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The Impact of Daylight Exposure on Injured Athletes: Implications for Rehabilitation

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ABSTRACT

During injury rehabilitation and return to competition, various factors impact outcomes, such as psychological parameters, sleep quality, and vitamin D levels. Studies have demonstrated that both natural and artificial daytime lighting can enhance these variables, as well as human health and performance. However, research into therapeutic methods is predominantly restricted to physical or psychological interventions that are costly and time-consuming, rather than integrated solutions. Research on the impact of daylight on injury rehabilitation among athletes is limited. Objective evaluation is necessary to establish effective recovery protocols, providing the rationale for this review. Therefore, this study analyzes existing research and theoretical explanations regarding the effects of daylight on athletes in the rehabilitation process. The results suggest that the underlying mechanism can be organized into sun-induced vitamin D synthesis, cognitive-behavioral processes, the circadian mechanism, and the visual processing of light stimuli. For practical implementation, we propose a cost-effective and time-saving artificial daylight intervention that can serve as an accompanying therapy for injuries. This intervention could be integrated into therapy facilities and sports clubs, for both competitive and recreational sports.

Keywords: daylight; injury rehabilitation; sports injury; athletes

INTRODUCTION

According to Kisser and Bauer (2012), the annual economic costs resulting from sports injuries amount to around €2.4 billion in the European Union, and between $113 million and $133 million in the United States of America (Bell et al., 2019). Physical factors influencing the rehabilitation of sports injuries, as well as the prevention of secondary injuries, are training load (Impellizzeri et al., 2020), soft-tissue overuse (Cassel et al., 2019), and biomechanics (Bulat et al., 2019), such as impaired strength or mobility (Chaabene et al., 2019). The practical implementation of these areas in the therapy of athletes requires cost-intensive equipment (Li et al., 2020) and time-intensive treatment by therapists or doctors (Stares et al., 2018) and is often applied to reduce therapy duration and expenses, as well as improve the overall results.

However, injuries in athletes can have enduring effects, prolonging an athlete's return to competition by months, sometimes years (Kellmann et al., 2018). This process can result in athletes discontinuing their sport or developing mental health conditions such as depression (Aron et al., 2019). Especially in the case of chronic overuse injuries, such as tendon pathologies, athletes show an increased fear of re-injury as well as limited confidence in their rehabilitation process compared to healthy controls (Niering & Muehlbauer, 2021). The underlying psychological factors influencing the outcome of sports injury rehabilitation are extremely diverse (Truong et al., 2020) and should therefore be considered in the development of treatment

strategies. The current literature particularly emphasizes an athlete's behavior, notably their adherence to the treatment process (Goddard et al., 2021), as well as the influence of mood swings on the outcomes of the recovery from surgically (Martin et al., 2018) and conventionally (Lentz et al., 2022) treated injuries. In addition, Christakou et al. (2022) showed that the development of sports confidence is crucial for the rehabilitation of sports injuries and is significantly influenced by alertness, enthusiasm, and the resulting physical drive.

While these psychological variables are relevant, understanding their underlying neurobiological correlates is crucial to developing novel treatment approaches. In this context, the perception of pain plays the most significant role in restoring confidence in one's body after a sports injury (Christakou et al., 2022), with higher pain sensitivity being associated with a higher risk of re-injury (Cheney et al., 2020). It is noteworthy that both the impact of psychological variables (Stee & Peigneux, 2021) and the mechanisms of neurophysiological pain regulation (Staffe et al., 2019) become particularly prominent during sleep. Many studies illustrate that the quality of sleep in athletes has a significant impact on performance (Fowler et al., 2021), injury duration and severity (Chung et al., 2019), as well as injury occurrence (Nédélec et al., 2019; Viegas et al., 2022). Therefore, sleep quality appears to be a crucial factor in the process of injury rehabilitation and return to the former performance of athletes (Reardon et al., 2019).

