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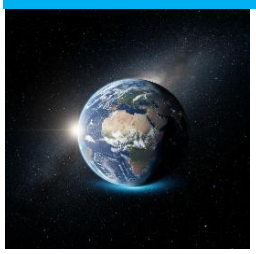

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# Sleep as an 'Ergogenic Supplement': The Role of Sleep Quality, Duration and Patterns in Preventing Sports Injuries - A Systematic Review

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## ABSTRACT

**BACKGROUND:** Sleep is recognized as a key factor influencing athletic performance and injury prevention. Despite growing interest in sleep as a modifiable risk factor, the relationship between sleep parameters and the risk of sports injuries requires systematic evaluation.

**AIM:** This study focuses on presenting the relationship between the duration, quality and patterns of sleep and the occurrence and prevention of sports injuries based on current knowledge.

**MATERIAL AND METHODS:** This systematic review was conducted using multiple databases, including ScienceDirect, PubMed and Google Scholar. After removing duplicates,

165 unique articles compatible with the study topic were identified. The 31 most relevant articles were selected and used to analyse the association between sleep parameters and the effects of sports injuries in athlete populations.

**RESULTS:** Strong evidence has been identified linking insufficient sleep to an increased risk of sports injuries in many groups of athletes. In addition, the study confirmed that poor sleep quality was associated with a significantly higher likelihood of injury. The study confirmed mechanisms connecting sleep and injury include impaired cognitive function, slowed reaction time, weakened neuromuscular control, increased inflammation and impaired tissue regeneration.

**CONCLUSIONS:** Evidence shows that sleep has a protective effect against injuries when it is sufficiently long and of adequate quality. Healthcare professionals, coaches and athletes should prioritise sleep hygiene measures as part of comprehensive injury prevention strategies.

**KEY WORDS:** sleep, sports injury, injury prevention, sleep duration, sleep quality, sleep patterns, athletic performance, systematic review

## 1. INTRODUCTION

Injuries related to physical activity are significant health problems that affect all athletes, generating serious physical, emotional and financial burdens [1, 2]. While traditional methods of injury prevention focus on biomechanical factors, training load management and equipment adjustment, new research suggests that sleep – a crucial biological process – may play a critical role in injury susceptibility [3, 4, 5].

Sleep has a number of important roles in recovery that are essential for athletic performance and healing, including tissue regeneration, immune system function, metabolic regulation and cognitive recovery [2, 6]. Although it is recommended that adults sleep 7 to 9 hours per day, athletes often struggle with sleep deprivation due to early morning sessions, late competitions, travels, academic commitments and psychosocial stressors [1, 7, 8]. Collegiate athletes, in particular, face exceptional challenges in balancing athletic, educational and social demands, which typically leads to chronic sleep restriction [2, 9]. Beyond sleep duration, daily changes in bedtime and wake-up times can negatively impact sleep quality and preparation for the next day, which can increase the risk of injury during intense workouts [20, 22].

The idea of sleep as an ‘ergogenic supplement’ – a performance-enhancing agent – has gained traction in sports science literature [10]. Experimental sleep extension in collegiate basketball players improved sport-specific performance and daytime alertness, supporting the concept of sleep as a practical ergogenic strategy [11]. However, while the performance benefits

of adequate sleep are increasingly recognised, the protective effects of sleep against sports injuries require systematic evaluation [4, 12]. Understanding the relationship between various sleep parameters (duration, quality and patterns) and the risk of injury is crucial for the development of evidence-based prevention strategies [3]. Standardized measurement of sleep quality in sport settings commonly relies on validated instruments such as the Pittsburgh Sleep Quality Index (PSQI) [13]. In addition, athlete-specific screening tools (e.g., the Athlete Sleep Behavior Questionnaire, ASBQ) help identify maladaptive sleep practices and show acceptable reliability and associations with actigraphy-derived sleep outcomes [14].

Previous studies have identified several potential mechanisms that may link sleep deprivation to an increased risk of injury, such as impaired cognitive and decision-making functions, reduced reaction time, compromised neuromuscular control, increased inflammation, impaired tissue repair and hormonal dysregulation [4, 12, 15]. However, the strength and consistency of these associations across different populations of athletes, sports disciplines, and levels of competition remain unclear [4, 16].

### 1.1 Research Objective

The main purpose of this systematic review is to examine in detail the relationship between sleep parameters and the risk of sports injuries among athletes. Specific objectives include:

1. Determining the relationship between sleep duration and injury frequency in different groups of athletes.
2. To analyse the relationship between sleep quality and injury consequences.
3. Identification of biological and physiological mechanisms connecting sleep deprivation to an increased risk of injuries.
4. To examine the consistency of research findings across different sports, skill levels, and age groups.
5. Evaluation of the quality and limitations of existing research.
6. Presentation of evidence-based recommendations for athletes, coaches, and sports medicine professionals aimed at optimising sleep in the context of injury prevention.

