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Research Article

A Systematic Review of Light Therapy on Mental Health on and Beyond Earth

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Abstract

Light can influence human emotional well-being, sleep quality, and circadian rhythms. The application of these qualities in a therapeutic context is currently being explored. Research has been conducted into the effects of light therapy on wound healing, sleep enhancement, stress management, and the improvement of depressive symptoms. Despite the extensive amount of studies in this field, a satisfactory framework for categorizing light therapies has yet to be developed. To address this problem, our research team proposes to categorize light therapy by wavelength (color). The benefit of this categorization is that, while therapeutic applications may evolve, the fundamental properties of light colors remain constant. Categorizing by color supports scientific innovation and maintains consistent categories even as new research emerges. On the other hand, light therapy's potential is undermined. Light therapy is characterized by its affordability, durability, consistency, and minimal side effects. While light therapy is interchangeable with other therapeutic methods in common scenarios, it is specifically suited for environments where all those attributes are essential. Space missions represent one such environment. Space exploration is a major frontier for humanity, yet the mental health and living conditions of astronauts have received limited attention. Space missions present unique environmental challenges to astronauts due to altered light exposure, high-pressure, and isolated living environments. These environmental problems need to be addressed, but the resource-scarce space environment requires a reliable and durable solution. Light therapy's advantages align well with these constraints. Moreover, its ability to address issues such as disrupted circadian rhythms and psychological stress caused by space environmental problems renders it an optimal intervention for space exploration. This article will examine the therapeutic effects of light therapy, with a particular focus on the ways in which different light colors address various health issues and recent discoveries. The potential of light therapy will be demonstrated through the use of space missions as an illustrative example. Additionally, we will briefly discuss future research directions for light therapy. Our primary objective is to establish an intuitive and stable categorization of light therapy. We will examine the potential of light therapy in unique environments, such as space missions, and discuss how it can address common symptoms experienced during these missions. Our ultimate goal is to fully realize the potential of light therapy in tailored environments and inspire the discovery of other scenarios where light therapy can be equally effective.

Keywords

Mental Health, Light Therapy, Application of the Light Therapy, Space Mission, Applied Psychology

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1. Introduction

The topic of psychological wellbeing has become increasingly prominent in recent years, with a growing awareness of its importance. The prevalence of psychological diagnosis has increased over the years [1]. The transition from in-patient to out-patient care for psychological disorders has led to an increased demand for day care equipment. This equipment supports various forms of treatment as patients manage their conditions outside of hospital settings. Light therapy is one of those methods that has high efficiency and minor side effects. Light therapy is an umbrella term for those therapy which utilize light to treat various psychological and physical conditions. Light therapy has a long history that proven to be effective in psychological issues including depression, seasonal depression and sleep problems [2-4] Additionally, evidence suggests that light therapy is effective in relieving stress from burnout and in correcting the biological clock. [4, 5].

Light therapy's functionality lies in a wide range of fields. In current review papers, light therapy is usually categorized by symptoms or disease they can cure, yet it's hard to conclude the capability of light therapy systematically. Thus, those seeking to understand light therapy often struggle to find a clear pathway through the scattered evidence. Furthermore, light therapy is a nascent field, and the information structure is undergoing constant evolution. Accordingly, to categorize light therapy in a stable yet adaptable manner, we propose classifying it by the wavelength, or color, of the light utilized. Classifying therapeutic effects based on the color of light provides a robust and enduring framework for scientific exploration. This method ensures that even if the specific therapeutic applications of a certain light color are reevaluated or disproven, the classification itself remains stable. Consequently, researchers can update their understanding of what each color of light can treat without altering the fundamental categories. This stability facilitates continuous innovation and refinement within the field, as it allows for the swift integration of new findings and the exploration of alternative therapeutic possibilities for each spectrum of light. Generally speaking, there are three most commonly used colors in the light therapy. Full spectrum white light typically addresses depressive symptoms, stress, and sleep issues. Red light is commonly used for wound healing, pain reduction, and anxiety relief. Blue light is employed to decrease stress and enhance focus. It is worth noticing that there are also lights like infrared used in the light therapy, and we briefly mention those as well. The primary objective of this paper is to categorize light therapy in different light colors and provide an overview of their functions. To ensure the information is up to date, we will focus on recent publications. In addition, since light therapy is a relatively new topic to study, researchers have not reached consensus in various aspects. As a result, we will conclude the general trend of studies happened in recent years and discuss their relationships with historical disputes.

On the other hand, we believe that the light therapy's potential is underestimated, but its potential can be fully released in some special circumstances. The light therapy device is compact, durable, and straightforward to operate, as such, it is an optimal choice for circumstances where resources are constrained. For example, the field of space exploration.

Research in the field of space exploration has historically focused on scientific advancement, with the wellbeing of astronauts and the quality of their lives often being overlooked. One of the pressing issues is the psychological wellbeing of astronauts. The life in the space is an isolated small society with limited resources, so the physical and mental wellness of people are crucial for their survival.