For this narrative review, a comprehensive literature search was conducted using the databases PubMed, PsycINFO, and Google Scholar, including publication dates 1 January 1960 to 20 October 2023. The search was guided by a combination of keywords encompassing both aspects of natural light and sports injuries, including only articles published in German or English language. Specifically, the search terms used were: (daylight OR sunlight OR light) AND ("sports injury" OR "athletic injury" OR "injury rehabilitation" OR "exercise therapy" OR "injured athletes"). However, no specific criteria were applied regarding study design, population, or study quality. This decision was made to ensure a broad capture of the available literature, aligning with the exploratory and comprehensive nature of a narrative review. All identified records were imported into a literature management software and scanned for duplicates. Additionally, a manual search was conducted within the reference lists of the included studies.

THE RELATIONSHIP BETWEEN NATURAL AND ARTIFICIAL DAYLIGHT AND INJURY REHABILITATION

Nutritional (Firth et al., 2020; Travica et al., 2020), psychological (Giummarra et al., 2018; Podlog et al., 2020), psychosocial (Gennarelli et al., 2020), pharmacological (Malve, 2018), computer-based (Zhuang et al., 2020), and exercise-based (Donia et al., 2019) interventions effectively modulate the aforementioned variables of psychological well-being and sleep quality. During an athlete's return to competition, a combination of several of these variables is considered the most effective (Cheney et al., 2020). Successful implementation of these strategies requires resources such as time, money, and motivation. In turn, identifying further, less demanding influential factors such as behavioral and environmental factors, which appear to significantly impact the results of sports rehabilitation (Truong et al., 2020), is of particular interest.

The positive and negative effects of daylight on human health are complex and have been the subject of many studies for years (Boyce, 2022). Davies and Smyth (2018) previously pointed out a global trend toward increased light intensity, changing day-night rhythms, and the increasing use of electric light in our society. They found that these changes have a significant impact on human health and behavior. These findings raise the question of whether these changes also significantly impact treatment outcomes. Depending on the time of the day, season, and geographical location, daylight is subject to constant changes in the light spectrum and radiation intensity (Giménez et al., 2022). Human biology and behavior are uniquely influenced by these variables, offering potential insights for enhancing and optimizing human capabilities, as well as their environment (Münch et al., 2020). In the past, the effect of daylight on the human body was mainly associated with its role in synthesizing vitamin D, a process initiated through skin exposure to sunlight (Wiciński et al., 2019). Vitamin D status plays a significant role in the prevention and rehabilitation of injuries (Dzik & Kaczor, 2019), as well as the improvement of performance-related parameters (Michalczyk et al., 2020). Due to increased physical, and therefore also enzymatic, activity, athletes are particularly susceptible to vitamin D deficiency (Pritchett et al., 2022) and should therefore be given special attention in this regard. The effects of daylight on therapy-relevant variables have been increasingly researched in recent years, whereby it has already been established that light and light

intensity influence mood and learning (Fernandez et al., 2018), thus also playing a central role in human behavior (Yanar & Halassa, 2018). Furthermore, research exemplified that environmental factors associated with sunlight, such as extreme heat (Tobías et al., 2021), seasonal differences (Otte im Kampe et al., 2016), air pressure and humidity (Rao & Mohan, 2021), and the synchronization of circadian rhythms (Figueiro et al., 2018), can significantly impact both physical and psychological parameters in humans. These findings are derived from experiments conducted using natural daylight and artificial daylight, whereby the use of artificial daylight appears preferable for reasons of practicability. Knoop et al. (2020) showed that the effects of natural daylight including both direct and indirect sunlight exhibit only partial similarities to artificial light. They described that while artificial daylight can replicate certain positive effects of real daylight, the exact effects of modern artificial daylight sources have not yet been sufficiently researched. However, the authors failed to provide precise evidence in which the two forms of daylight differ. Haans (2014) also stated that the literature does definitively delineate the differences between natural and artificial daylight. In addition, Meier et al. (2019) showed that due to the natural-is-better bias, differences in cognitive-psychological parameters could be anticipated. For this reason, studies with both real and artificial daylight are considered in this review.

