International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Scholarly Publisher
RS Global Sp. z O.O.
ISNI: 0000 0004 8495 2390

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ARTICLE TITLE	CIRCADIAN RHYTHM AND SLEEP DISORDERS IN ATHLETES: RISK OF INJURY AND PHYSICAL PERFORMANCE - A REVIEW OF CONTEMPORARY DATA
DOI	https://doi.org/10.31435/ijitss.3(47).2025.3851
RECEIVED	30 July 2025
ACCEPTED	19 September 2025
PUBLISHED	30 September 2025
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CIRCADIAN RHYTHM AND SLEEP DISORDERS IN ATHLETES: RISK OF INJURY AND PHYSICAL PERFORMANCE - A REVIEW OF CONTEMPORARY DATA

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ABSTRACT

Background. Disrupted circadian timing and poor-quality sleep are common in elite sport and are linked to impaired recovery, reduced performance and a higher incidence of injury.
Aim. To synthesise contemporary evidence on how specific sleep and circadian disorders affect physical performance and injury risk in athletes.
Materials and methods. Narrative review of English-language studies published 1997–2024 identified through PubMed and Scopus using the terms athlete, sleep disorder, circadian, performance and injury; 109 articles met the inclusion criteria.
Results. Pre-competition insomnia, delayed sleep-phase disorder, jet-lag–related disturbance and chronic sleep restriction collectively affect 30 to 70 % of athletes, with prevalence highest during congested travel and training periods. Sleep loss ≥ 2 h $night^{-1}$ or efficiency < 80 % reduces VO_2max, sprint speed and strength by 3–10 %, slows reaction time, elevates cortisol and inflammatory cytokines, and doubles musculoskeletal-injury risk. Chronotype misalignment further impairs performance when competition occurs at non-optimal times of day.
Conclusions. Sleep and circadian disorders are widespread in competitive sport and materially degrade both performance and tissue resilience. Systematic screening, chronotype-aligned scheduling, travel-fatigue management, sleep-extension strategies and judicious melatonin use should be embedded in athlete healthcare to optimise outcomes and minimise injury.

KEYWORDS
Circadian Rhythm, Sleep, Chronotype, Athletic Performance, Injury Risk, Jet Lag

CITATION

Izabela Stachowicz, Kacper Gryboś, Maria Wydra, Ilona Kamińska, Anna Łysik, Katarzyna Ciepłucha, Jakub Przerwa. (2025). Circadian Rhythm and Sleep Disorders in Athletes: Risk of Injury and Physical Performance – A Review of Contemporary Data. *International Journal of Innovative Technologies in Social Science*, 3(47). doi: 10.31435/ijitss.3(47).2025.3851

1. Introduction

The circadian rhythm and sleep quality are fundamental determinants of both physiological and psychological functioning, shaping the capacity for peak athletic performance. Disruptions of circadian rhythm such as insomnia, delayed sleep phase, or jet lag adversely affect sports performance and increase injury risk among athletes. The circadian system, coordinated by the suprachiasmatic nucleus (SCN), regulates key processes including the sleep-wake cycle, hormonal secretion, and metabolic integration; its disturbance leads to dysregulation of melatonin and cortisol, which in turn negatively impacts physical performance, reaction time, and cognitive abilities. Insufficient or poor-quality sleep in athletes is associated with reduced aerobic capacity and impaired coordination. The aim of this article is to present the current state of knowledge regarding circadian mechanisms, the prevalence of sleep disorders in athletes, and their impact on injury risk and physical performance.

2. Circadian Rhythm and Its Physiological Mechanisms

2.1. Definition of the circadian rhythm and its regulation

Circadian rhythm is an internal biological cycle that regulates many physiological and behavioral processes such as sleep-wake cycle, hormone releasing, blood pressure, cognitive functions and concentration. The cycles last approximately 24 hours. [1] The crucial structure that controls generating and synchronizing the rhythm is the suprachiasmatic nucleus (SCN) located in hypothalamus. The SCN coordinates hormone secretion and neuronal activity in response to the light signals from the retina. [2]

The functioning of the circadian rhythm is based on two major hormones:

- **melatonin**- increases somnolence and regulate the sleep-wake cycle, produced by the pineal gland, darkness stimulates secretion and light (especially high wavelength light) inhibits release of melatonin[3]
- **cortisol**- stress hormone, stimulates the body to action and promotes cognitive activity after waking up, produced by the adrenal cortex (zona fasciculata) and released in the morning in the first 30-45 minutes after awakening [4]

2.2. Synchronizing factors

There are certain environmental factors, so called “zeitgebers” [5] (from German “time givers”) which can modify the circadian rhythm, including:

- physical activity- may cause circadian phase-shifting effect, especially afternoon exercises[7]
- food- the time of eating influences peripheral circadian rhythms in humans [8]
- the light- inhibits production of melatonin by the SCN, the strongest zeitgebers [6]

2.3. Characteristic of the chronotypes

Chronotype is an individual feature that describes the preferences for sleep and wakefulness period. Researches distinguish three primary types:

- **morning chronotype**- prefer to be active in the morning, wake up and fall asleep early [9], their cognitive and physical performance is the most efficient in the morning hours,
- **evening chronotype** – prefer to be active in the evening, wake up and fall asleep late [9], they reach the peak of their cognitive and physical performance in the afternoon,
- **intermediate chronotype**- has no preference for morning and evening.[9]

3. Circadian Rhythm & Sleep Disorders in Athletes

Athletes encounter several circadian- and sleep-related disturbances that slow recovery, hamper performance and heighten injury risk *(Figure 1).* This section reviews the five most common disorders and summarises their prevalence *(Table 1).*

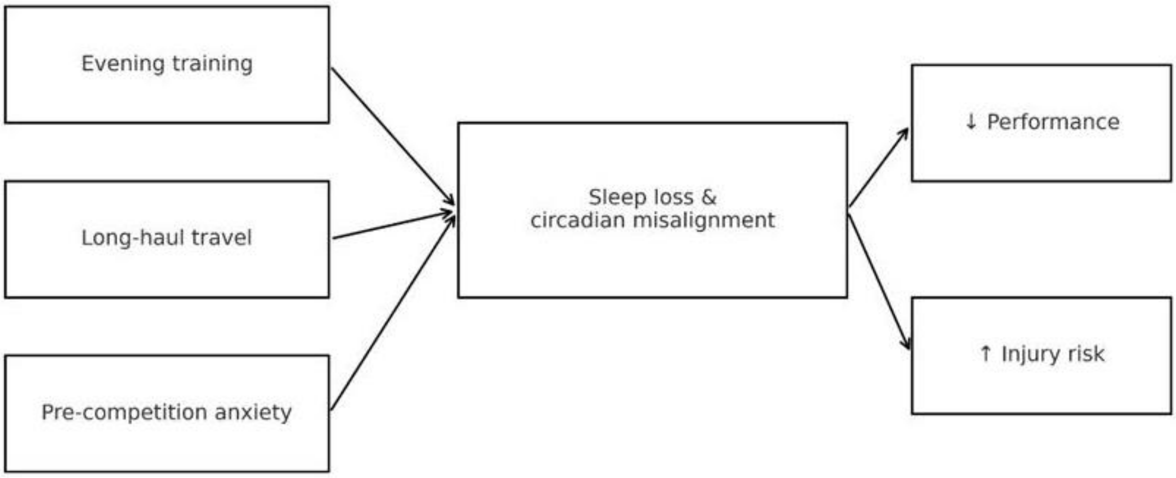

Fig. 1. *Sport-specific stressors, sleep/circadian disruption and outcomes*

3.1 Pre-competition insomnia

Performance anxiety and an anticipatory evening cortisol rise lengthen sleep-onset latency (SOL) and fragment slow-wave/rapid-eye-movement (REM) sleep. The pre-competition night sleep patterns of Olympic sprinters and swimmers show through actigraphy that they spend more time in bed but achieve lighter and more fragmented sleep (total sleep time [TST] + 26 min; sleep efficiency [SE] ≈ 82 % vs 88 % on control nights) [10] . The final 48 hours of taper results in sleep deterioration that athletes experience according to questionnaire studies with difficulty initiating sleep affecting 82 % of athletes and intrusive race thoughts affecting 83 % of athletes and anxiety being the primary cause of awakenings for 44 % of athletes [11]. The observed sleep quality deterioration affects approximately two-thirds of competitors according to field observations[12]. Athletes who show high stress-reactivity scores face a 2.3-fold increased risk of developing acute insomnia during event phases[13].

