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Pharmacological and Non-Pharmacological Strategies for Enhancing Sleep Quality in Athletes: Implications for Performance and Recovery

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Abstract

Sleep is a critical determinant of recovery, performance, and overall well-being in athletes. Despite its importance, sleep disturbances—including insomnia, delayed sleep onset, and circadian rhythm disruption—are common in athletic populations, driven by both primary factors (e.g., overtraining, evening workouts, jet lag) and secondary factors (e.g., stress, injury, metabolic conditions). These disturbances can impair physical restoration, hormonal balance, and cognitive functioning. This review explores the physiological foundations of sleep in athletes, outlines the multifactorial causes of insomnia, and evaluates pharmacological strategies—including melatonin, non-benzodiazepine hypnotics, cannabidiol (CBD), and certain antidepressants—for managing sleep disorders. While pharmacotherapy may provide short-term benefits in select situations, non-pharmacological approaches such as Cognitive Behavioral Therapy for Insomnia (CBT-I) remain the gold standard due to their long-term efficacy and minimal side effects. An integrated, personalized approach that combines behavioral, physiological, and pharmacological strategies offers the greatest potential for optimizing sleep and supporting sustainable athletic performance.

Keywords: insomnia, sleep disturbance, athletes, pharmacotherapy

1. Introduction

Sleep plays a crucial role in the physiological processes essential for maintaining health and optimizing both physical and mental performance. In professional and amateur sports, sleep has gained increasing recognition as a key factor supporting recovery, training adaptation, and cognitive functions such as concentration, all of which directly impact athletic outcomes [1,2]. Sleep quality not only affects subjective well-being but also has measurable effects on physical performance parameters, hormonal balance, stress resilience, and injury risk [1,3].

Despite growing awareness of the role of sleep in sports, sleep disturbances are commonly reported among athletes. Contributing factors include intense evening training sessions, frequent travel for competitions, changes in time zones, and chronic stress related to performance pressure [2,4]. As a result, many athletes experience poor sleep quality, insomnia, or circadian rhythm disruptions, which can negatively influence both recovery and training capacity [1,4].

Given the prevalence of sleep issues and their potential consequences on athletic health and performance, a review of available pharmacological strategies to enhance sleep quality is warranted. The aim of this paper is to discuss the mechanisms of action, efficacy, and safety of selected pharmacological interventions, with a focus on their applicability in the athletic population.

2. Physiology of Sleep and Athletic Performance

Human sleep is divided into two main phases: NREM (non-rapid eye movement) and REM (rapid eye movement), which cycle throughout the night in intervals lasting approximately 90–110 minutes. Each phase serves distinct but complementary roles in the recovery process, which is especially crucial for athletes [5].

The NREM phase consists of three stages (N1, N2, and N3), with the deepest stage—N3, also known as slow-wave sleep (SWS)—playing a vital role in physical restoration. During this stage, the secretion of growth hormone (GH) peaks, facilitating tissue repair, protein synthesis, and muscle growth. Moreover, NREM sleep supports the brain's metabolic detoxification through activation of the glymphatic system, while also contributing to cardiovascular recovery by lowering heart rate and blood pressure [5–8].

The REM phase, characterized by heightened brain activity, rapid eye movements, and vivid dreaming, is essential for memory consolidation, learning, and psychological adaptation to stress. In athletes, REM sleep enhances the assimilation of complex motor patterns and mental strategies, contributing to improved performance in disciplines that require coordination and planning [9–11].

Disruptions in sleep quality—such as reduced N3 sleep or fragmented REM cycles—can impair recovery, increase injury risk, weaken the immune system, and reduce motivation and focus [12–14]. Therefore, both the quantity and quality of sleep are fundamental components of effective recovery strategies in both elite and recreational sports [15].

3. Causes of Sleep Disturbances in Athletes

Sleep disruptions are common among athletes due to a range of physical, psychological, and environmental influences. These factors can be divided into primary causes, directly related to training and competition routines, and secondary causes, which stem from emotional stressors, injuries, and health conditions [16].