Light therapy has several advantages compared to traditional therapy or medication. The therapy devices are compact and portable. Such devices are typically constructed from LED or other light bulbs with minor modifications, thus are small and does not require complex technology. Light therapy devices are also easy to control. Furthermore, the devices can be operated remotely or by pre-programmed algorithms, eliminating the need for users to possess professional skills. Moreover, administration of light therapy can overlap with other activities like reading or exercising. This obviates the necessity for a specific period of time to be set aside for the administration of therapy. Lastly, the cost of light therapy tends to be very low compared to other forms of treatments. Compared to light therapy, traditional psychotherapy requires personals with specialized skills, and it requires dedicated time to conduct. While pharmacological treatments are highly effective, they are often limited by supply shortages. Additionally, determining the right dosage and type of medication for different individuals usually involves a trial-and-error process. Pharmacological treatments sometimes exhibit a range of unpredictable side effects.

The lightweight and durable nature of light therapy equipment addresses the weight constraints of space travel. It does not acquire specialized knowledge to operate because it can be controlled with internal program or controlled remotely. Moreover, light therapy can be integrated into astronaut's daily schedule when they are simultaneously preforming other tasks, making the process not taking up extra time.

The second objective of this paper is to discuss the potential of light therapy in space missions and how it can help to resolve various challenges presented in space without taking up much resources. The goal is to use space mission as an example to demonstrate light therapy's potential under special circumstances.

Light therapy is an underregulated area. Although there are many evidence-based researches done on the effect of light therapy, the guidelines for how to administer such treatment is usually varied and largely depends on physicians' personal experiences. It is clear that more researches are needed for us to understand the logistic and effectiveness of this therapy method. As a result, our last objective will be discussing the future research directions of light therapy.

2. Methods

To answer the selected questions, a literature review is conducted by our research team. We followed the guideline provided by PRISMA guideline [6] to make sure the literature review meets the standard in academia. To ensure the accuracy of information presented in this paper, we only included peer review articles [7].

2.1. Term Definition

To ensure the accuracy and the precision of our literature research, we decided to define several key terms that are closely related to our article.

Light therapy: It involves the use of specific wavelengths of light to treat various medical and psychological conditions. To be counted as a light therapy, it needs to at least exposure clients under a light source. The light source needs to include some wavelengths in the visible light spectrum but it can also include none visible lights like near infrared.

White light: We define white light as the full spectrum white light. The color of light used in therapy must be perceived as white color. The light can be directly or indirectly perceived by human eyes during the therapy. In this review, enhanced or reduced specific spectrum in the white light are excluded from white light category because authors did so to discover the therapeutic effect of modified wavelength.

Red light: Light used in this therapy type must be perceived as red. The wavelength typically ranged between 630 to 700 nanometers. The light can be directly or indirectly perceived by human eyes during the therapy. The red light can include some spectrums of invisible light like near infrared as long as the overall perceived color is red.

Blue light: The definition of blue light therapy is the light used in this therapy type must be perceived by human eyes to be blue color. The wavelength typically ranged between 400 to 495 nanometers. The light can be directly or indirectly perceived by human eyes during the therapy. The blue light can include some spectrums of invisible light like ultraviolet as long as the overall perceived color is blue.

2.2. Search Strategy

Although the goal of this search is focusing on recent studies, we did review papers published before 2014 for pilot studies. We acknowledged that publications prior to 2014 were crucial in the initial phases of our research in terms of helping to establish a general understanding of the field. However, we used them primarily to support our logistical framework and are not discussed detailly in the current analysis. Other than that, we will also use sources outside of scholarly article to build our logistics, but we will give reasonable justification about why those sources are scientificly appropriate and will not use those sources to build our arguments.

We searched articles from various database including Google Scholar, PubMed and National Health Institute. The reviewers used key word search to find articles related to this topic from title and abstract. For Google scholar, the keyword is applied to the titles only based on its limitation.

The key words our researchers used are Light therapy and Phototherapy. After we have determined the major light types as subgroups, we also use subtype in the subgroup interchangeably to find more articles. For instance, after we determine the white light as a major category, we used bright light therapy as a keyword to search information related to white light function since bright light therapy is a type of light therapy using white light.

We set the publication date between 2014 and 2024. The reason we choose a 10 year range instead of shorter because light therapy is a relatively new field first recognized officially as a treatment in 1980 [8]. As a result, 10 year period will provide us with more comprehensive view of the field to construct the understanding while also keeping the information up to date. We will prioritize the publication 1) within the 5 years from today 2) Has high citation number.

Afterwards, we rank the result in terms of relevance until 1) we reached n=20 for each topic according to guidelines provided by University of Kent [9] 2) The irrelevant results start to appear.

Then, three researchers collectively decide if the article should be included in this review paper according to our search criteria described below.

Each article was then reviewed to ensure that it can contribute to our research objectives. We aimed to draw reasonable assumptions and engage in meaningful discussions based on these papers, selecting only those that provided insight and contributed meaningfully to the advancement of knowledge in this field.