3.2 Delayed sleep-phase disorder (DSPD)

The endogenous sleep-wake rhythm shifts more than 2 hours to delay its natural end time which results in reduced restorative slow-wave sleep before morning training sessions. Professional esports players show delayed sleep onset times after 02:00 and DSPD-like delay patterns in 16 % of their population according to wearable and dim-light melatonin-onset data [14]. The PSQI scores of evening-type athletes are lower and their morning reaction times are slower according to research [15] while functional MRI studies show that extreme eveningness disrupts attention-network connectivity and increases daytime sleepiness [16]. Swimmers and distance runners who train before dawn show a genetic predisposition to eveningness because of PER3 polymorphisms which favor this sleep pattern [17].

3.3 Jet-lag-related sleep disturbance

The suprachiasmatic nucleus becomes desynchronized from the external light–dark cycle when people make rapid time zone transitions which results in decreased nocturnal melatonin production and increased inflammatory cytokine levels. A cloud-based analysis of over 1.5 million sleep episodes recorded by wearable devices shows the typical pattern for flights spanning ≥ 5 time zones:

- Night before departure: sleep is already 46 min shorter than the traveler's baseline.
- First two nights after arrival: total sleep time drops by 48 ± 22 min per night and sleep efficiency falls by 5–8 percentage points [18].

The direction of travel matters: eastward flights tend to delay melatonin offset and lengthen sleep-onset latency (SOL), while westward flights lead to more fragmented sleep later in the night[19]. In professional rugby, east-to-west travel was shown to reduce 20-metre sprint performance by approximately 6 % and impair tactical decision-making for up to 72 hours post-arrival[20].

3.4 Sleep deprivation and insufficient sleep duration

Both chronic and acute restriction of sleep increase autonomic strain and lead to slower muscle-tendon regeneration. A 2025 meta-analysis of 45 randomised trials found that sleep < 7 h reduces aerobic endurance (standardised mean difference [SMD] − 0.66, 95 % CI − 0.85 to − 0.47; I^2 = 62 %), explosive power (− 0.63, 95 % CI − 0.88 to − 0.39) and sprint speed (− 0.52, 95 % CI − 0.70 to − 0.34) while increasing perceived exertion (+ 0.39, 95 % CI + 0.19 to + 0.59)[21]. A 2022 review reported a moderate negative effect on maximal force (g ≈ − 0.38) [22]. Actigraphy shows 9 – 15 % of athletes obtain < 6 h sleep on competition eves, and 30 – 40 % record SE < 80 % during heavy micro-cycles [23,24]. The 2021 international consensus lists late-evening training, very early sessions and frequent travel as primary drivers of chronic restriction [25], conclusions echoed by narrative reviews [26].

3.5 Prevalence of sleep problems in elite cohorts

- **Swiss national survey (N = 1 004)** — 65 % reported poor sleep quality; 17 % had SOL > 30 min and 18 % experienced frequent awakenings[27].
- **Elite and junior cyclists** — 41 % scored > 5 on the PSQI, indicating dysfunctional sleep quality [28].
- **NCAA student-athletes** — 28 % reported "difficulty sleeping" on the American College Health Survey [29].

Table 1. Overnight autonomic and inflammatory markers during normal sleep versus after curtailed sleep

Autonomic marker	Normal overnight trend	Effect of curtailed sleep	Practical read-out
Sympathetic activity ("fight-or-flight")	Falls during the first half of the night	Stays elevated → higher resting heart-rate (HR) next day	↑ waking HR; ↑ norepinephrine & cortisol
Parasympathetic (vagal) activity ("rest-and-digest")	Dominates deep non-REM sleep and early REM	Suppressed → lower heart-rate variability (HRV)	↓ HRV metrics (e.g., RMSSD)
Blood-pressure dipping	Systolic BP typically drops 10–15 % at night	Blunted or absent ("non-dipping")	↑ next-morning BP
Inflammatory tone	Cytokine levels fall	IL-6, TNF-α rise	↑ C-reactive protein

These data, distilled in *Table 1*, demonstrate that insomnia, DSPD, jet-lag disruption and chronic sleep restriction are widespread in sport and often triggered by discipline-specific stressors such as late training, long-haul travel and competitive pressure. Routine screening and tailored interventions should therefore be integral to athlete health programmes.