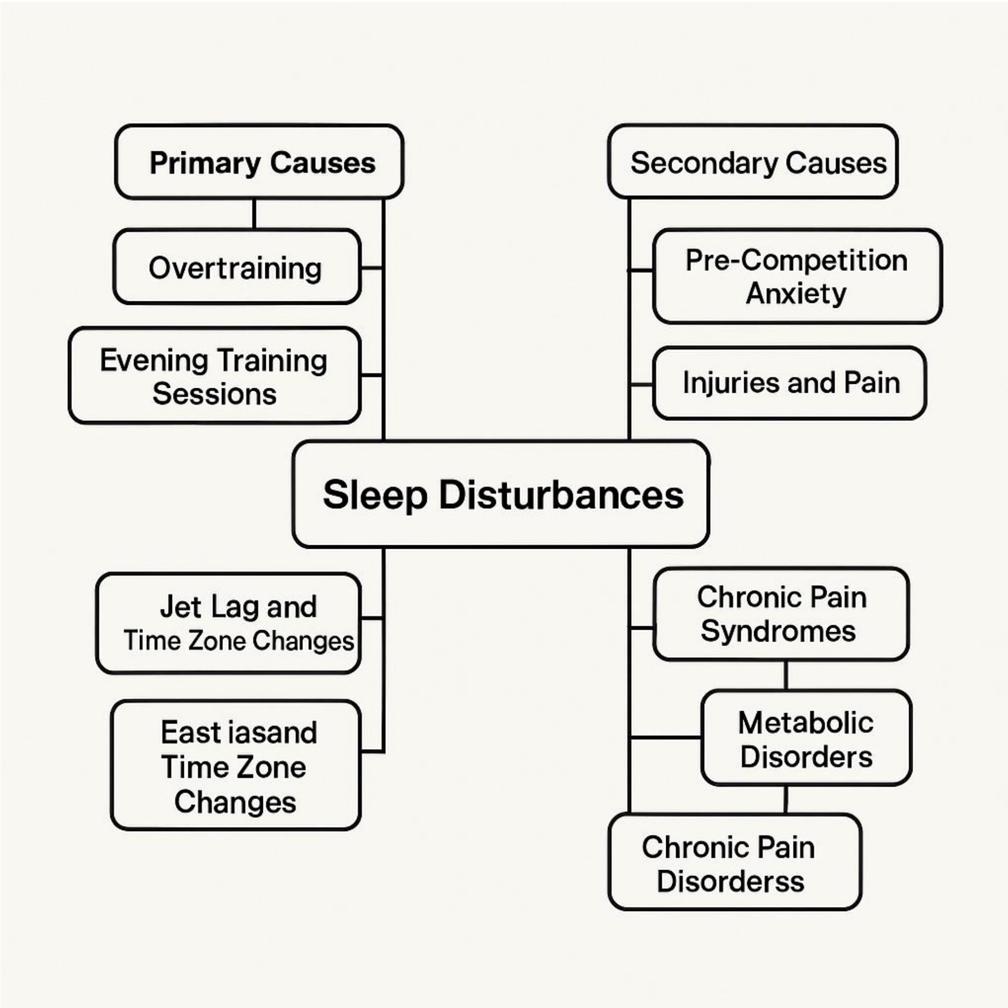

Fig. 1. Causes of Sleep Disturbances in Athletes.

3.1 Primary Causes

Overtraining and Inadequate Recovery

An excessive training load without sufficient recovery can lead to the development of overtraining syndrome (OTS)—a maladaptive physiological and psychological response to prolonged high-intensity exercise. OTS is characterized by persistent fatigue, performance decline, and alterations in hormonal, immune, and neurological systems, all of which contribute to disturbed sleep patterns. One of the key physiological features of OTS is the dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis, which results in chronically elevated cortisol levels. Cortisol, known as the primary stress hormone, plays a central role in the body's circadian rhythm. When elevated persistently, it can disrupt the normal cycling of melatonin and suppress the onset of sleep, leading to delayed sleep onset, fragmented sleep, and reduced sleep efficiency [17,18].

