predict the emotional state of participants. Skin conductivity is significantly affected by internal emotional fluctuations. When experiencing stimulating emotions, sweat glands produce sweat, which is an effective conductor of electricity. The greater the emotional stimulation of an event, the more sweat is produced, thereby reducing the longitudinal resistance of the dermis and leading to greater changes in the electrical properties of the skin. EDA helps overcome three limitations: the difficulty of obtaining continuous measurements, the inability or unwillingness of participants to accurately report their emotions, and the inability to capture subconscious emotions. Skin conductance activity can indicate the level of arousal caused by emotional stimuli. Two disposable pre gel Ag/AgCl sensors placed on the protuberance of the fish and small fish edges of non dominant palms record the skin conductivity level.

The combination analysis of multiple physiological signals can improve the accuracy of capturing emotions. The researchers chose to combine electrocardiogram and EDG in their study of rural landscape living environment, achieving highly accurate recognition rates. In this study, changes in heart rate, respiratory rate, and skin conductance were used to characterize the non visual biological effects brought about by changes in the visual and auditory environment of rural landscape living environments. The data was recorded using the PhysioLab wireless human physiological data recording system from Germany's ERGENEERS. For heart rate measurement, the 3-lead method is used, with electrode placement as shown in **Figure**

5 and a sampling speed of 1000 Hz. Respiratory sensors are applied to the chest. The skin electrode is located on the surface of the palm. During physiological parameter monitoring, display continuous waveforms and parameter values. All data analysis in this study was conducted using SPSS version 25.0 (IBM, USA).

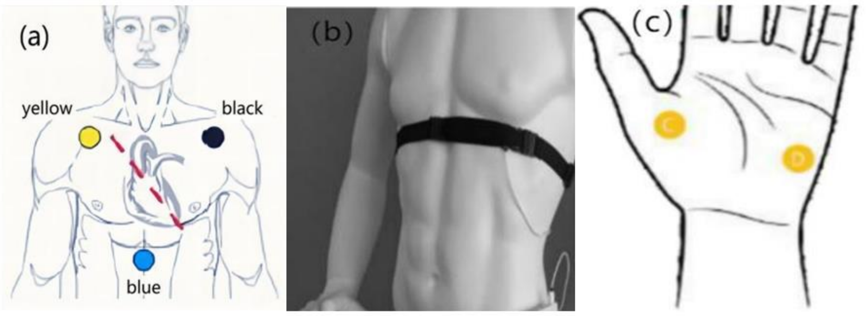


Figure 5. Physiological parameter collection method. **(a)** ECG; **(b)** RESP; **(c)** EDA.

2.2.4. Muscle tone measurement

To evaluate the effect of light on muscle tone, we used an advanced surface electromyography measurement system (brand and model). During the experiment, disposable Ag/AgCl surface electrodes were placed on the surfaces of muscle groups such as the frown muscle, zygomaticus major muscle, sternocleidomastoid muscle, trapezius muscle, deltoid muscle, biceps brachii, triceps brachii, quadriceps femoris muscle, and gastrocnemius muscle in accordance with international standards for muscle belly placement, in order to accurately record changes in muscle electrical activity under different light environments. Connect the electrode to the electromyography amplifier and set the sampling frequency to 50 Hz to ensure the capture of subtle changes in muscle electrical activity. Before each light stimulation, the subjects need to maintain a quiet and relaxed state for 30 min to obtain stable baseline data.

2.2.5. Measurement of joint range of motion

The measurement of joint range of motion adopts high-precision electronic angle measuring instruments (brand and model), with a measurement accuracy of ±0.1°. Before the experiment, strictly calibrate the measuring instrument to ensure the accuracy of the measurement data. The subjects performed flexion, extension, rotation, and other movements of the cervical joint, shoulder joint, elbow joint, wrist joint, hip joint, knee joint, and ankle joint in different lighting environments according to standardized movement procedures. For each joint, repeat measurements 20 times and take the average as the range of motion data for that joint in a specific lighting environment. At the same time, a motion capture system is used to record the full body joint movements of the subjects in three-dimensional space. Key joint parts of the subjects (such as the head, shoulders, elbows, wrists, hips, knees, ankles, etc.) are pasted with markers, and the motion trajectories of the markers are captured by multiple high-speed cameras arranged around the experimental space to obtain more comprehensive and accurate joint activity data, further analyzing the influence of light environment on joint motion coordination and flexibility.