Since, to the author's knowledge, there is no previous review of the direct and indirect effects of natural or artificial daylight on athletes during injury rehabilitation, the present review is intended to fill this gap. Therefore, the effects of daylight on a) psychological, b) sleep-related and c) physiological parameters in athletes during injury rehabilitation will be researched, analyzed, and considered in terms of practical applicability. However, as there are only a few studies to date that have investigated the effects of daylight on parameters of injury rehabilitation, the current literature in the relevant fields will be used to provide an exploratory answer to the research question. Furthermore, these findings with be used to develop a therapeutic intervention and its subsequent evaluation. The findings of effective but inexpensive additions to the therapy process, such as light or sunlight exposure, could be useful for therapists in the field of rehabilitation. Moreover, insights on the influence of daylight on psychological variables and sleep behaviour could be used to improve the therapy of other, for example, psychiatric or neurodegenerative diseases.

MECHANISMS UNDERLYING THE EFFECTS OF DAYLIGHT ON INJURY REHABILITATION OUTCOMES

The current state of research can be organized into a) sun-induced vitamin D synthesis, b) cognitive-behavioral processes, c) the circadian mechanism, and d) the visual processing of light stimuli. However, the effects of light exposure on these factors cannot be considered separately, as all of them influence each other bidirectionally (Moldofsky, 2001; Staffe et al., 2019; Steptoe et al., 2008). Therefore, this review will identify and investigate variables that cause changes in one, both, or all four areas.

Sun-induced vitamin D synthesis

Vitamin D deficiency affects about 40% of Europeans, with severe deficiency affecting about 13% (Cashman et al., 2016), while worldwide prevalence ranges from 24 to 49% and 5 to 18% respectively (Cashman, 2022). Amrein et al. (2020) described the worldwide prevalence of vitamin D deficiency that it is not only widespread but also that there is no uniform guideline for supplementation. They emphasized the role of dietary supplements while pointing out that implementation can be challenging in practice due to highly individualized nutritional needs. Sufficient serum 25-hydroxyvitamin D (25(OH)D) concentration in the blood is essential for the function of the musculoskeletal and endocrine system (Hertig-Godeschalk et al., 2021), as well as pain sensitization and immune responses (Habib et al., 2020). Yet, Bouillon et al. (2022) determined that the evidence is inconclusive and that a link between vitamin D deficiency and various orthopedic and internal diseases cannot be definitively established. Although there is no consensus on the impact of vitamin D concentration on health, several recent studies illustrate that sunlight can increase serum 25(OH)D concentration and potentially enhance athletic performance (Abrams et al., 2018; Carswell et al., 2018; de la Puente Yagüe et al., 2020; Michalczyk et al., 2020). Michalczyk et al. (2020) showed that the effects of 10 days of sunlight exposure in winter nearly matched the effect of a 6-week daily vitamin D supplementation regimen of 6000 IU/d cholecalciferol without concomitant sunlight exposure in increasing serum 25(OH)D and testosterone levels. In addition, they found significantly better performance in speed, endurance, and jumping performance in both intervention groups compared to a group without supplementation or sunlight exposure. Intriguingly, the researcher also found that sunlight exposure during the wintertime resulted

in a significantly higher testosterone concentration compared to the summertime. This observation aligns with the conclusions drawn by Gimenez et al. (2022), suggesting that not only the duration and intensity of sunlight exposure but also the season significantly influences the effects of sunlight on the human body. In contrast, Carswell et al. (2018) were able to raise serum 25(OH)D concentrations through both artificial sunlight exposure and vitamin D supplementation. However, no significant change ($p > .05$) in athletic performance was found. A major difference between the two studies is that Carswell et al. (2018) investigated non-athletes and Michalczyk et al. (2020) investigated high-performance athletes, which could potentially account for the differing responses in relation to vitamin D concentration and its impact on athletic performance. This hypothesis could be justified by the fact that high-performance athletes need substantially more vitamin D than non-athletes due to the longer training duration and intensity (Nunes et al., 2018). This could therefore lead to a more significant influence of the serum 25(OH)D concentration on physical performance in athletes compared to non-athletes.