2.3. Search Criteria

We followed these concepts to determine whether to include articles in our research review:

1. Integrity. We only use papers published in trustworthy scientific sites like research gate or science direct (which can ensure the peer review component of the paper), or sources in government websites. Standalone documents are not accepted.
2. Light therapy is the central focus. Light therapy must be either the primary objective of studying or the method of intervention. Stating light therapy as a moderator or side statement is not considered relevant to this essay.
3. English or Chinese draft. The literatures we selected need to be written either in English or Chinese. Essays without English or Chinese translations are excluded.

3. Literature Review

3.1. White Light

The color of the light largely determines the potential function of light therapy. Bright Light Therapy (BLT) is a common light therapy method that uses white light with high intensity. Comprehensive research has proven that BLT has therapeutic effect on various psychological disorders. The sectional review mainly focuses on describing BLT's methodologies, and providing the overview of conditions it treats. Subsequently, there will be a discussion on some new findings on biological bases of light therapy published recently. Afterwards, we will discuss some new findings about the conditions that BLT can treat, and will conclude the trends of those discoveries. Finally, we will explore BLT's effectiveness for psychological treatments in unique settings like space exploration.

There has not been one unanimous agreement about what is the empirical standard for Bright Light Therapy. Typically, the therapy involves exposing individuals to full spectrum white light several times brighter than typical room settings. Researchers will sometimes strength specific color spectrum in the white light to study therapeutic effect of that changed variable. During the therapy, clients are expected to open their eyes to perceive light without direct eye contact. As a reputable medical research group, Mayo clinic [10] provided a baseline protocol for BLT. It involves exposing individuals to 10,000 lux of white light while minimizing UV exposure. This exposure should occur within the first hour of waking and last for 20-30 minutes at a distance of 16-24 inches from the light source.

Bright light therapy has proven to be effective in treating many psychological conditions. Strong evidences alone the history have indicated bright white light's effectiveness in treating Seasonal Affective Disorder (SAD) [11, 12]. Health field has considered BLT as a primary treatment for SAD. Moreover, it is possible that BLT can also prevent the occurrence of seasonal affective depression [13]. Many studies have also discovered BLT's capability in treating nonseasonal depression, including depressive symptoms presented in more complex conditions [14]. However, the robustness of evidence is medium, even in those more recent researches. Some studies proved that bright white light can serve as a treatment for depressive symptoms alone [15, 16], others presented mixed results [17] while some suggested null effect [13, 18]. Regardless, BLT still listed as a secondary/auxiliary treatment method for depression, providing insights about its potential. Indeed, there are multiple researches shown evidences that BLT can enhance the overall effectiveness of treatment when combined with other methods in addressing non-seasonal depression. [19, 20]. Other than that, another major usage of Bright Light Therapy is to correct circadian rhythm and improve sleep quality, which we will discuss more in the latter of this section.

Next, we will discuss some recent publications about Bright Light Therapy. Compared to earlier ones, the recent studies are designed more rigorously thus being more trustworthy. Some other recent publications are meta-analyses done with newer statistical methods, which effectively concluded the ideas in previous findings. We will start by discussing two cases that explore biological mechanisms under the BLT.

The mechanisms underlying the efficacy of light therapy are still not fully understood. Huang et al. (2023) [21] discovered that chronic stress increases non-rapid eye-movement (NREM) sleep, suggesting stress leads to decline in sleep quality and the induction of depressive-like symptoms. The control and experimental group are differentiated by exposure to 3000 lux of light, which is significantly brighter than standard indoor lighting. The result revealed that this bright light treatment mitigates stress-induced sleep alterations. It does so by modulating a specific neural pathway involving the lateral habenula and the rostromedial tegmental nucleus, which is normally activated by stress. By attenuating the activity in this circuit, bright light therapy effectively normalizes the stress-altered sleep patterns.

Costello et al. (2023) [22] investigated the impact of bright light therapy (BLT) on neuroinflammatory and neuroplasticity markers in diurnal rodents exposed to winter-like dim light conditions. The study involved male and female grass rats exposed to either an hour of early morning bright light (10,000 lux) or a control narrowband red light for four weeks. Results indicated that BLT significantly reduced the expression of the neuroinflammatory marker TNF-α in the basolateral amygdala of female rats. It also variably affected the expression of BDNF and TrkB, key markers of neuroplasticity, across different brain regions in both sexes. These findings suggest that BLT may have sex-specific and region-specific effects on brain inflammation and plasticity, highlighting its potential therapeutic impact on conditions associated with neuroinflammation, such as depression.

In addition to the conditions previously discussed, recent research has identified other symptoms that may potentially benefit from white light therapy. For instance, bright light therapy can improve the symptom on antepartum depression [23] and perinatal depression [24]. It has been effective in managing depressive symptoms and sleep disorders in patients with Parkinson's disease [25]. There is also emerging evidence supporting its use in treating eating disorders such as anorexia and bulimia nervosa [26].