## 2. RESEARCH MATERIAL AND METHODS

This section presents the research strategy and selection criteria used to conduct a systematic review of the available literature. To ensure objectivity and reproducibility of results, the data collection and analysis process followed a structured framework. This included a

thorough search of electronic databases, the use of specific keywords, and a rigorous quality assessment of identified publications.

### 2.1 Qualification Criteria

*Inclusion criteria:*

- Studies investigating the relationship between sleep parameters (duration, quality, patterns, disturbances) and the effects of sports injuries
- Groups of athletes, including competitive athletes, students, young people and recreational athletes
- Prospective cohort studies, retrospective analyses, cross-sectional studies, systematic reviews, and meta-analyses
- Studies describing quantitative relationships between sleep and injuries (e. g., odds ratios, relative risks, risk ratios, injury rates)
- Studies written in English
- Studies with human participants

*Exclusion criteria:*

- Studies that do not present original data on the relationship between sleep and injuries
- Populations that do not participate in sports
- Studies focusing exclusively on sleep and performance, ignoring the effects of injuries
- Case reports without the possibility of generalising the results
- Studies with inadequate methodological details

### 2.2 Sources of Information

A systematic search of the literature was conducted in multiple databases to provide comprehensive coverage of suitable literature:

1. ScienceDirect database: 297 articles were found
2. PubMed database: 61 articles were found
3. Google Scholar: 119 articles were found

### 2.3 Search Strategy

The search strategy used a combination of keywords to find relevant literature. All searches were done without date restrictions to cover the full range of available evidence. However,

during the selection process, emphasis was placed on contemporary research to ensure the findings reflect current athletic environments and modern recovery protocols.

*Search Terms:*

- Sleep-related: ‘sleep’, ‘sleep duration’, ‘sleep quality’, ‘sleep deprivation’, ‘sleep disorders’, ‘sleep hygiene’, ‘sleep patterns’
- Injury-related: ‘sports injuries’, ‘athletic injuries’, ‘injury risk’, ‘injury prevention’, ‘musculoskeletal injuries’
- Population-related: ‘athletes’, ‘sport’, ‘sport performance’, ‘university athletes’, ‘elite athletes’
- Intervention-related: ‘ergogenic’, ‘ergogenic aids’, ‘ergogenic supplements’

*Search Sequences:*

- (‘sleep’ OR ‘sleep duration’ OR ‘sleep quality’) AND (‘sports injuries’ OR ‘athletic injuries’) AND (‘prevention’ OR ‘risk factors’)
- (‘sleep deprivation’ OR ‘insufficient sleep’) AND (‘athletes’ OR ‘athletic performance’) AND ‘injury’
- ‘ergogenic’ AND ‘sleep’ AND (‘athletes’ OR ‘athletic performance’)

**2.4 Selection Process**

The selection process was carried out using a systematic approach:

1. Preliminary search: a total of 477 articles were found in all databases (297 from ScienceDirect, 61 from PubMed and 119 from Google Scholar).
2. Duplicate removal: duplicate articles were identified and removed using manual verification (records after deduplication: n = 165).
3. Accuracy ranking: articles were ranked according to their relevance to the research question using an algorithmic rating system based on title, abstract and keyword matching.
4. Selection: the 31 most accurate articles were selected for full review based on relevance scores.

**2.5 Data Collection Process**

Data collection was carried out systematically using a standard extraction form. The following information was gathered for each study included:

- Study characteristics (authors, year, journal, study design)

- Characteristics of the population (sample size, age, gender, type of sport, level of proficiency)
- Sleep parameters (duration, quality, patterns)
- Effects of injuries (type of injury, severity, incidence)
- Statistical associations (odds ratios, relative risk, risk ratios, confidence intervals, p-values)
- Possible mechanisms linking sleep and injuries
- Study limitations and risk of methodological bias

**2.6 Data Elements**

*Primary Outcomes:*

-Frequency or prevalence of sports injuries

-Risk ratios for injuries, odds ratios or risk ratios associated with sleep parameters

-Time to injury

*Sleep-Related Exposure Variables:*

- Sleep duration (hours per day)
- Sleep quality (subjective ratings, validated questionnaires)
- Sleep patterns (regularity, timing, disturbances)
- Sleep disorders (insomnia, sleep apnoea, restless legs syndrome)

*Secondary Outcomes:*

- Severity of injury (need for medical attention)
- Type of injury (acute or overuse, specific anatomical locations)
- Mechanisms linking sleep to injury

**2.7 Study Risk of Bias**

Study quality and risk of bias were measured using the appropriate tools based on study design:

1. Prospective cohort studies: Newcastle-Ottawa Scale for Cohort Studies
2. Systematic reviews and meta-analyses: AMSTAR 2
3. Cross-sectional studies: Modified Newcastle-Ottawa Scale

Risk of bias domains assessed included: selection bias (representativeness of sample, selection of controls); performance bias (measurement of exposures and outcomes); detection bias (blinding of outcome assessment); attrition bias (completeness of follow-up); reporting bias (selective outcome reporting).