2.2.6. Body posture stability measurement

This study uses an advanced force platform system (brand and model) to evaluate body posture stability. The platform uses high-precision piezoelectric sensors that can measure small displacement changes of the human center of gravity in both horizontal and vertical directions in real time, with a data acquisition frequency of 50 Hz. The subjects stood barefoot in the center of the force platform under different lighting conditions, maintaining a natural relaxed posture, with their eyes looking straight ahead, their arms naturally hanging down, and their feet spaced shoulder width apart. The subjects need to stand quietly on the platform for 10 min, during which the system automatically records the distribution of foot pressure and center of gravity displacement data. In order to further analyze the stability of dynamic posture, participants also need to complete a series of designated movement tasks, such as standing on one foot, standing with eyes closed, and standing still, to comprehensively evaluate the impact of light environment on body posture control. In addition, some participants wear wearable inertial measurement unit (IMU) devices (brand and model), which have built-in accelerometers, gyroscopes, and magnetometers. Through wireless transmission technology, real-time motion posture data of various parts of the body is transmitted to a computer for analysis. IMU devices are fixed on the subjects' torso (such as sternum and lumbar spine) and limbs (such as upper arm, forearm, thigh, and calf), continuously monitoring the acceleration, angular velocity, and angle changes of various parts of the body during daily activities and specific exercise tasks (such as walking, balance beam walking, climbing stairs, etc.), providing multidimensional data support for in-depth research on the influence of light environment on dynamic posture stability.

3. Subjective emotional perception in the acoustic-optical environment of static lighting

Some people may experience a feeling through another feeling; For example, seeing a color when hearing sound is a characteristic of 'strong synesthesia'. For most people, daily experiences involve simple cross sensory correspondences, such as associating specific tones with specific brightness, known as' weak synesthesia '. Research has shown that the color experience in strong synesthesia and the corresponding relationship in weak synesthesia in rural landscape living environments are related to potential emotions associated with music and color. In fact, rural landscapes, living environments, music, and colors are always associated with emotions. Generally speaking, positive emotions in rural landscape living environments are related to bright colors such as yellow, orange, green, and blue, while negative emotions are related to dark colors such as black, gray, and brown. The selection of music for certain rural landscapes and living environments can also ensure the elicitation of specific emotions.

3.1. Experimental objectives

Whether lighting helps evoke emotions in rural landscapes and living environments depends on whether the lighting matches the expected emotional tone of the music. It is only effective when the emotional connotations of light and music are consistent. Compare the different or similar effects of various lighting and music stimuli on human emotional perception through subjective emotional responses in rural landscape living environments. Different color temperatures or wavelengths of light stimulation in rural landscape living environments can trigger different valence arousal responses in emotions. In the context of audio-visual fusion, identifying which key of music in rural landscape living environment will trigger an emotional response similar to its corresponding lighting scene, thus achieving a coordinated audio-visual fusion effect. If the combination of the two can trigger stronger emotional responses than any single stimulus alone, this proves that rural landscape living environment audio-visual synesthesia is a feasible method.

3.2. Experimental parameter settings and spatial environment

This study selected three monochromatic LED light sources (red, green, blue) and white light of different color temperatures (3000 K, 6000 K) as the research subjects. To avoid the interaction between the wavelength and color of the lights, this study used a controllable color-changing light (Philips Smart Light Strip Hue) for the light color experiments. The illuminance at the human eye was uniformly set at 150 lx; studies have shown that even dim lighting can significantly affect the heart rate of young people. The Yuangfang HS-2000 photoelectric test system was used to measure the color temperature and spectral distribution of the light sources. The light source spectrum is shown in **Figure 6**.