Since the relationship between sun exposure and vitamin D can be established and the influence on athletic performance can be assumed in athletes, but not non-athletes, the question about a direct relationship between serum 25(OH)D concentration and sports injuries remains unanswered. Dao et al. (2015) and Millward (2020) referred to a strong association ($p = .007$, $p < .001$) between low serum 25(OH)D concentration and a higher risk of bone injuries, as well as their recovery time. Similarly, in American football players, an increased prevalence ($p = .03$) of muscle injuries was found in players with low serum 25(OH)D levels (Rebolledo et al., 2018), although no explanation regarding muscle physiology, hormonal regulation, or metabolic state was provided. Research clearly illustrates that the link between vitamin D and the prevalence of bone and muscle injuries has promising preventive potential, however, there are no studies that examine the direct effects of vitamin D on the rehabilitation of sports injuries. Although Caballero-Garcia et al. (2021) suggested that vitamin D plays an active role in muscle inflammatory response and protein synthesis, both of which are crucial factors in determining the recovery time of damaged muscles, a direct correlation with rehabilitation success or duration is yet to be established. Furthermore, as supported by D'Andrea et al. (2021), sunlight significantly increases ($p = .04$) testosterone concentration in correspondence with serum 25(OH) D concentration. Increased blood testosterone promotes neuromuscular recovery by affecting anabolic processes (Otzel et al., 2018), and aids in recovery from physical and mental fatigue by altering the testosterone-cortisol ratio (DeBlauw et al., 2021).

Thus, while the current evidence does not support a direct correlation of sunlight exposure with therapy-related parameters, there is a clear association with the influence on vitamin D, testosterone, and cortisol regulation. However, considering this evidence and the importance of hormonal regulation, it remains that the majority of literature within this field of research has been conducted with males and therefore no conclusions can be drawn for the female sex.

Cognitive-behavioral processes

An athlete's perception of a physical injury often triggers significant changes in various psychological, sociological, and cognitive parameters (Wiese-Bjornstal, 2010). According to Whatman et al. (2018), changes in behavior such as attempting to downplay or conceal their discomfort can be found in over 80% of athletes upon perceiving an injury. Similarly, almost the same percentage of coaches and staff ignore or overlook the obvious symptoms and continue to let the athlete perform at full capacity. Prompt diagnoses and treatment initiation are critical for quicker healing times, especially in the case of tendon injuries, which are among the most common overuse injuries in sports (Aicale et al., 2018). Adolescents are at particular risk of permanent physical and psychological damage due to the ongoing growth processes (Caine et al., 2021) and loss of identity (Haraldsdottir & Watson, 2021). In general, athletes show an emotional response after an injury commonly characterized by feelings of frustration and anger (Von Rosen et al., 2018), along with a decline in sleep quality and overall quality of life (Watson et al., 2021). This often leads to symptoms of anxiety and depression (Piussi et al., 2022), or maladaptive pain coping behaviors (Sündermann et al., 2020). Also, the importance of addressing re-injury anxiety in the cognitive rehabilitation of sports injuries was illustrated by Kotler et al. (2022). Their study with cyclists showed the significance of mitigating fear and anxiety during the competition after traumatic accidents or collisions to avoid secondary injuries.

It has been well-established for some time that light exposure influences emotional regulation in the brain (Vandewalle et al., 2010), rendering

individuals in certain work situations such as shift work more susceptible to changes in this area (Chellappa et al., 2020). However, the specific link between light exposure through the eye and its direct impact on mood and affective behavior in neurophysiology was first established by Fernandez et al. (2018). They found that distinct light patterns, intensity, and wavelength directly affect a previously unknown region of the brain, the perihabenular nucleus, which is directly linked to mood-regulating areas, as well as the emotion-regulating limbic system. This knowledge has already been applied in practice in the form of light exposure therapy, especially in ameliorating symptoms of anxiety and stress (Yoshiike et al., 2018), as well as depressive symptoms (Feigl et al., 2018), and promises positive, but short-term changes (Golden et al., 2005). Li et al. (2017) precisely described these symptoms of psychiatric disorders as decisive psychological influencing factors in sport-related injury prevention and rehabilitation, which makes the practical implementation of light as a therapy-improving element appear reasonable.