Furthermore, bright light therapy has been found to improve depressive and agitation symptoms in dementia patients [27]. These findings suggest that bright light therapy may have universal applicability in treating various mood disorders.

Recent studies have also revisited previously examined symptoms, such as the effects of Bright Light Therapy (BLT) on non-seasonal depression.

A single blind clinical study [28] demonstrated that when combined with standard pharmaceutical treatments, BLT successfully reduced irritability in patients with bipolar disorder. It revealed BLT's potential in stabilizing the mood.

Meta-analyses [29, 30] reinforced the growing evidence of BLT's effectiveness in non-seasonal depression.

Moreover, a study by Berger et al. (2022) [31] employed EEG devices to measure brain stimulation levels with and without BLT, suggesting that BLT can stimulate the brain and consequently lead to reduced levels of depressive symptoms. Higher brain arousal observed after BLT corresponded with lower depressive scores.

In conclusion, recent research trends support the effectiveness of Bright Light Therapy (BLT) in treating non-seasonal depression, either as a standalone treatment or in combination with other therapeutic approaches.

Researchers have also conducted more detailed studies on the logistics of administering Bright Light Therapy.

The timing of light therapy administration varies. Most studies indicate that treatments are most effective when administered in the morning [19]. We will discuss some newer hypothesizes later suggesting that aligning the onset of light therapy with an individual's circadian rhythm typically yields the best results.

The duration of exposure required for BLT treatment decreases as the intensity of the light increases. Determining the appropriate dosage for each individual is crucial for the success of the treatment [19]. Therapeutic effects can be achieved with varying dosages, such as 10,000 lux for 30 minutes, 5,000 lux for 1 hour, or 2,500 lux for 2 hours.

Compared to other forms of treatment, BLT's side effect are usually mild and well tolerated. Potential side effects of the treatment include headache, eyestrain, nausea, and agitation.

BLT can be administered concurrently with other daytime activities, such as reading or exercising. It can also be administered simultaneously during other forms of treatment, such as repetitive Transcranial Magnetic Stimulation (rTMS) [20].

Studying the logistics of BLT can offer valuable insights into the factors that contribute to its effectiveness and the most efficient ways to implement it. This will also help to guide the direction of understanding the mechanisms of light therapy.

Among various logistical considerations, personalization appears to be an important aspect for the success of treatments [30].

A control-based experiment has suggested that individualized chronotype light therapy combined with standard psychotherapy treatment has superior effect over psychotherapy treatment alone in hospitalized burnout patients [32].

In this pilot clinical study, participants suffering from severe burnout symptoms were allocated to two groups: one receiving standard multimodal psychiatric treatment, and the other receiving this treatment with additional bright light therapy. The light therapy was administered early in the morning for 30 minutes daily, using a light intensity of 4246 lux and irradiance of 1802.81 μW/cm². Importantly, the timing of the light exposure was personalized based on the patients' chronotypes, assessed through questionnaires that identified their natural wake times. Treatment sessions were initiated 1.5 hours before each patient's usual wake-up time to align with their biological morning, maximizing the potential therapeutic effects.

During the light therapy sessions, patients were required to sit in front of the light box at a specified distance to ensure consistent exposure, but they were allowed to engage in passive activities such as reading or eating breakfast, provided these did not involve electronic screens. This was to avoid any additional light exposure from devices that could interfere with the therapy's effectiveness. The strict protocol aimed to maintain the integrity of the therapeutic environment and to standardize the treatment conditions across participants.

The findings revealed that bright light therapy significantly improved several symptoms of burnout. Notably, patients receiving light therapy reported marked reductions in exhaustion and cynicism, and they experienced an increase in feelings of personal accomplishment. Furthermore, these patients demonstrated improved sleep quality and a reduction in daytime sleepiness, suggesting an overall enhancement in well-being and daily functioning. However, the study did not observe significant changes in attentional performance or depression severity.

Another aspect that light therapy can help is correcting circadian cycle and improve sleep quality.

In this clinical experiment, the researchers have found that bright light therapy alone can reduce depressive symptom in adolescents with MDD [33]. This article has also reinforced the idea that light therapy is helpful in terms of correcting people's circadian cycle. The article suggested that the consistency of using light box is the key for the adjustment. The time of administering light therapy has some flexibility since the effect can be seen in morning or in middle day. Adolescents underwent light therapy also shown increased sleep efficiency.

Right circadian cycle can provide benefits like enhanced cognitive performance. Light exposure is also related to sleep length. Less daytime exposure leads to longer biological night thus longer sleep duration [34, 35].

In conclusion, bright white light therapy is a promising treatment for depressive symptoms, particularly seasonal affective disorder (SAD) which is caused by insufficient light exposure. It also helps correcting circadian rhythms and improving sleep quality. Other than that, bright light therapy has general mood enhancement effect. This is especially true in reducing stress and burnout symptoms. Two factors are important for light therapy to work efficiently: timing of the day and consistency. Personalized onset time of bright light therapy aligned with individual's circadian cycle can improve effectiveness.