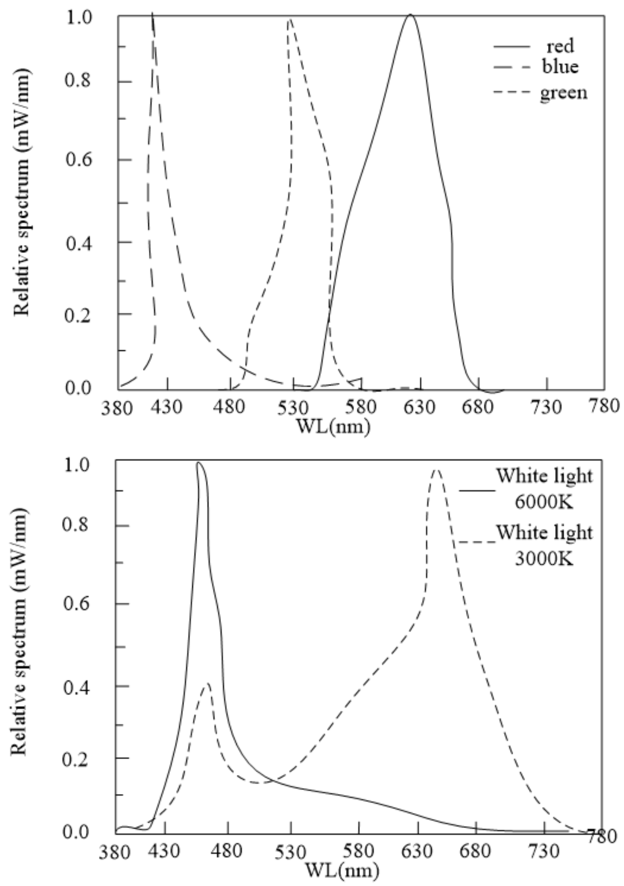


Figure 6. Spectra of five experimental lights.

Before the experiment, three major and three minor pieces of music were selected. In trials with only single-factor stimuli, both subjective emotional valence and arousal changes were analyzed simultaneously. From the major and minor selections, one piece each that caused the most significant emotional fluctuation and had the largest valence difference was chosen for matching with light colors. The selected major piece was Beethoven's Moonlight Sonata No. 2, and the minor piece was Beethoven's Moonlight Sonata No. 3. A 60-second segment from each piece was selected as the stimulus clip (the excerpts are shown in **Figure 7**). The decibel level of each piece of music was set to the same level.

Figure 7. Music in major and minor episodes for experiment.

In a darkroom, an experimental environment was set up. This darkroom could block noise, and its inner walls were coated with light-absorbing materials. The room temperature varied between 22~24Â °C, and the humidity remained relatively stable between 74%~78.5%. As shown in **Figure 8**, a 1.6 m × 2 m × 3 m experimental area was constructed. To prevent participants from directly looking at the light source and avoid potential afterimage effects, diffuse reflection of the pupil by a white platform was used for the pupillary light reflex experiment, enhancing the immersive atmosphere.

Figure 8. Lab environment.

3.3. Participant selection

20 undergraduate and graduate students (10 males and 10 females each) voluntarily participated in the experiment, aged between 20 and 27 years old (M = 22.7, SD = 1.78). All participants had no ear disorders and passed color blindness and color weakness tests. Before the experiment, each participant was informed of the complete experimental procedure. During the experiment, they were required to maintain regular and normal daily routines and minimize consumption of foods like tea and coffee that could affect blood pressure, heart rate, and physiological rhythms. The experiment was conducted from 13:00 to 18:00, ensuring that each participant was tested within a similar circadian rhythm cycle.

3.4. Experimental procedure

The experimental process is shown in **Figure 9**. After reading the information about the study and signing the consent form, participants were briefed on the experimental procedure and each filled out a background information questionnaire. Subsequently, participants were guided to wear Bluetooth noise-canceling headphones (Sony WH-H800) and adjust them for comfort. Before the experiment began, participants sat quietly in the baseline scenario for 5 min to calm their emotions. The experimental setup included the following seven environmental stimulus conditions:

1) Two single-factor music stimulus environments;
2) Five single-factor light color stimulus environments.

Each stimulus lasted for 1 min, followed by a 1-minute emotional recovery phase, during which participants filled out a subjective questionnaire. To avoid potential order effects, music or lighting modes were played randomly. The experiment lasted approximately 25 min.