Fischerauer et al. (2018) found that pain catastrophizing also plays a role in maladaptive processes during the rehabilitation of an injury and is significantly (p = .001) correlated with pain intensity, often leading to avoidance behavior during or after rehabilitation. These findings have recently sparked extensive discussion regarding the use of painkillers in the treatment of sports injuries. Painkillers and opioids should only be used temporarily and in a controlled manner due to their potential for abuse (Zadro et al., 2019). However, despite potential side effects, their use is recommended to facilitate an athlete's effective participation in rehabilitation by reducing pain (Kulemzina et al., 2021). Recently, Martin et al. (2021) found in patients with chronic joint and muscle pain that injury-related pain can be alleviated by green light exposure for 1 to 2 hours daily. These findings are supported by Cheng et al. (2021), demonstrating that the predominant green light spectrum of the sun, especially in the late morning or the midday, can exert pain-modulating effects.

Apart from the demonstrated effects on emotion and pain regulation, Parikh et al. (2021) recently revealed a positive influence of sunlight on sexual behavior in individuals of both biological sexes, alongside an increase in testosterone levels in men. Most notably, the results were found independently of the effects of vitamin D synthesis as a hormonal response of the skin to sunlight. Instead, this reaction appeared to be mediated via the body's opioid, immune, and nervous system. In particular, the increase in testosterone levels has previously been associated with positive effects on the rehabilitation of sports injuries (DeBlauw et al., 2021; Otzel et al., 2018), thus confirming the effects of sunlight-induced hormonal processes on therapy-related parameters.

Therefore, it can be concluded that while there are currently no specific studies detailing the direct effects of sunlight on athletes during the rehabilitation phase, sunlight does have relevant effects on therapy-related cognitive processes and behavior.

The circadian mechanism

The circadian clock has a central regulatory function in synchronizing the human body with its environment and preparing the metabolic system for certain activities by using daylight (Zee et al., 2013). The light spectrum, intensity, and wavelength are perceived by photosensitive retinal ganglion cells, particularly through pigments in the human eye known as melanopsin, and modulate physiological and psychological factors (Walker et al., 2020). Further, a complex interaction between the circadian and pain modulatory systems has been reported in current literature (Bumgarner et al., 2021). The potential implications of these processes and their impact on humans, and consequently on social life and individual health, have prompted widespread discussion. The ongoing debate on abolishing Daylight Saving Time in Europe compares a multitude of factors that can have an influence on human health through altered sleep-wake cycles, sunlight exposure, and social activities (Sládek et al., 2020). The risks during the transition could be caused by chronobiological adaptation processes (Martín-Olalla, 2022). In so, the twice-yearly disruption of the circadian rhythm has long been linked to increased occurrence of cardiovascular and psychiatric diseases (Manfredini et al., 2018).

Numerous recent publications have investigated the interplay of light with sleep behavior and the psychological and physiological parameters that influence the sleep-wake rhythm to specifically influence the circadian mechanism with natural or artificial daylight. Ostrin (2019) described that light intensity, light duration, and the time of day have a significant influence on melatonin production and thus on the regulation of sleep. Bilu et al. (2020) also found that morning exposure to bright, full-spectrum light significantly improves physiological

and psychological factors such as glucose tolerance, symptoms of stress and depression, and inflammatory parameters. Furthermore, light exposure during sleep has been associated with the occurrence of cardiac arrhythmias (Mason et al., 2022), increased alertness and difficulty falling asleep (Vetter et al., 2019), and general disturbances in emotion regulation (Walker et al., 2020). In contrast to these results, Amdisen et al. (2022) found no significant influence on sleep quality after intensive light exposure in the morning or evening. To explain these unexpected results, which are contrary to the prevailing literature, the authors suggest that further non-measured parameters such as exposure duration or wavelength could also be involved alongside the measured light intensity.