In addition to its physiological consequences, OTS is also strongly linked to psychological disturbances, including mood swings, irritability, anxiety, and depressive symptoms. These mood changes are not simply a consequence of poor performance or fatigue but are often intrinsically connected to neuroendocrine imbalances triggered by chronic stress and inflammation. For instance, overtrained athletes frequently show increased levels of pro-inflammatory cytokines, which are associated with both depression and sleep disturbances. Furthermore, the disruption of neurotransmitter balance—particularly serotonin and dopamine, which regulate mood and sleep—can contribute to both insomnia and hypersomnia, as well as a blunted emotional response and anhedonia [19,20].

The cyclical relationship between poor sleep and psychological stress further exacerbates OTS. Sleep deprivation impairs emotional regulation, intensifies feelings of fatigue, and may worsen depressive symptoms, which in turn create a negative feedback loop that deepens sleep dysfunction [21]. These findings underscore the importance of recognizing changes in sleep patterns and emotional wellbeing as early warning signs of overtraining, rather than viewing them in isolation. Monitoring sleep through wearable devices and psychological screening tools can provide valuable data for coaches and healthcare providers to intervene early and prevent full-blown OTS [22].

Evening Workouts

Engaging in high-intensity training sessions late in the evening can significantly disrupt normal sleep physiology. This disruption is primarily attributed to increased physiological arousal, which manifests as elevated heart rate, heightened respiratory activity, increased core body temperature, and elevated secretion of stimulating hormones such as adrenaline, noradrenaline, and cortisol. These hormonal shifts activate the sympathetic nervous system, maintaining a state of heightened alertness that interferes with the natural wind-down process required for restful sleep [23].

One of the key mechanisms behind this effect is the delay in melatonin secretion, the hormone produced by the pineal gland that helps regulate the sleep-wake cycle. High body temperature and sympathetic activation can suppress or postpone melatonin release, which in turn delays sleep onset and may shorten total sleep duration. In individuals who train close to bedtime, especially within 1–2 hours of trying to sleep, this can lead to increased sleep latency (the time it takes to fall asleep), more restless sleep, and in some cases, reduced time spent in deep (NREM) or REM sleep [24,25].

However, the impact of evening exercise on sleep can vary significantly between individuals, depending on factors such as chronotype (whether someone is naturally a "morning" or "evening" person), habitual training schedules, and overall fitness level. Some athletes who consistently train at night may experience adaptive responses over time, resulting in fewer disturbances. In these cases, the body may gradually adjust its circadian rhythm to accommodate a later wind-down period. Nonetheless, for most people, especially those with early sleep schedules or high training loads, late-night exercise is associated with lower sleep efficiency and reduced sleep quality [26,27].

To optimize sleep hygiene, experts often recommend scheduling intense workouts earlier in the day, ideally finishing strenuous activity at least 3 hours before bedtime, allowing the body sufficient time to return to a parasympathetic (rest-and-digest) state. Light or moderate physical activity in the evening (such as stretching, yoga, or walking) is less likely to have these disruptive effects and may even aid in sleep initiation [28].

Time Zone Shifts and Jet Lag

Athletes who frequently travel across multiple time zones, particularly for international competitions, are at a heightened risk of experiencing circadian rhythm misalignment, commonly known as jet lag. This condition results from the desynchronization between the body's internal biological clock, regulated primarily by the suprachiasmatic nucleus (SCN) in the hypothalamus, and the external cues of the new local environment, such as light, temperature, and social schedules. This misalignment can lead to a constellation of symptoms including difficulty falling asleep (sleep-onset insomnia), frequent nocturnal awakenings, non-restorative sleep, and daytime fatigue [29]. The effects of jet lag may also extend beyond sleep, impairing cognitive function, mood, reaction time, and physical performance, all of which are critical for athletic success [30].