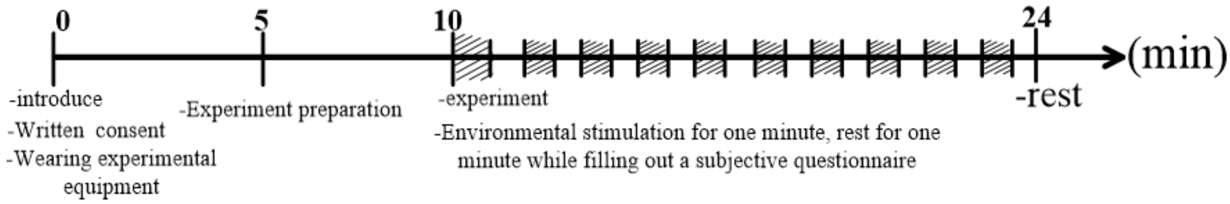


Figure 9. Overview of the experiment process.

First, the subjective evaluation values to be analyzed were subjected to a normality test. According to the Q-Q plot and histogram results, both valence and arousal values followed a normal distribution (P > 0.05). A one-way analysis of variance (ANOVA) was used for the significance analysis of the subjective evaluations of valence and arousal values, and the Least Significant Difference (LSD) method was employed for post-hoc multiple comparisons to determine whether the environmental stimulus factors used in the experiment had statistical significance in terms of emotion.

Emotion is a psychological experience that arises from the interaction between individual psychological states and environmental influences. The concepts of valence and arousal are explained based on specific motivational systems in the brain. The subjective evaluation data were subjected to a one-way ANOVA analysis, with the results shown in **Table 3** below. According to **Table 3**, the stimulus environments used in the experiment had statistical significance in both valence ($F = 7.419$, $P = 0.000$) and arousal ($F = 3.344$, $P = 0.004$).

Table 3. ANOVA results of single-factor environmental stimulus.

Subjective Dimensions	Sum of Squares	Degrees of Freedom	Mean Square	*F*	Significance
Valence	52.796	6	8.799	7.419	0.000***
Arousal	24.171	6	4.029	3.344	0.004**

Note: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

Furthermore, a Least-Significant Difference (LSD) post-hoc multiple comparison was conducted as shown in **Tables 4** and **5**. From **Table 4**, it can be seen that there is a significant difference in valence between major and minor music regarding the emotional perception of the participants. Since the volume of the music was set to the same level, these two factors did not show a significant difference in arousal.

Table 4. LSD results of music environmental stimulus.

Subjective Dimensions	Subjective Variable I	Subjective Variable J	Mean Difference (I-J)	Significance	95% Confidence Interval (Lower Bound)	95% Confidence Interval (Upper Bound)
Valence	Major Music	Minor Music	−0.800	0.022**	−0.148	−1.119
Arousal	Major Music	Minor Music	−0.550	0.115	−1.240	0.140

Note: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

As shown in **Table 5**, colored light and white light had a significantly different impact on the participants' emotions. For example, red light and cool white light showed a significant difference in valence ($P = 0.001$), while green light and warm white light showed a significant difference in arousal ($P = 0.003$).

Table 5. Comparison of significant differences in emotional potency and arousal under different light conditions.