4. Impact of Sleep and Circadian Disorders on Physical Performance

Athletes' physical capabilities are closely linked to the quality and quantity of sleep, as well as the synchronization of their internal circadian rhythm. The circadian rhythm is primarily regulated by the suprachiasmatic nucleus (SCN) in the hypothalamus, and disturbances in this rhythm-resulting from sleep fragmentation, restriction, or desynchronization-can lead to a decline in physical performance.

4.1 The Impact of Sleep Deprivation on Aerobic and Anaerobic Capacity

Even slight sleep restriction can lead to a significant decrease in both aerobic and anaerobic performance. In terms of aerobic capacity, sleep limitation results in reduced VO_2max, shortened time to exhaustion, and a subjective increase in fatigue. Mejri et al. (2016) demonstrated that after one night of total sleep deprivation, endurance athletes experienced a 9% decline in aerobic performance [30].

Regarding anaerobic performance, which includes short, high-intensity physical efforts (e.g., sprints, throwing, jumping), studies have shown a decrease in peak and average power, impaired muscle responses, and reduced movement precision.

In research by Bulbulian et al. (1996), one night of sleep deprivation resulted in more than a 10% drop in anaerobic power output, which had significant implications for speed- and strength-based sports. These changes are underpinned by hormonal imbalances (cortisol, growth hormone), reduced activation of the HPA axis, and impaired thermoregulation [31].

4.2 Circadian Misalignment and Its Effect on Strength, Power, and Motor Coordination

Jet lag, shift work, or long-distance travel across time zones can impair motor and strength capabilities. Chtourou and Souissi (2012) reported that athletes competing at non-optimal times of day, misaligned with their chronotype, performed worse due to reduced isometric strength and impaired neuromuscular coordination. These changes are associated with the circadian fluctuation in core body temperature, which peaks in the late afternoon-a time that coincides with optimal muscle performance [32].

This suggests that athletes training at atypical times, such as in the evening for a morning-type individual, may experience up to a 20% reduction in strength compared to their optimal time of day.

4.3 The Impact of Sleep Quantity and Quality on Cognitive Function and Reaction Time

Adequate sleep duration and quality are essential for proper functioning of the central nervous system. Sleep deprivation or poor sleep quality can lead to reduced attention, slower reaction times, and impaired decision-making-factors crucial in competitive sports [33]. Even a nightly sleep reduction of 2–3 hours over several days negatively affects working memory, spatial perception, and adaptive capacity.

Walker and Stickgold presented evidence that the absence of adequate slow-wave (NREM) sleep-which is essential for cortical and muscular recovery-disrupts motor memory consolidation and the learning of new skills. This may hinder progress in training [34].

4.4 Chronotype and Athletic Performance

Individual time preferences for physical and mental activity-referred to as chronotypes-are highly relevant in planning sports training and physical exertion. Two primary chronotypes are distinguished: morning and evening types. Morning-type athletes perform better in the early hours of the day, while evening types show higher performance in the afternoon and evening.

In a study by Facer-Childs and Brandstaetter (2015), athletes who trained in alignment with their chronotype scored 5–6% higher on tests of strength, speed, and reaction time. In contrast, those performing physical activity at times misaligned with their internal biological clock exhibited poorer results [35].

5. Sleep Disorders and Injury Risk in Athletes

5.1 Mechanisms of increased injury risk due to sleep deficits

Sleep deficits - including acute or chronic restriction, poor quality and circadian misalignment - adversely affect neural, hormonal, immune and musculoskeletal systems, collectively elevating injury risk in athletes.