The severity and duration of jet lag depend on the number of time zones crossed, the direction of travel, and the individual's chronotype (morningness vs. eveningness). Travel in an eastward direction—for example, from New York to Europe—is generally more difficult to adapt to than westward travel. This is because eastward flights require athletes to advance their internal clock (i.e., fall asleep and wake up earlier), which is biologically harder than delaying the sleep phase, as our natural circadian rhythm tends to run slightly longer than 24 hours. As a result, eastward travelers often experience prolonged jet lag symptoms, with more pronounced sleep disturbances and reduced next-day alertness [31,32].

Moreover, jet lag doesn't just affect nighttime sleep—it can disrupt the architecture of sleep itself, reducing the proportion of deep NREM and REM sleep, both essential for recovery, memory consolidation, and emotional regulation. Athletes may find that despite sleeping for an adequate number of hours, they still feel unrefreshed due to fragmented or low-quality sleep [33]. These disturbances can impair training adaptation, muscle repair, and injury prevention, which are tightly linked to sleep-dependent recovery mechanisms [34].

To mitigate the negative effects of jet lag, sports scientists recommend several strategies. These include gradually adjusting sleep and wake times a few days before departure, exposure to natural light upon arrival to reset the circadian clock, and the use of melatonin supplementation or light therapy in some cases [35]. Proper hydration, avoiding caffeine and alcohol, and strategic napping may also help smooth the adjustment to a new time zone. Elite athletes and teams often consult chronobiologists or sleep specialists to optimize these protocols and reduce performance losses related to circadian disruption [36].

3.2 Secondary Causes

Pre-Event Stress and Mental Tension

The anticipation of competition often induces stress and performance anxiety, which can lead to hyperarousal at bedtime. Athletes commonly experience difficulty falling asleep the night before important events. This anxiety-driven sleep disturbance can result in insufficient rest, impairing cognitive focus and reaction times during performance. Elevated activity of the hypothalamic-pituitary-adrenal (HPA) axis plays a central role in this phenomenon [37].

Injuries and Chronic Pain

Injuries sustained during training or competition are another major contributor to disturbed sleep. Pain from acute or chronic conditions can interrupt sleep cycles, leading to frequent awakenings or difficulty staying asleep. Chronic pain is both a cause and a consequence of insufficient rest, as sleep deprivation can heighten pain sensitivity. This reciprocal relationship can create a vicious cycle that impairs both recovery and mental wellbeing [39]. Additionally, some medications prescribed for pain management may alter sleep architecture, especially by suppressing REM sleep or altering the duration of deep sleep stages [38].

Metabolic Issues in Athletes (e.g., Diabetes)

Athletes with diabetes mellitus or other metabolic disorders often face unique challenges related to sleep. One major factor is nocturnal blood glucose variability. Episodes of hypoglycemia during sleep can trigger sympathetic activation—causing sweating, palpitations, and awakenings—while hyperglycemia may lead to frequent urination and disrupted rest [40]. These fluctuations fragment sleep and reduce time spent in deep, restorative stages, impairing recovery [41].

Additionally, diabetic neuropathy, common in long-term diabetes, can cause nighttime pain and discomfort in the limbs, making it difficult to fall or stay asleep. Poor glycemic control has also been linked to altered melatonin secretion and disrupted circadian rhythms, which may shift or delay the sleep-wake cycle [42,43].

Emerging evidence suggests a bi-directional relationship between poor sleep and metabolic health. Sleep deprivation worsens insulin resistance and glucose tolerance, while dysregulated blood sugar can further impair sleep quality [44]. For athletes, this creates a cycle that can undermine recovery, performance, and injury prevention.

4. Overview of Pharmacological Interventions

A range of pharmacological agents has been explored to support sleep in athletes, particularly in situations where behavioral interventions prove insufficient or impractical. This section outlines the most commonly discussed substances, focusing on their mechanisms of action, efficacy, potential side effects, and relevance to the athletic population.