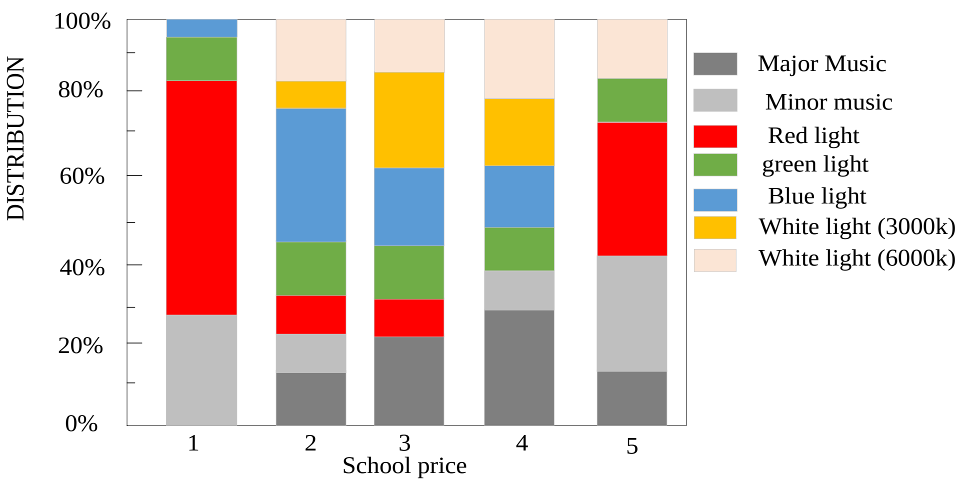
Subjective Dimensions	Subjective Variable I	Subjective Variable J	Mean Difference (I-J)	Significance	95% Confidence Interval (Lower Bound)	95% Confidence Interval (Upper Bound)
Valence	Red Light	Green Light	−1.125	0.065	−1.806	−0.444
		Blue Light	−0.525	0.130	−1.206	0.156
		Warm White Light	−1.175	0.001*	−1.856	−0.494
		Cool White Light	−1.150	0.001**	−1.831	−0.469
	Green Light	Blue Light	0.600	0.084	−0.081	1.281
		Warm White Light	−0.050	0.885	−0.731	0.631
		Cool White Light	−0.025	0.942	−0.706	0.656
	Blue Light	Warm White Light	−0.650	0.061	−1.331	0.031
		Cool White Light	−0.625	0.072	−1.306	0.056
	Warm White Light	Cool White Light	0.025	0.942	−0.656	0.706

Table 5. (*Continued*).

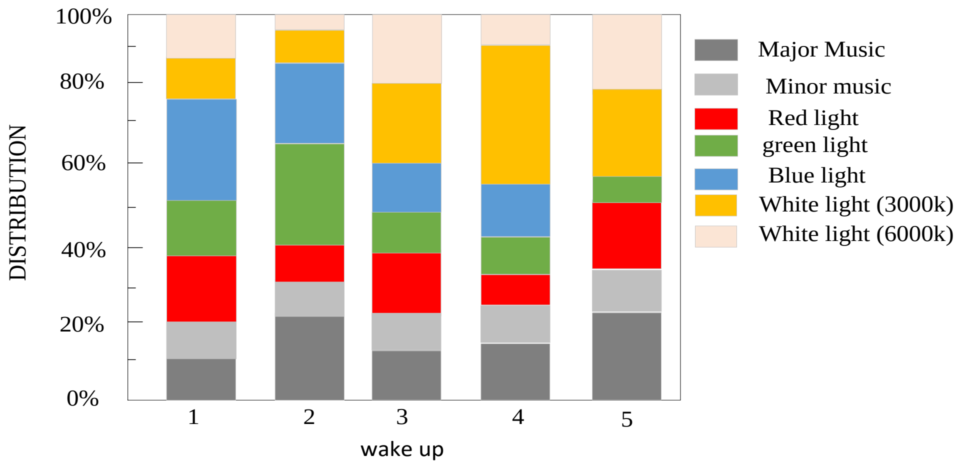
Subjective Dimensions	Subjective Variable I	Subjective Variable J	Mean Difference (I-J)	Significance	95% Confidence Interval (Lower Bound)	95% Confidence Interval (Upper Bound)
Arousal	Red Light	Green Light	0.550	0.115	−0.140	1.240
		Blue Light	0.450	0.197	−0.240	1.140
		Warm White Light	−0.500	0.152	−1.190	0.190
		Cool White Light	0.150	0.666	−0.540	0.840
	Green Light	Blue Light	−0.100	0.774	−0.790	0.590
		Warm White Light	−1.050	0.003**	−1.740	−0.360
		Cool White Light	−0.400	0.251	−1.090	0.290
	Blue Ligh	Warm White Light	−0.950	0.007*	−1.640	−0.260
		Cool White Light	0.300	0.389	−0.990	0.390
	Warm White Light	Cool White Light	0.650	0.063	−0.040	1.340

Note: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

A visual analysis of the participants' subjective evaluations is shown in **Figure 10**. After creating this color distribution, we studied the relationship between colors and emotional words. The red light was most commonly chosen as the most negative emotion (fear); however, the emotions caused by minor music were also negative, with minor music scoring the highest in negative valence. Cold-toned white light and blue light made people feel lonely, while a warm white light environment produced feelings of laziness. Major music generally gave rise to positive feelings. In terms of arousal, energy arousal under white light was stronger than that under colored light, with major music scoring the highest in arousal. It can be concluded that the pattern combining major music with warm white light most easily elicits emotional fluctuations in people.