5.1.1. Impaired neuromuscular control and reaction time

Partial or total sleep deprivation impairs reaction time and neuromuscular coordination. For example, one-night sleep deprivation in student-athletes resulted in significant slowing of simple and choice reaction time. It did not affect anaerobic power but substantially impaired cognitive alertness and coordination. [36] Reduced cortical excitability and delayed motor firing are additionally documented in experimental studies using transcranial magnetic stimulation, illustrating slower muscle activation and suboptimal joint stabilization after sleep loss. [37, 38]

5.1.2. Elevated perception of effort and fatigue

Sleep restriction elevates perceived effort and central fatigue during exercise. Controlled trials revealed increased interleukin-6 (IL-6) levels and heightened exertion ratings following sleep deprivation. [39]

5.1.3. Hormonal and metabolic dysregulation

Chronic partial sleep deprivation significantly decreases testosterone levels [40] and blunts the nocturnal growth hormone (GH) surge [41], while augmenting evening cortisol concentrations. [42] This catabolic hormonal profile impairs muscle protein synthesis and tissue repair following training-induced microtrauma, increasing vulnerability to musculoskeletal injury.

5.1.4. Impaired immune function and inflammation

Sleep loss triggers mild systemic inflammation through elevated pro-inflammatory cytokines (IL-6, TNF-α) and activation of NF-κB signaling. [43] Persistent inflammation can delay microtrauma repair in muscles, tendons and ligaments, raising susceptibility to overuse injuries - experimental and epidemiological evidence supports this association.

5.1.5. Cognitive and executive function deficits

Sleep deprivation impairs executive functions (attention, decision-making, working memory) critical during sports. [44, 45] In athletes such deficits manifest as slower vigilance, poor anticipatory responses and risk-taking behaviors under fatigue - factors contributing to collisions or failure to adjust movement under stress.

5.2 Relationship between sleep duration and injury incidence

Several cohort studies have investigated the association between sleep duration and risk of injury among physically active populations. A large U.S. Army cohort study of 7,576 soldiers reported that those sleeping ≤4 hours per night had a 2.35 times (95% CI: 1.89-2.93, $p < 0.01$) higher likelihood of sustaining a musculoskeletal injury compared with those who slept ≥8 hours. [46] In a prospective investigation of collegiate basketball athletes, a one-hour increase in nightly sleep was associated with a 43% reduction in next-day injury risk, after controlling for training load. [47] A systematic review by Dobrosielski et al. [48] analyzed 12 prospective cohorts, finding that ≤7 h of sleep sustained for at least 14 days was associated with an increased risk of musculoskeletal injury in adult athletes.

These studies consistently illustrate a dose-response relationship, where shorter sleep durations are linked to elevated injury incidence across diverse athletic and physically active populations.

5.3 Impact of jet lag and shift work on injury rates

Circadian disruption - due to rapid time-zone travel (jet lag), rotating schedules or shift work - is consistently associated with impaired sleep and elevated injury risk. In elite and professional athletes, expert consensus indicates that travel fatigue and jet lag can impair recovery, elevate fatigue and increase injury susceptibility, although direct injury outcome data remain limited. [49] Prolonged travel across ≥3 time zones produces circadian disruption, sleep disturbance and physiological fatigue, all of which impair performance and may elevate injury risk. [50, 51]. A descriptive review of elite athletes emphasized that jet lag adversely affects mood, cognitive function and upper-body strength for up to 3–4 days post-travel - suggesting increased risk of training or competition injuries during this window. [50] While limited research exists among athletes, data from shift-working populations highlight parallel risks. Night shift workers experience 60% higher rates of workplace injuries and accidents compared to day workers, attributed to fatigue, sleep fragmentation and impaired cognitive control. [52]

5.4 Oxidative stress, recovery and muscle microtrauma in the context of circadian rhythm

During adequate sleep, anabolic processes in skeletal muscle and the central nervous system support repair, removal of reactive oxygen species and synaptic homeostasis. [53, 54] However, sleep deprivation impairs clearance of oxidative metabolites, leading to increased ROS accumulation, DNA damage, and cellular apoptosis. [55]