Bright light therapy's characteristics make it particularly suited for specialized applications, such as space missions. Reduced gravity and alternated light patterns will disturb astronomers' circadian cycles, leading to reduced sleep duration and quality [36]. The unpredictability of space living environment contributes the risks of developing symptoms like phobias or homesick [37]. Together, these elements will cause increasing in stress level and be risk factors of developing more severe psychological disorders. Stress is problematic because it affects people's metabolic, immune, cardiovascular, and neurobiological systems, causing conditions like mental health issues and immune system problems [38]. These are detrimental for space missions because of the limited availability of medical resources. Additionally, elevated stress levels can significantly impair cooperation among astronauts, potentially leading to conflicts within the team [37].

Moreover, astronauts can receive light therapy while engaging in other necessary activities, such as daily exercise. This activity routine and it is crucial for maintaining their muscle mass in low-gravity environments. The scheduling of exercise routines presents a perfect opportunity to implement light therapy, as the light therapy requires consistency to be effective and it can be integrated into astronauts' existing schedules without requiring extra time.

As mentioned above, light therapy can not only improve astronauts' circadian rhythms and sleep quality but it can also reduces stress and stabilizes mood. It is a simple, effective method to manage the psychological and physiological challenges in space missions.

That was one example of how Bright light therapy can be used in the special circumstances. More researches are needed to explore exact method of implementation or discover bright light therapy's potential in other conditions.

3.2. Red Light

This section explores the diverse therapeutic applications of Low-Level Laser (or light) Therapy (LLLT), focusing on researches from foundational studies to recent advancements in red light treatments. LLLT, also known as photobiomodulation, is a noninvasive and nonthermal approach that uses low-power light sources to promote tissue repair, reduce pain and inflammation, and stimulate healing and tissue regeneration. [39, 40] Initially discovered by Dr. Endre Mester in 1967, LLLT's potential for various medical treatments has been extensively studied over the decades.

Dr. Endre Mester first identified the therapeutic potential of LLLT during an attempt to replicate the tumoricidal experiments of McGuff et al. Mester utilized a ruby laser with a wavelength of 694 nm but at a lower intensity. While his study did not replicate the tumoricidal effects reported by McGuff, Mester observed an unexpected outcome: accelerated hair growth in mice exposed to the low-level laser. [41-43] This discovery provided the first evidence of LLLT's potential, laying the groundwork for subsequent research into its therapeutic properties.

Building on this foundational work, Mester later demonstrated the effectiveness of a helium-neon (HeNe) laser at 632.8 nm in stimulating wound healing in mice and treating patients with non-healing skin ulcers. [44] These pioneering studies initiated further research into the effects of red light for therapeutic applications.

The biochemical mechanism underlying the therapeutic effects of LLLT are not yet fully understood, and they vary across different applications. Within cells, LLLT acts on mitochondria [45] to boost ATP production [46], modulate reactive oxygen species (ROS), and induce key transcription factors such as NF-κB, p53, and HIF-1. [47] This regulation triggers protein synthesis, leading to increased cell proliferation, cytokine modulation, and enhanced tissue oxygenation [48], providing therapeutic benefits.

While the understanding of LLLT remains incomplete, numerous studies have been conducted to explore its applications. These studies provided key insights into the diverse effects of red-light therapy and highlight its promising potential in various fields.

For instance, Lin's study examined the effects of HeNe laser therapy (632 nm) on arthritic cartilage in rats. The therapy, administered for 15 minutes, three times a week, over 8 weeks, increased mucopolysaccharide density and reduced arthritis severity indices in the treated group. [49] In another example, a study using a cold laser with a 635 nm wavelength and 10 mW intensity found that 4 minutes of irradiation disrupted 80% of the adipocytes' membranes, increasing to 99% with 6 minutes, as seen through electron microscopy. [50]

Further research explored the impact of far red and near-infrared light (R/NIR) on releasing nitric oxide (NO) from nitrosyl heme proteins, enhancing cardioprotective effects during ischemia-reperfusion injury in rabbit hearts. [51] In addition, the anti-inflammatory capabilities of LLLT were highlighted in a study that used red and NIR LED to reduce inflammatory markers in lipopolysaccharide-induced otitis media in various cellular models, indicating significant reductions in inflammation-related markers and signaling pathways. [52]

In neurological applications, the combination of LLLT with electrical stimulation was explored in spinal cord–injured rats, indicating stimulation of osteoblasts albeit without significant improvements in densitometry. [53] This insight into LLLT's limitations contrasts with its successful application in pediatric ophthalmology, where a clinical trial found that repeated low-level red-light therapy effectively controlled myopia progression in children. [54]