(a)



(b)

Figure 10. Color distribution according to **(a)** valence and **(b)** arousal.

For each single-factor stimulus environment, standardized for each single-factor stimulus environment, standardized scores were calculated by taking standardized valence and arousal scores were calculated by taking the mean value divided by the standard deviation. The two-dimensional coordinates of different stimulus environments are shown in **Figure 11**. The figure indicates that the ratings of the seven single-factor environments effectively cover the dimension of valence but all fall within the low arousal range. We used environments with similar levels of arousal but varied in valence for our experiments to study whether the combination of environmental stimuli with different emotional states at similar levels of arousal could increase or decrease emotional arousal. Minor music is located in the low valence area, while major music is in the high valence area, indicating that musical valence is significantly influenced by the mode, and different modes of music have distinct emotional labels. The emotional labels for different light colors also show significant differences: the three primary colors tend towards low valence, while white light tends towards high valence. At the same level of illuminance, compared to the three primary colors, white light feels brighter and generates more positive emotions; red light is located in the low valence, low arousal region, which may be due to the experimental setting where the red light has a low illuminance level and high saturation, making it easier to induce negative emotions. Studies have shown that both major music and green light can produce positive emotional effects, while minor music and red light can produce negative emotional effects.

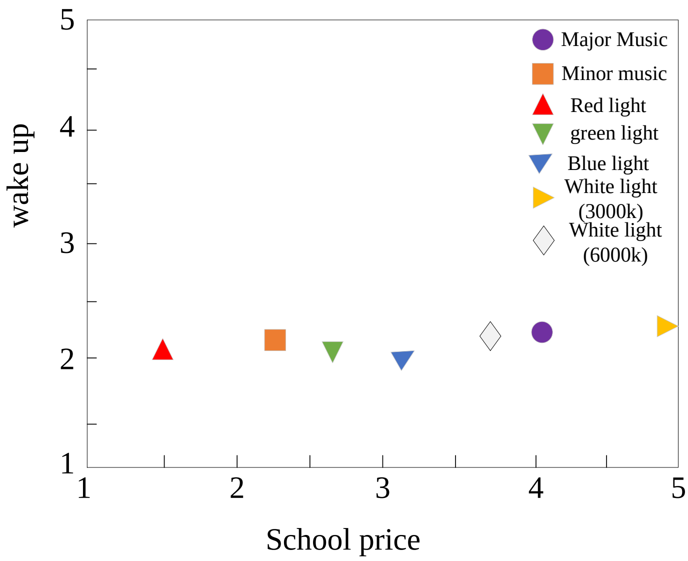


Figure 11. Two-dimensional graph of emotional valence-arousal.

The changes in muscle tone are closely related to emotional expression and body posture adjustment. By measuring the fluctuations in muscle tone under different light environments, we can reveal from a biomechanical perspective how light affects human emotional perception and stress response. The range of joint movement and body posture stability reflect the human body's ability to control movement and balance regulation in different environments. Changes in these indicators may affect the functional status of the neuromuscular system, which in turn is interrelated with the regulation of emotions and physiological rhythms. The analysis of skeletal stress helps us understand the potential impact of changes in light environment on the long-term adaptability of the skeletal system, and explores the deep relationship between light and human structure and function from a biomechanical perspective, providing key information for a comprehensive analysis of the mechanism of light's impact on residents' health.

4. Results and discussion

During exposure to red light, the average electromyographic amplitude of the neck extensor muscles of the subjects increased by 11% compared to the white light (3000 K) environment, indicating that red light may lead to an increase in neck muscle tension. At the same time, the maximum force output of the knee joint during flexion and extension was reduced by 27 N in blue light environment compared to green light environment, indicating that blue light may affect the power generation characteristics of lower limb muscles.