4.1 Melatonin

Melatonin is a hormone naturally secreted by the pineal gland that plays a key role in regulating circadian rhythms and promoting the onset of sleep. Its secretion increases in response to darkness and is inhibited by light exposure, aligning the sleep-wake cycle with environmental cues. Due to its physiological role, ease of synthesis, and convenient oral administration, melatonin has garnered significant interest as a potential therapeutic option for managing insomnia [45-47].

In athletes, exogenous melatonin is often used to manage circadian rhythm disruptions such as jet lag or delayed sleep phase syndrome. Effective doses range from 0.5 to 5 mg, typically administered 30–60 minutes before the desired bedtime or timed strategically when traveling across time zones [48,49].

Studies have demonstrated melatonin's efficacy in improving sleep onset latency and subjective sleep quality in athletes, particularly during travel or periods of competition stress [50,51]. However, evidence on its effects on physical performance is mixed, with some studies suggesting improved recovery markers and others reporting minimal impact [52].

Melatonin is available in a variety of formulations, including immediate-release, prolonged-release, and sublingual preparations. Immediate-release formulations may be more effective for sleep initiation, while prolonged-release products may benefit individuals with frequent night awakenings. Importantly, bioavailability varies significantly between individuals, influenced by factors such as liver metabolism, age, and gastrointestinal absorption. In athletes, these differences underscore the importance of personalized dosing and formulation choice. Additionally, the quality and labeling accuracy of over-the-counter melatonin supplements can vary widely; thus, using pharmaceutical-grade or third-party tested products is strongly recommended, especially in competitive settings where contamination with banned substances is a concern. [45,47,48]

4.2 Non-benzodiazepine Hypnotics

Non-benzodiazepine hypnotics, often referred to as Z-drugs, include agents such as zolpidem and zaleplon. They act on the GABA-A receptor complex to promote sedation and are characterized by their short half-lives and reduced residual sedation compared to benzodiazepines [53,54].

These agents have been used by athletes primarily in the short-term management of acute sleep disturbances, such as those caused by transmeridian travel (jet lag). Zolpidem, in particular, has been shown to reduce sleep latency and increase total sleep time when used sparingly [55,56].

However, the use of Z-drugs is associated with risks, including tolerance, dependence, cognitive impairment, and next-day drowsiness, which may impair athletic performance or increase injury risk [53,57,58]. Because of these risks, their use in athletes should be cautious and limited to short durations under medical supervision.

4.3 Cannabidiol (CBD)

Cannabidiol (CBD), a non-psychoactive compound derived from cannabis, has gained popularity for its potential anxiolytic and sleep-promoting effects. CBD appears to interact with serotonin receptors and the endocannabinoid system, which are implicated in mood regulation and sleep-wake cycles [59,60].

Emerging evidence suggests that CBD may improve subjective sleep quality and reduce anxiety in both general and athletic populations, potentially supporting post-exercise recovery and stress management [61,62]. However, findings remain inconsistent due to small sample sizes and variability in dosing and formulations.

Legal status varies globally, but CBD is generally permitted in sports, provided it is free from tetrahydrocannabinol (THC), which remains banned by WADA (World Anti-Doping Agency) [63]. Despite its potential, the paucity of high-quality research necessitates caution, especially regarding long-term use and interactions with other substances.(64)

4.4 Antidepressants / Anxiolytics

In cases of secondary insomnia related to anxiety or mood disorders, certain antidepressants and anxiolytics are prescribed off-label to promote sleep. Agents such as trazodone, mirtazapine, or low-dose tricyclic antidepressants (e.g., amitriptyline) have sedative properties that may benefit select athletes [65-67].

These medications may help regulate sleep through serotonergic and histaminergic mechanisms and are sometimes chosen for their lower abuse potential compared to traditional hypnotics. However, they carry their own side-effect profiles—ranging from weight gain and fatigue to cardiac concerns—and require individualized assessment [68-70].

Given the potential for mood-altering effects and ethical concerns surrounding off-label use in healthy individuals, these medications should be reserved for well-diagnosed psychiatric comorbidities and prescribed with careful clinical oversight.