Daylight exposure has shown positive effects on sleep quality in various diseases, including Parkinson's disease (Endo et al., 2020), glaucoma (Kawasaki et al., 2021), Alzheimer's disease (Figueiro & Leggett, 2021), and musculoskeletal diseases (Walch et al., 2005). It is important to note that these studies are currently some of the few in this emerging field, and they have small participant numbers ranging from one to 20. Therefore, the limited statistical power of these studies should be taken into account when interpreting the findings. This represents a constraint in the current research landscape on this topic. However, the evidence for a direct relationship between better sleep quality and pain inhibition in the area of joint or muscle pain is particularly well-established among patients with musculoskeletal disorders (Finan et al., 2013; Haack et al., 2020). Considering the influence of light exposure on sleep quality which consequently impacts muscle and joint injuries, it's reasonable to suggest its role in sports injuries. A detailed examination of this particular type of injury reveals that insufficient sleep quality and duration correlate with a higher risk of sports injuries in elite (Nedelec et al., 2018) and adolescent athletes (Fox et al., 2020). Charest and Grandner (2020) reported strong evidence indicating the adverse impact of poor sleep quality on injury risk, rehabilitation, and return to competition. They specifically highlighted the negative influence on psychological and psychomotor effects associated with sleep quality.

The effects of daylight exposure on the sleep quality of athletes can thus be explained by the affected mechanisms of the circadian clock, which may mediate therapy-related parameters. However, no study has investigated the direct effects of daylight on the prevalence or rehabilitation of sports injuries.

Fowler et al. (2021) investigated the influence of light exposure on physical and psychological factors in athletes. They examined jumping power, endurance, fatigue, motivation, and mood in two groups of ten male athletes, one group receiving light exposure adapted to the individual circadian rhythm, and the other with no intervention. The study aimed to conclude performance improvement after a long-haul intercontinental flight and found that light exposure adapted to the circadian mechanism has large effects in improving sleep duration during (1.61 ± 0.82) and across four nights following travel (1.28 ± 0.58). Further physical performance showed small to moderate improvements in jump peak power (1.10 ± 0.55), 5-m (0.54 ± 0.67), and 20-m (0.74 ± 0.71) sprint. Another relationship between time of day, light intensity, and sleep quality was shown by Carlson et al. (2019), who compared the influence of exercise in the morning, in the evening, and no exercise on melatonin production. They found that morning workouts significantly increased melatonin production in the evening compared to the other two protocols, suggesting that exercising in the morning may contribute to overall improved sleep quality.

Visual processing of light stimuli

Stanhope et al. (2020) reported that sunlight can reduce pain intensity through hormonal regulation, changes in gene expression, and reduced inflammation. They indicated that these pain-related effects are not only linked to vitamin D pathways and concluded that natural sunlight has a broader range of effects than artificial light. However, the authors were unable to definitively determine whether the observed effects were solely attributable to sunlight exposure, or if they were mediated by concurrent factors such as warmth or the natural environment. In very few studies, light-induced enhancements to the nervous system, as well as various physiological processes that contribute to pain modulation, have already been identified as therapeutic applications. Walch et al. (2005) previously found that patients staying in rooms with direct sunlight required significantly less pain medication after spinal surgery than patients in shaded rooms, but could not identify the cause for this. De Lussanet et al. (2012), illustrated that subcortical processing of visual stimuli is impaired in chronic pain patients, linking pain to the performance of the visual system. Recent experimental studies showed that bright light exposure directly affects brain areas which can induce a pain-modulating effect. Using an animal model, Hu et al. (2022) were the first to demonstrate a therapeutic effect on pain and found that bright