In animal and human models, circadian misalignment (e.g., experimental 'jet lag') induces oxidative stress via central activation of sympathetic pathways through AT_1 receptors. [56] Exercise-loaded muscles depend on non-REM sleep-mediated anabolic hormone release and metabolic substrate regulation for repair. Disrupted sleep reduces secretion of growth hormone and impairs muscle protein synthesis, limiting recovery from microtrauma induced by training. [57, 58] Impaired recovery can potentiate persistent microdamage accumulation, reducing tissue resilience and predisposing athletes to overuse injuries. [59]

Circadian phase influences antioxidant enzyme expression, inflammatory response timing and muscle perfusion. Misaligned light-dark cycles blunt mitochondrial adaptations to exercise - evidenced in rodent models of social jet lag - suggesting circadian dysregulation disrupts physiological recovery pathways. [60]

6. Interventions and Strategies to Improve Sleep Quality and Circadian Alignment in Sports

6.1 Sleep-hygiene fundamentals

All interventions require good sleep hygiene practices, which should be emphasized for athletes regardless of their age or competitive level. Athletes need to establish a stable sleep-wake pattern by keeping their daily wake-up and bedtime hours consistent and develop relaxing pre-sleep routines. The evening should be free from caffeine and stimulants and electronic screens, while the sleeping area needs to remain dark and quiet, with a slightly cool temperature. [61] The practice of establishing consistent habits, including bed usage only for sleep, daytime phone use and pre-sleep relaxation (through reading or stretching), helps develop good sleep patterns. The reinforcement of consistent habits becomes crucial for youth and amateur athletes as they are more likely to face irregular schedules from early school hours and late social events. Maintaining a stable sleep routine, avoiding late caffeine intake and evening screen use, and ensuring an optimal sleep environment form the foundation of effective sleep hygiene and the first line of defense against sleep disturbances. [61] [62]

6.2 Light-based chronotherapy

The circadian clock alignment can be enhanced through non-pharmacological strategies. The body's rhythm can be advanced through morning exposure to natural sunlight right after waking up. Blue-light exposure from phones and TVs should be avoided during the last 1-2 hours before bedtime to prevent melatonin suppression. [61] Evening practices, such as dimming ambient light and using blue-blocker filters, can support the natural rise in sleepiness. [63]

6.3 Relaxation techniques and emerging phototherapies

Despite the limited number of high-quality trials in athletes, relaxation techniques such as breathing exercises, meditation, and gentle yoga are still widely recommended to reduce pre-competition stress and facilitate sleep onset. [64] [65] [66] Emerging evidence suggests light therapies can help: for example, a controlled study showed that nightly red-light irradiation over two weeks improved female basketball players' sleep quality and increased nocturnal melatonin levels. [67] Such noninvasive therapies may aid recovery, but their use remains experimental and should complement rather than replace good sleep habits.

6.4 Sleep extension and strategic napping

Supplemental sleep through extension or napping is another important intervention. In practice, this means encouraging athletes to build up sleep reserves by going to bed earlier or sleeping longer when possible, especially before intense competition or travel. Strategic napping can offset occasional sleep loss: short naps (20–90 minutes) after a normal night, or following partial sleep restriction, have been shown to restore alertness and motor performance to baseline. [68][69] In fact, systematic reviews conclude that increasing total sleep time, either through longer night-time sleep or scheduled naps, is among the most effective ways to boost both physical and cognitive performance in athletes. [68] [69] Coaches and trainers should therefore build in extra rest opportunities (e.g. midday naps after evening games) whenever schedules permit.

6.5 Chronotype-aligned scheduling

Training and competition timing should, where feasible, be aligned with individual chronotype. Athletes have innate morning/evening preferences that affect their peak performance times. [70] "Morning larks" tend to perform better earlier in the day, whereas "night owls" peak later. Recent expert analysis argues for tailoring practice and competition schedules to these chronotypes. [71] For example, if an adolescent (who is often a late chronotype) must train early, a gradual advance of wake time and use of bright light could be employed to shift their rhythm. Conversely, forcing an evening-type athlete into very early events without adjustment is likely to degrade performance. Recognizing and accommodating chronotype is increasingly viewed as a strategic advantage: one narrative review emphasized that diurnal preferences "significantly affect performance," suggesting that training sessions be personalized around each athlete's optimal times of day. [70] [71]