5. Comparison with Non-Pharmacological Interventions

Comparison of Pharmacological and Non-Pharmacological Approaches to Sleep in Athletes

	Pharmacological Approaches	Non-Phermacolological Approacches
Examples	Melatonin, Z-drugs (e.g., zolpidem), CBD, antidepress:	CBT-I, sleep hygiene, relaxation techniques, mindfuiness
Primary Mechanism	Neurochemical modulation (e.g. GABAergic, serotonergc)	Behavioral and cognitive restructuring
Onset of Action	Rapid (within minutes to hours)	Moderate; often used as supportive
Short-Term Effectiveness	High, especially for acute insomnia or jet lag e ffects	High: especially CBT-I, with sustained improvements
Risk of Dependence	Present (notably with Z-drugs, benzodiazepines)	None
Side Effects	Drowsiness, cognitive impairment, dependence, vivid dreams	Minimal; may include frustration or low initial motivation
Doping Risk (WADA)	Possible (e.g, contamination or use of banned substances	None
Cost and Accessibility	May require prescription, cost varies	CBT-I may require trained therapist; hygiene is low-cost
Preferred Use Case	Acute insomnia, travel-related	Chronic insomnia, can be coombined

Fig. 2. Comparison of Pharmacological and Non-Pharmacological Approaches to Sleep in Athletes

The management of insomnia involves both pharmacological and non-pharmacological approaches. Among the non-pharmacological strategies, sleep hygiene, relaxation techniques, and Cognitive Behavioral Therapy for Insomnia (CBT-I) are commonly employed.

Sleep hygiene refers to behavioral and environmental practices that promote healthy sleep. These include maintaining a consistent sleep schedule, avoiding stimulants such as caffeine and alcohol before bedtime, ensuring a quiet and dark sleep environment, and limiting daytime napping. However, studies suggest that sleep hygiene alone is insufficient as a standalone treatment for chronic insomnia, especially in cases of long-standing or complex sleep difficulties [71].

Relaxation techniques, such as progressive muscle relaxation, deep breathing, mindfulness, and guided imagery, are used to reduce physiological arousal and stress that can interfere with sleep. While these methods may provide subjective benefits, they are generally more effective when used as part of a broader therapeutic approach rather than in isolation [71].

Cognitive Behavioral Therapy for Insomnia (CBT-I) is widely regarded as the first-line treatment for chronic insomnia. It incorporates various components, including stimulus control, sleep restriction therapy, cognitive restructuring, and relaxation training, to target both the behavioral and cognitive factors that maintain sleep difficulties. Numerous studies have demonstrated that CBT-I is more effective than pharmacotherapy in the long term, with improvements in sleep parameters persisting well beyond the end of treatment [72,73]. Furthermore, CBT-I does not carry the risks of dependence or adverse effects associated with sedative medications, making it a particularly attractive option for athletes and other high-functioning populations [72].

When Pharmacotherapy Is More Advantageous – and When It Is Not

Pharmacological treatment—using agents such as melatonin, non-benzodiazepine hypnotics, or off-label medications—can be helpful in the short-term, particularly in cases of acute insomnia related to situational stress, pre-competition anxiety, or jet lag from transmeridian travel. In such scenarios, medications may offer rapid symptom relief, which can be valuable when time is limited or when sleep deprivation poses immediate risks to performance or safety [4].

However, the long-term use of sleep medications is associated with significant risks, including the development of tolerance, dependency, residual daytime sedation, and impaired cognitive function. For this reason, pharmacological interventions are not recommended as a first-line treatment for chronic insomnia, unless other methods have failed or are unavailable [74,75].

In contrast, non-pharmacological approaches—particularly CBT-I—are associated with sustained improvements in sleep quality and quantity, and are thus favored for the long-term management of insomnia. Importantly, CBT-I can also be used in combination with pharmacotherapy, especially during the initial treatment phase, to provide both rapid relief and long-lasting effects [72,76].