light directly affects specific retinal ganglion cells near the retina that innervate GABAergic neurons and therefore have antinociceptive effects. In theory, this implies that sunlight or daylight has direct physiological effects on pain and thus on injury rehabilitation. Raver et al. (2020) noted that apart from the previously recognized retinal pathway, bright light stimuli also impact the parabrachial complex. The parabrachial nucleus serves as a pathway for peripheral sensory signals that regulate the perception of pain. Both nociceptive and visual stimuli transmitted through this area are mainly responsible for the affective-motivational components of pain (Pondelis & Moulton, 2022). Iyengar et al. (2019) illustrated in animal models that bright light as a stressor can have a pain-promoting, neutral, or pain-relieving effect depending on how the stimuli conducted via this pathway are evaluated. Since the mechanisms and genetic predisposition of this evaluation process in humans are still unknown (Caval-Holme et al., 2019), it is not possible to distinguish which individuals will perceive bright light as a positive or negative stressor. Further, age differences in the physiological effects of visual processing of daylight have been demonstrated (Cajochen et al., 2019), but have not been specifically studied for therapy-related parameters. This indicates that the direct effects of daylight on humans are still difficult to assess and thus, in summary, confirming interindividual differences in the affective evaluation of light stimuli.

CURRENT PRACTICE TO IMPROVE OUTCOMES IN INJURY REHABILITATION

To regulate circadian rhythms and sleep quality among athletes, other procedures suggested include impractical applications such as wearing blackout glasses at certain times of the day (Venter, 2012) and training during wintertime in southern countries (Michalczyk et al., 2020). Intensive supplementation with artificial vitamin D is also often recommended (de la Puente Yagüe et al., 2020; Wilson-Barnes et al., 2020), although it has only a minimal and highly interindividual influence on the parameters relevant to injury rehabilitation (Rawson et al., 2018). In terms of psychological factors, time-intensive independent interventions such as mental training or relaxation are proposed to improve sports injury anxiety (Giummarra et al., 2018; Kaplan et al., 2009), psychological readiness (Ashton et al., 2020), and distress (Gennarelli et al., 2020). As physical rehabilitation after an injury is already extremely time-consuming, the aforementioned psychological factors are rarely considered in the return to competition process of athletes, despite their importance (Schwab Reese et al., 2012). Therefore, the interventions are not practicable, especially in recreational sports, and therefore often lead to.

PROPOSING A HOLISTIC AND FEASIBLE APPROACH DURING THE SUMMER AND WINTER SEASONS

Because there are no existing studies on the impact of daylight on the psychological and sleep parameters of athletes in rehabilitation, any practical recommendations based on findings must consider all contributing factors. The proposed interventions are designed with insights from previous research (Brown et al., 2008; Cajochen et al., 2019; Choi et al., 2019; Facer-Childs & Brandstaetter, 2015; Geerdink et al., 2016; Kunorozva et al., 2014; Tamm et al., 2009; Thompson et al., 2014) and can be implemented into any injury rehabilitation program (Table 1).

We suggest scheduling therapy sessions based on circadian typology (Morningness-Eveningness Questionnaire [MEQ]; (Horne & Ostberg, 1976)). The morning types (MEQ = 59-86) should complete therapy in the morning, 2-4 hours after waking, and the evening types (MEQ = 16-41) after sunset to align with their chronotype. However, sessions should be completed three hours before bedtime to minimally disrupt melatonin production and the phase shift of circadian rhythms. Intermediate types (MEQ = 42-58) do not benefit from a specific time of day. This classification corresponds to the current classification of circadian typology in athletes (Lastella et al., 2016) and can indicate whether a person is more likely to perform better in the morning or the evening. In addition, the athletes should be exposed to an electric dawn simulation device for 30 minutes before waking, and to a bright daylight LED for 30 minutes after waking, as well as daily during therapy, which can be achieved by daylight LED bulbs in the gym or treatment room. To improve therapy adherence through social and situational factors (Goddard et al., 2021), therapy should preferably take place in a group and not as individual sessions. In the development of the intervention, particular attention was paid to the importance of practical feasibility and thus high practical relevance for therapists and clubs, leading to the choice of artificial daylight. Scheduling therapy sessions according to chronotype, the application of artificial daylight exposure for 30-minute therapy

Table 1. Overview of the proposed intervention effects.