This article delves into the application of color psychology in rural living environment lighting design, proposing design principles such as people-oriented, coordinated and unified, and combining functionality and artistry. The effectiveness of these principles is verified through experiments. With the continuous advancement of technology and the increasing improvement of people's aesthetic concepts, rural living environment lighting design will pay more attention to meeting people's psychological needs and emotional experiences. Looking forward to further research and application of color psychology theory, combining science and art to continuously improve the quality of rural living environment lighting design, and create a more comfortable, harmonious, and beautiful lighting environment for residents and tourists.

In terms of muscle tone measurement, we found that when subjects were exposed to a red light environment, the sEMG signal amplitude of the frown muscle significantly increased, indicating an increase in muscle tone, which may be related to emotional arousal caused by red light; In a blue light environment, the muscle hardness value of the trapezius muscle significantly decreases, indicating an increase in muscle relaxation, which is consistent with the soothing effect of blue light. The measurement results of joint range of motion showed that under green light stimulation, the range of flexion and extension of the knee joint increased compared to white light (3000 K) environment. At the same time, motion capture data showed that the smoothness and coordination of joint motion were also improved, which may suggest a positive impact of green light on the human motion system. The results of the power platform test indicate that there are significant differences in the stability of the subjects' body posture under different light environments. In a yellow light environment, the length and area of the subject's center of gravity shaking trajectory significantly decreased, and the offset of the pressure center on the soles of the feet decreased, indicating enhanced posture stability, which may be related to the positive emotional stimulation of the human body by yellow light, thereby affecting the body's balance control ability. From the analysis of skeletal stress, the finite element simulation results show that under bright white light (6000 K) environment, the stress distribution in the proximal femur changes, and the stress concentration in some areas increases. This may be related to the influence of light environment on human posture and muscle exertion, which in turn affects the skeletal mechanics environment and may have a long-term impact on bone health.

We observed a positive correlation between increased muscle tone and elevated heart rate, which may be due to the increased metabolic demands of the body during muscle tension. The heart needs to pump more blood to meet the energy needs of the muscles, leading to an increase in heart rate. At the same time, there is a certain correlation between changes in joint range of motion and respiratory rate. In the case of limited joint motion, breathing may be affected to a certain extent, which may be due to restricted body posture and movement affecting the normal movement of the chest, thereby regulating respiratory rate. The relationship between skin conductance response and body posture stability suggests that when posture stability decreases, the body's stress response may increase, leading to an increase in skin conductance. This further illustrates the important role of biomechanical factors in emotional and physiological regulation.

Subjective surveys indicate that each individual's response to external stimuli is specific and unique. According to the two-dimensional emotion valence-arousal chart, major music and minor music have opposite values on the valence coordinate, indicating that musical valence is significantly influenced by the mode. In terms of color, under low illumination, the primary colors red, green, and blue tend towards negative emotions, while two different color temperatures of white light tend towards positive emotions. Red light tends towards the most negative valence, which is related to Chinese people's preference for using red in horror scenes and warning signs, making it more likely to be associated with negative emotions such as fear, tension, and warning. The application of colors in different scenarios directly affects personal behavior as well as psychological and physiological responses. The emotional valence of cool white light tends towards the positive, presumably because the shorter wavelength of cool light may enhance a person's perception of an environment and intensify their emotions. The experimental darkroom was always under dim incandescent lighting; when suddenly illuminated by bright cold light, it enhanced the test subjects' yearning for the cool light.