Research by Zhang et al. revealed that red light significantly influences sleep architecture, providing a non-invasive approach to managing sleep disorders. The study found that red light at 420 lx markedly induced sleep and modified sleep patterns, impacting the duration and number of sleep episodes, stage transitions, and EEG power density. In contrast, red light at intensities of 10 lx or lower did not affect sleep-wake behavior, unlike white light, which disrupted sleep even at these lower intensities. [55]

More interestingly, Cui's team developed a composite antibacterial hydrogel that combines photodynamic therapy (PDT) and photothermal therapy (PTT), activated by white and NIR light. This integration of photothermal nanoparticles and cell-penetrating peptides into the hydrogel led to synergistic antibacterial effects by enhancing ROS production and ensuring uniform temperature increases. The study found that this dual-light activation significantly improved the hydrogel's antibacterial performance, showing promise for clinical wound treatment. [56]

Building on the innovative use of light therapies for medical treatments, similar technological advancements have been realized in the field of physical therapy. Specifically, light-emitting diode therapy (LEDT) has emerged as a powerful tool for enhancing muscle recovery and performance. This progression from using light therapies like PDT and PTT in hydrogels to applying LEDT in muscle recovery demonstrates the versatility and expanding applications of photobiomodulation in healthcare.

A comprehensive study conducted a randomized, double-blinded, placebo-controlled trial to evaluate the effects of phototherapy using a combination of lasers and LEDs on muscle performance and recovery in 40 healthy male volunteers. It was found that phototherapy significantly increased maximum voluntary contraction (MVC), decreased delayed onset muscle soreness (DOMS), and reduced creatine kinase (CK) activity, indicating reduced muscle damage. The most effective results were observed with a 30 J dose, which consistently improved performance and recovery metrics from immediately after exercise to 96 hours later. [57]

Further research explored the impact of LEDT at 630 nm on muscle recovery following strenuous eccentric exercise in healthy male volunteers. This study found that a single session of LEDT immediately after exercise substantially alleviated muscle soreness, reduced strength loss, and minimized impairments in the range of motion up to 96 hours compared to a placebo group, highlighting LEDT's effectiveness in accelerating recovery. [58]

Another study examined the therapeutic effects of 850 nm wavelength LED therapy on muscle tissue recovery and collagen remodeling after acute cryoinjury in rats. This research demonstrated that LED therapy significantly reduced inflammatory infiltrates within three days and increased the number of immature muscle fibers by the seventh day. Additionally, it decreased the activity of MMP-2, an enzyme involved in collagen breakdown, and enhanced collagen deposition, thereby facilitating muscle repair and reducing inflammation. [59]

Significant advancements have also been noted in the metabolic aspects of muscle function, particularly in ATP production. One study investigated the effects of LEDT on adenosine triphosphate (ATP) levels and fatigue resistance in mice, revealing that LEDT significantly enhanced ATP content and fatigue resistance, with the most notable effects observed six hours after treatment. This suggests that the optimal timing for LEDT application is approximately six hours prior to intensive exercise, maximizing metabolic benefits and enhancing overall muscle performance. [60]

Recent research on LLLT, particularly in the red-light spectrum, reveals significant therapeutic advancements. Studies have demonstrated that red light therapy enhances tissue repair, reduces inflammation, and improves muscle recovery by targeting cellular mechanisms like mitochondrial function and transcription factor regulation. For instance, investigations into its effects on arthritic cartilage, adipocyte disruption, and nitric oxide release have established LLLT's precision in specific tissue healing. Moreover, its applications in neurological conditions, sleep disorders, and physical therapy confirm its effectiveness in muscle recovery, inflammation reduction, and metabolic enhancement. Collectively, these findings underscore the potential of red-light therapy across diverse healthcare applications, providing a strong foundation for exploring its use in space missions.

Building on the potential of light therapies, particularly within the red-light spectrum, these technologies offer significant advantages that could be pivotal during space missions. The unique challenges of space, characterized by microgravity, radiation exposure, and the psychological stress of confinement, require robust health maintenance strategies to effectively counteract the adverse effects on astronauts' bodies.

Photobiomodulation (PBM) using LLLT within the red-light spectrum could play a critical role in this setting. The benefits of red-light therapy, known for its deep tissue penetration and efficacy in enhancing tissue repair, reducing inflammation, and aiding in muscle recovery, can directly address common issues faced by astronauts, such as muscle atrophy and slower wound healing. Specifically, red light at wavelengths typically ranging from 630 nm to 700 nm has been shown to significantly increase cellular ATP production, enhance cell proliferation and migration, and reduce pro-inflammatory cytokines. These properties make it ideal for maintaining muscle function, accelerating wound healing, and reducing the risk of injury during spaceflight.