Category	Effects	References
Electric dawn simulation device	↑ sleep quality (p = 0.01) ↑ daytime altertness (p = 0.04) ↑ cognitive performance (p < 0.0005) ↑ reaction time performance (p < 0.0005)	Thompson et al. (2014)
Daylight LED in the morning	↑ circadian rhythm synchronization (p < 0.05) ↑ sleep integrity (p < 0.05) ↑ performance (p < 0.05) ↓ melatonin level (p = 0.019, d = 0.84) ↓ sleepiness (p = 0.017, d = 0.70) ↑ mood (p = 0.042, d = 0.58) ↑ visual comfort (p = 0.015, d = 0.72)	Geerdink et al. (2016); Choi et al. (2019)
Daylight LED during therapy	↑ visual comfort (p < 0.04) ↑ daytime altertness (p < 0.001) ↑ mood (p < 0.02) ↑ sleep intensity (p < 0.009)	Cajochen et al. (2019)
Chronotype based exercise timing	↑ aerobic endurance (p < 0.05) ↑ MVC torque (p = 0.005) ↑ sprint performance (p = 0.001) ↑ rate of perceived exertion (p < 0.001)	Facer-Childs and Brandstaetter (2015); Tamm et al. (2009); Brown et al. (2008); Kunorozva et al. (2014)

MVC = maximum voluntary contraction

sessions, as well as an electric dawn simulation device are simple and inexpensive to implement. Therefore, it can be integrated by clubs or medical centers into the daily routine of an injured athlete and provide an addition to the physical rehabilitation strategy. In addition, the use of bright screens, such as looking at a mobile phone right before going to bed or when waking up during the night, can significantly influence sleep quality (Knufinke et al., 2019). Educating athletes about these effects is crucial. However, as the potential target group primarily comprises active athletes between 15 and 30 years of age and thus mostly from Generation Z, a guideline on restricted media consumption would significantly affect adherence even among body-conscious athletes (Gould et al., 2020).

Beute and de Kort (2018) reported that natural daylight and sunlight are often associated with exposure to nature and other environmental variables, and thus are not comparable to artificial daylight. Although the proposed intervention deliberately uses artificial daylight to enable implementation during all seasons, current literature suggests stronger effects from an intervention with natural sunlight (West et al., 2019). Moreover, a deeper understanding of the effects of sunlight on therapy- and performance-determining factors could encourage greater consideration of daylight and sunlight exposure when planning training and therapy in sports. For instance, in Sweden, residential building regulations stipulate specific daylight requirements for certain rooms, which has significantly improved the psychological parameters of residents (Bournas & Dubois, 2019). Fernandez (2022) also reported that due to architectural practices of the 20th century, many people are exposed to less sunlight, potentially leading to disruptions of sleep quality and circadian rhythms.

CONCLUSION

After analyzing the results of this review, it appears there could be further possibilities in the supplemental therapy of sports injuries. Exposure to sunlight has been found to influence hormonal processes which may lead to improved performance and reduced recovery time. They could potentially interact with various therapy-relevant factors, due to their influence on pain modulation and thus perceived therapy outcomes. Furthermore, the circadian mechanism and exposure to specific light stimuli mediate therapy-relevant parameters in sports injuries.

For future research, investigating the sex- and age-specific differences in the effects of natural or artificial daylight on athletes could be of interest to address the need for an individual approach to the rehabilitation of sports injuries. In summary, although the effects of psychological, sleep-related,

and physiological parameters on the rehabilitation of injured athletes have been extensively studied, their interaction with daylight and sunlight is a major research gap. A possible application in combination with physical therapy methods can be of high practical relevance for athletes and clubs, reduce injury duration, and thus enable a faster return to competition. The intervention outlined in this paper can be implemented at minimal cost and time, making it suitable for use in both competitive and recreational sports.

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CONFLICTS OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization: M.N. and J.S.; formal analysis: M.N. and J.S.; writing—original draft preparation: M.N.; writing—review and editing: M.N. and J.S. Both authors discussed the results and contributed to the final manuscript. Both authors read and approved the final version.

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