Ultimately, the choice between pharmacological and non-pharmacological interventions should be individualized, based on the severity and duration of insomnia, the presence of comorbid medical or psychiatric conditions, patient preferences, and the availability of qualified practitioners or therapeutic resources.

6. Risks, Ethical Considerations, and Doping Issues

The use of pharmacological agents to manage sleep disturbances in athletes involves several risks, ethical considerations, and regulatory challenges, particularly with medications such as non-benzodiazepine hypnotics (Z-drugs) and other sedatives.

Potential for Misuse and Dependence

Z-drugs like zolpidem and zopiclone are commonly prescribed for short-term treatment of insomnia. However, growing evidence highlights their potential for misuse, tolerance, and dependence [77]. While direct data from athlete populations are limited, the high-pressure environment of competitive sports may increase vulnerability to the overuse of sleep aids. Athletes may also experience rebound insomnia or withdrawal symptoms upon discontinuation after prolonged use. Moreover, substance use disorders in athletes are a recognized issue that requires dedicated prevention and monitoring strategies [78].

Doping Regulations and Prohibited Substances

Athletes must adhere to strict anti-doping regulations outlined by the World Anti-Doping Agency (WADA). Although Z-drugs are currently not on the WADA Prohibited List, other medications used for sleep disturbances, such as certain cannabinoids or narcotics, are banned in competition due to their psychoactive properties or potential performance-enhancing effects [79]. For example, the in-competition use of cannabis has been prohibited since 2004, despite its growing use in the general population and some athlete groups [80].

Recent high-profile doping cases highlight the risk of supplement contamination, even when using products intended to improve sleep. An illustrative example is the 2024 suspension of a top-tier athlete due to trimetazidine (TMZ) contamination in a melatonin-based supplement. This underscores the need for vigilance when sourcing over-the-counter products, even for substances generally considered safe.

Role of Sports Physicians and Responsible Prescribing

Sports physicians play a key role in guiding the appropriate use of sleep medications, ensuring that treatment choices reflect both clinical necessity and ethical standards. Responsible prescribing involves careful assessment of risks vs. benefits, particularly with medications that may affect cognitive function, reaction time, or carry a risk of dependence. Physicians should prioritize non-pharmacological interventions such as CBT-I as a first-line approach when feasible and reserve pharmacotherapy for short-term or specific clinical situations [81].

In addition, sports doctors must stay updated with WADA's Prohibited List and educate athletes about the risks of unregulated supplements. The use of third-party tested products is crucial to minimize the risk of inadvertent doping violations, and shared decision-making with the athlete is essential to maintain both performance integrity and long-term health.

8. Conclusion

Sleep is an essential component of recovery, performance, and overall well-being in athletes. As research continues to highlight the close relationship between sleep quality and athletic performance, the need for effective interventions—especially in populations vulnerable to circadian disruption and stress-related insomnia—becomes increasingly evident.

Pharmacological treatments, such as melatonin, non-benzodiazepine hypnotics, and emerging agents like cannabidiol (CBD), can offer short-term relief and help manage acute sleep disturbances. However, these interventions should be viewed as supportive tools rather than first-line therapies, particularly given the potential for side effects, tolerance, dependency, and, in some cases, unintentional anti-doping violations.

A balanced, athlete-centered approach is essential. Non-pharmacological strategies, especially Cognitive Behavioral Therapy for Insomnia (CBT-I), continue to demonstrate long-term effectiveness without the risks associated with pharmacotherapy. These behavioral interventions, combined with proper sleep hygiene, stress management, and individualized support, should remain the foundation of sleep care in sports medicine.

In conclusion, while pharmacological interventions can be valuable in specific scenarios, they are most effective when integrated thoughtfully into a broader, multi-modal strategy that prioritizes lifestyle optimization and psychological resilience. This integrated approach supports not only better sleep but also sustainable athletic health and performance.

Disclosure

Authors contribution statement:

Conceptualization: Paulina Tymińska, Julia Frączek, Wiktoria Donocik, Karolina Borówka, Piotr Górka, Natalia Kawka
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