Meanwhile, depression is considered to be related to abnormal activity in frontal lobe, reflected in changes in cerebral blood flow in the frontal lobe area. Near-infrared light is penetrating, which may change the cerebral blood flow in the prefrontal lobe and affect the emotional state of patients with depression. Studies revealed that, by applying near-infrared laser (810 nm/980 nm) to the bilateral prefrontal and temporal lobe areas for 9 to 12 minutes in each area, some patients' depressive symptoms are relieved within 4 weeks. [74]

The application of red-light therapy in regulating sleep cycles and circadian rhythms can significantly benefit astronauts. Disrupted sleep is a major issue in space due to the lack of natural light cycles, which can impair cognitive function and overall health. Red light therapy has been proven to positively influence melatonin levels and promote sleep quality, which could be utilized to normalize sleep patterns and enhance rest quality aboard spacecraft. This not only improves performance but also helps mitigate the psychological stress associated with long-duration spaceflight.

In 2020, a randomized controlled trial with generalized anxiety disorder showed that by accepting red light therapy to the forehead and chest once a week for eight weeks, 40 patients were observed to have reduced anxiety symptoms and improved quality of life, in comparison with sham treatment. This may be based on red light's capability on enhancing vagal nerve activity and parasympathetic tone, which are associated with relaxation. [75]

By integrating red light therapy into the daily routine of astronauts, space missions could see improved physical and mental health outcomes, contributing to the success of long-term expeditions. The targeted use of the red-light spectrum within the broader framework of LLLT embodies a compelling synthesis of innovation and practicality, promising to safeguard and enhance astronaut health in the demanding environment of space.

3.3. Blue Light

Blue light therapy, utilizing the 400-500 nm segment of the visible light spectrum, has emerged as a versatile tool in in LLLT and LLLT via LEDT. This method has been extensively researched for its efficacy in antimicrobial applications, dermatological treatments, and circadian rhythm regulation.

Research indicates that blue light can effectively destroy bacteria [61, 62] and fungi [63], offering a promising alternative for treating infections without antibiotics. and fungus. In dermatological applications, blue light LEDT has shown significant efficacy in treating acne vulgaris by targeting *Propionibacterium acnes*, the bacteria involved in acne development. By activating porphyrins within these bacteria, blue light induces ROS production, leading to bacterial destruction. Moreover, its efficacy extends to managing psoriasis and eczema by modulating inflammatory pathways, thereby reducing itching and lesion severity.

What's more impressive is that blue light seems to eliminate bacteria with drug resistance [64, 65]. It is worth noticing that some papers suggested that blue light help wound to heal through killing the pathogens, but there are also papers suggesting blue light can help wound to heal by directly facilitating the recover process [66].

Blue light's therapeutic use has expanded into dental treatments for oral bacteria control, wound healing by improving collagen production and blood circulation, and circadian rhythm regulation, which has proven effective in mitigating seasonal affective disorder (SAD). This broad application highlights the versatility and growing importance of blue light within the spectrum of LLLT, showcasing its potential to improve healthcare outcomes across diverse fields.

On the other hand, another research [67] suggests that blue light at a wavelength of 480nm, maximally activates melanopsin, influencing brain regions associated with attention, alertness, and emotional processes. This activation not only enhances responses to cognitive and emotional stimuli but also benefits patients with mood disorders like Seasonal Affective Disorder (SAD), where blue light has shown effectiveness in stimulating brain areas involved in depression and reward mechanism. Other researches reported similar result that blue light influence SAD or other forms of depression by having effects on melatonin system [68].

The research by Wang et al., 2017 [69] suggested that blue light can enhance work efficiency and reduce fatigue. The result indicated the potential applications of blue light in both working and living environments. This implies that incorporating blue light into these settings could help improve alertness and productivity, making it a valuable tool for designing spaces where mental clarity and sustained attention are desired. In living environments, its use could also help regulate circadian rhythms, potentially improving sleep quality and overall well-being. The blue light therapy has proven to have effect on Patients with Delayed Sleep-Wake Phase Disorder [70]. Such applications align with the broader understanding of blue light's influence on cognitive functions and mood regulation.

Blue light can not only have this effect alone, but also have the similar effect when combined with white light [71]. Compared to standard bright white light, blue enriched white light has more profound effect on improving people's energetic arousal. The effect is particularly strong in the morning and midday. One the other hand, participants reported that blue enriched white light are perceived to be brighter even it is the same intensity as the white light in the control group. The difference is reported to be the largest in the start and the end of workday.

However, there is also evidence to support null result [72], but the differences in light intensity might also play a role. The strength of the effect is depending on the time of the day [73].

The application of blue light therapy offers significant benefits for enhancing focus and work efficiency, while also reducing daytime sleepiness. This makes it a promising candidate for integration into astronauts' working environments aboard space missions. The use of blue light could potentially serve as a preventive mechanism against depressive symptoms, and it might also enhance their work efficiency and energy levels.

Additionally, specialized blue light devices can be employed in first aid scenarios to treat minor wounds that astronauts may sustain. The antibacterial properties of blue light make it effective in managing minor skin issues and preventing infection, which is crucial in the confined and resource-limited conditions of space.

In conclusion, blue light therapy holds significant potential across various domains. However, to optimize its applications, further studies are required to understand its underlying molecular mechanisms and how best to translate these into clinical and practical applications.