6.6 Pharmacological support (melatonin)

Pharmacological support is limited mainly to short-term melatonin supplementation, which can help re-entrain the circadian clock. Taken at the right time, melatonin (a hormone normally secreted at night) can advance or delay the sleep phase. For instance, low-dose melatonin in the late evening can help an athlete fall asleep earlier, especially after westward travel. A Cochrane meta-analysis found melatonin "remarkably effective" in reducing jet lag symptoms after transmeridian flights, with occasional short-term use being safe. [72] In practice, many sports medicine guidelines now include melatonin (typically 0.5–5 mg) for athletes who regularly cross ≥2 time zones. [72] Over-the-counter sleep aids besides melatonin are generally not recommended for routine use, both because of potential side effects and because they do not correct the underlying circadian misalignment. [72]

6.7 Travel and jet-lag management

Managing travel and competition schedules can help maintain circadian alignment. Before intercontinental travel, athletes can begin shifting their sleep times toward the destination time zone. During travel, adjusting the travel device clocks and adhering to the new time's light–dark cycle (e.g. using blackout masks on the plane, seeking morning light upon arrival) accelerates re-entrainment. Online tools and jet-lag calculators can provide individualized light-exposure schedules for eastward or westward travel. Coaches are also advised to encourage athletes to extend their sleep in advance of anticipated sleep loss. For example, a pilot study found that extending sleep in the days before intentional sleep deprivation (such as an early game after a late flight) improved subsequent performance[61].Bringing familiar items (pillows, blankets) from home and maintaining pre-sleep routines in new environments can further ease the transition to a new schedule. In sum, careful planning of sleep and light exposure around travel (often with melatonin at the new bedtime) helps minimize jet-lag effects on athletes' recovery and readiness.

7. Conclusions

The circadian rhythm and sleep quality exert a significant impact on the health and physical performance of athletes. Various forms of sleep deprivation lead to the deterioration of cognitive and physiological functions, reduced strength and motor coordination, lengthen reaction time and increased exhaustion. It is shown that circadian rhythm and sleep deprivation are common among athletes which derive from extensive training, travelling across time zones and competitions held at hours misaligned with athletes' chronotypes. The impact of sleep on mental and physical performance is crucial as both aerobic and anaerobic endurance decrease due to sleep deprivation. Sleep disturbances result in hormonal imbalances including increased cortisol levels, decreased testosterone and growth hormone levels. Poor sleep quality is connected to impaired tissue regeneration, inflammation and weakened motor and cognitive functions. All mentioned factors contribute to higher risk of injury. Chronotype significantly affects athletic performance thus athletes following their natural chronotype achieve better results than those whose schedules lead to circadian misalignment. Performance differences in strength and reaction time tests reach up to 5-6%.

There are some effective strategies for improving sleep quality such as maintaining sleep hygiene, using relaxation techniques, extending sleep through earlier bedtimes or daytime naps, using melatonin especially to manage jet lag, adjusting training and competition schedules to athletes' chronotypes. Assessment of sleep and circadian rhythm should become a standard component of medical care for athletes. Injury prevention and performance optimization could be supported by regular monitoring of sleep quality, chronotype as well as responses to travel across time zones. Nonetheless, factors such as chronotype, differences in sport disciplines and level of advancement need further research in order to develop more personalized recommendations for athletes.

Disclosure:
Author's contribution
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Writing – review and editing: Katarzyna Ciepłucha, Maria Wydra
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All authors have read and agreed with the published version of the manuscript.

Funding Statement: The study did not receive funding.

During the preparation of this paper, the authors utilized artificial intelligence (AI) tools, specifically ChatGPT, for writing and supporting scientific work. AI was employed to assist in tasks such as content generation, data analysis, and the structuring of the paper.

All AI-generated content has been properly reviewed, verified, and integrated into the research in accordance with academic integrity standards and the authors take full responsibility for substantive content of the scientific work.

Institutional Review Board Statement: Not applicable.
Informed Consent Statement: Not applicable.
Data Availability Statement: Not applicable.
Conflict of interest Statement: The authors declare no conflicts of interest.
Acknowledgments: Not applicable.

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