From the perspective of muscle biomechanics, changes in muscle tone caused by changes in light environment may be achieved by affecting signal transmission at neuromuscular junctions. Light of different wavelengths or color temperatures may stimulate retinal cells, alter the excitability of motor neurons through nerve conduction, and thereby regulate the contraction and relaxation state of muscles. The changes in muscle tone not only affect body posture and athletic performance, but may also affect the emotional regulation areas of the brain through proprioceptive feedback, thereby regulating emotional states. In terms of joint mobility, the impact of light on joint flexibility and stability may be related to changes in the mechanical properties of soft tissues surrounding the joint, such as ligaments and tendons. Light stimulation may alter the viscoelasticity of soft tissues, affecting their constraint and support on joints, thereby affecting joint range of motion and body posture stability. This change in the biomechanical state of joints may affect the control of the nervous system over body posture and movement through signal transmission from joint receptors, interacting with the regulation of emotions and physiological rhythms. For the analysis results of bone stress, changes in bone stress and strain caused by light environment may trigger the mechanosensitive signaling pathway of bone cells, affecting bone metabolism processes such as the balance of activity between osteoblasts and osteoclasts. Long term changes in the light environment may lead to adaptive changes in bone structure and strength, which are not only important for bone health, but may also indirectly regulate emotions and physiological rhythms by affecting the body's mechanical support and exercise ability.

Understanding the impact of light on the biomechanical mechanisms of the human body has important physiological significance. In daily life, reasonable light environment design can optimize muscle function, improve joint flexibility and stability according to the biomechanical needs of the human body, reduce physical discomfort caused by poor posture and muscle fatigue, and thus improve the quality of life of residents. In the professional environment, considering the impact of light on biomechanics, suitable lighting environments can be designed for people engaged in specific jobs (such as long-term sitting work, fine operation work, etc.) to reduce the risk of musculoskeletal diseases and improve work efficiency. For residential environment design, we can choose appropriate light colors and lighting intensities based on the functional requirements of different rooms (such as bedrooms, living rooms, study rooms, etc.), combined with the biomechanical characteristics of the human body in different activity states, to create a lighting environment that not only conforms to visual aesthetics but also benefits human physical and mental health. For example, using soft blue or warm white light in the bedroom can help relax muscles, stabilize emotions, and promote sleep; In the living room or activity area, appropriately increasing the application of bright white or colored light can improve the vitality and alertness of the body, and enhance the enthusiasm for social interaction.

In places such as bedrooms that require relaxation, blue or green light should be prioritized to reduce muscle tension, optimize joint mobility, and promote body relaxation and comfort. In the workplace or areas that require increased alertness, the proportion of red light can be appropriately increased, but attention should be paid to avoiding excessive muscle tension and fatigue. At the same time, lighting design should consider the differences in biomechanical characteristics of different populations, such as the different biomechanical responses of elderly and young people to light, thus requiring personalized lighting solutions

Although this study has achieved some preliminary results in the impact of light on human biomechanics, there are still many issues that need to be further explored. Future research can further focus on the differences in biomechanical responses of light to different age groups, genders, and health status populations, and investigate the manifestations and regulatory mechanisms of light biomechanical mechanisms in individual differences. In addition, combining multidisciplinary technologies such as molecular biology, neuroscience, materials science, etc., in-depth research on the coupling mechanism between the transmission pathways of light signals at the cellular and molecular levels and biomechanical changes will help us to have a more comprehensive understanding of the impact of light on human health. In terms of applied research, developing an intelligent lighting system based on biomechanical principles that can monitor the biomechanical state of the human body in real time and automatically adjust light environment parameters will be an important research direction for improving human living environment and promoting health in the future. At the same time, further research on the biomechanical effects of light and other environmental factors (such as temperature, humidity, sound, etc.) will provide important basis for us to construct a more realistic and comprehensive human environmental perception model.

Future research can further explore the adaptive changes of human biomechanical properties under long-term exposure to light and its impact on health. At the same time, by combining multidisciplinary technologies such as biomechanical modeling and neuroimaging, we can deeply analyze the complex biomechanical network mechanisms of how light affects emotions and physiological rhythms. In addition, developing an intelligent lighting system based on biomechanical principles to monitor the biomechanical state of the human body in real time and automatically adjust light environment parameters will be an important direction for future research, which is expected to create a healthier, more comfortable, and efficient living environment for humans.

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manuscript.

Ethical approval: This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Xi'an University of Architecture & Technology (Protocol Code: MCB-2024-1194; Date of Approval: 15 November 2024). Written informed consent was obtained from all participants prior to the experiment.

Conflict of interest: The authors declare no conflict of interest.

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