4. Conclusion and Discussion

A review of the most recent articles in the field of light therapy has been conducted with the objective of categorizing their functions, treated symptoms, and treatment outcomes based on the color of the light used. This method of categorization provides a stable and intuitive framework for classification while leaving the space for ongoing discoveries that may alter our understanding of each color's specific therapeutic effects. Moreover, this way of classifying allows for a clear, structured overview that can adapt to new research without losing its foundational categorization (the light color will not change), thus is flexible enough for continuous scientific innovation.

White light therapy is recognized for treating psychological conditions such as Seasonal Affective Disorder (SAD) and depression. It can also help to regulate circadian rhythms, improve sleep quality, reduce stress, and improve burnout symptoms. When combined with other treatments, white light enhances overall effectiveness of those treatments. On top of that, It can prevent the onset of SAD.

Red light therapy primarily offers physical health benefits. It promotes tissue repair, reduces pain and inflammation, supports muscle recovery, and improves muscle performance. Additionally, red light has mental health benefits like reliving depression and anxiety, as well as helping to regulate sleep patterns.

Blue light therapy has a broad range of applications. Its antimicrobial properties are valuable in dermatology and wound healing. In terms of blue lights' psychological functions, it enhances cognitive and emotional functions, increases work efficiency, and reduces fatigue.

Light therapy, characterized by its durability and reliability, offers a unique therapeutic solution particularly suited to environments where these attributes are crucial. Space missions exemplify such an environment, where traditional medical and therapeutical interventions may be less feasible due to resource constraints. The challenges present by the space environment, such as altered light cycles leading to disrupted circadian rhythms and reduced sleep quality, or the high-pressure environment that can heighten stress levels, can be addressed properly by light therapy. White light therapy can treat astronauts' depressive symptoms, manage stress and regulate their circadian cycle. Red light supports wound healing when medical supplies are scarce and enhances astronauts' daily exercise routines that are crucial for maintaining their physical health. Meanwhile, blue light acts as an antimicrobial agent to prevent infections and can be deployed in living areas to boost work efficiency and reduce stress.

Additionally, this review has highlighted recent discoveries in light therapy and demonstrated its expanding applications in treating a range of conditions from mood disorders to wound healing. Overall speaking, recent research increasingly supports the effectiveness of light therapy in treating those conditions. These advancements underscore the therapy's adaptability and potential for broader medical and psychological interventions.

This review paper has several limitations. First, our analysis was restricted to the three most studied light colors in light therapy—white, red, and blue. This does not mean that other light colors such as yellow and green lack therapeutic potential. However, the current knowledge related to those colors is limited, thus preventing us from making a systematic evaluation. Second, the current research field has an incomplete understanding of the mechanisms underlying the therapeutic effects of different light colors. Although the effect of each color's light on the symptoms they can treat is observable, scientists only have superficial understanding about underlining biological pathways and interactions. Third, while numerous studies have pointed out that individualized light therapy can yield to the best outcomes, the specific factors that should be considered in the process of tailoring individualized treatments remain poorly defined. Existing research do not adequately define which variables—such as individuals' metabolic conditions or circadian rhythms—impact the efficacy of light therapy across different clients. Consequently, clinicians are left without clear guidelines on how to adjust therapy variables to truly personalize treatment.

Given the current understanding, we propose that future research should focus on refining the light therapy's protocols. While there is a basic consensus on effective approaches, more researches are required on detailed optimization of the light therapies and how the variations in treatment parameters affect overall outcomes. On the other hand, future studies should focus on enhancing the individualization process of light therapy to investigate how the specific biomarkers or characteristics of clients can guide adjustments in therapeutic factors to maximize therapeutic outcomes. Additionally, the reason that clinicians are hesitate to use light therapy in their practices might stem from light therapy's current inconsistency in clinical evidence. Therefore, conducting larger scale clinical trials is critical to strengthen light therapy's credibility and acceptance. Overall, investigating those aspects of light therapy enables us to fully reveal the therapeutic potential of light therapy across various domains.

Abbreviations

SAD	Seasonal Affective Disorder
BLT	Bright Light Therapy
LED	Light-Emitting Diode
LLLT	Low-Level Laser Therapy
PDT	Photodynamic Therapy
PTT	Photothermal Therapy
LEDT	Light-Emitting Diode Therapy
MVC	Maximum Voluntary Contraction
DOMS	Delayed Onset Muscle Soreness

CK	Creatine Kinase
ATP	Adenosine Triphosphate
NREM	Non-Rapid Eye Movement
BDNF	Brain-Derived Neurotrophic Factor
TrkB	Tropomyosin Receptor Kinase B
TNF-α	Tumor Necrosis Factor alpha
R/NIR	Red/Near-Infrared
PBM	Photobiomodulation
ROS	Reactive Oxygen Species
NF-κB	Nuclear Factor Kappa-Light-Chain-Enhancer of Activated B Cells
HIF-1	Hypoxia-Inducible Factor 1

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Research Field

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