### 2.8 Synthesis Methods

Due to the diversity of study designs, populations, sleep measurements, and definitions of injuries, a narrative synthesis method was used instead of a meta-analysis. The studies were grouped thematically according to:

1. Sleep duration and injury risk
2. Sleep quality and injury risk
3. Sleep patterns and injury outcomes
4. Findings for specific populations (adolescents, university athletes, elite athletes, endurance athletes)
5. Findings for specific sports disciplines

For each topic, findings were synthesised narratively, highlighting consistent patterns, contradictory findings, and evidence gaps. Quantitative findings (odds ratios, relative risks, hazard ratios) were extracted and presented with 95 per cent confidence intervals, where available.

## 3. RESEARCH RESULTS

### 3.1 Sleep Duration and Injury Risk

The relationship between sleep duration and sports injury risk has been studied in 18 different studies and the results have been consistent across different groups and sports.

*Young Athletes:* Milewski and his team carried out an important study involving 112 young athletes (average age 15, range 12 to 18) and found that those who sleep less than 8 hours per night are 1.7 times more likely to experience an injury compared to those who sleep 8 hours or more (95% CI: 1.0-3.0, p=0.04). Single-factor analysis revealed an even clearer association, with a relative risk of 2.1 (95% CI: 1.2-3.9, p=0.01). The amount of sleep per night was found to be a significant independent predictor of injuries in a multi-factor analysis [16]. A systematic review and meta-analysis conducted by Gao focused on adolescents under the age of 19 and found that those who regularly sleep less than 8 hours per night or have frequent sleep problems are more likely to suffer sports injuries or musculoskeletal disorders [10]. An annual cohort study of young competitive athletes showed that sleep duration is a significant risk factor for sports injuries, alongside female gender and training intensity. The athletes participating in this study slept an average of only 6.3 hours, which is well below the recommended level [18].

*Collegiate Athletes:* Among university basketball players, it was observed that short sleep duration is a separate factor predicting injuries during the season in men. This association persisted even after taking into account training load and personal well-being, suggesting that sleep duration has an independent effect on injury risk [12]. Senbel and other authors analysed Division 1 female basketball players over a 22-week period and found that student athletes slept less than recommended (6-7 hours instead of 8). This insufficient amount of sleep, together with breaks in training, significantly increased the risk of injury. Their machine learning model predicted injuries with over 90% accuracy (F2 score of 0.83) and unhealthy sleep habits were found to be a key prognostic factor [1]. A total of 181 student athletes playing football and basketball (42% female, mean age 20.0±1.7 years) were examined and it was found that 36.1% of them experienced insufficient sleep duration (<7 hours). Student athletes with poor sleep quality had a significantly higher risk of injury (OR: 2.2, 95% CI: 1.04-4.79, p=0.039) [3]. Over 24 NCAA Division I female football players were examined during the 2019 autumn season and K-means clustering was used to divide the players into three groups based on their injury status. Sleep time was significantly shorter in the group of athletes with serious injuries than in the other groups, with small but important effect (d=0.282, p<0.001; d=0.278, p<0.001) [27].

*Elite and Professional Athletes:* A study conducted on a group of 152 professional footballers (91 men, 61 women; average age 21.82±4.44 years) from the premier and first leagues revealed that shorter total sleep time during the off-season was significantly associated with football injuries (OR: 0.66, 95% CI: 0.51-0.85, p=0.002). Athletes who answered ‘no’ to the question ‘did you regularly get enough sleep during off-season’ were 5.64 times more likely to suffer injuries, while those who answered “no” to the question ‘do you think that your sleeping hours during off-season were enough’ had a 4.76 times higher risk [8]. Butovskiy's study analysed 236 talented young footballers from leading football academies and youth national teams. Sleep disorders, assessed using the Pittsburgh Sleep Quality Index (PSQI), had a significant impact on injuries. Seven per cent of the subjects had sleep problems according to the PSQI, while 10 per cent had sleep problems according to the ASBQ questionnaire, and 59 per cent experienced significant or moderate daytime sleepiness [19].

*Endurance Athletes:* A prospective study was conducted involving 95 professional endurance athletes from disciplines such as running, triathlon, swimming, cycling and rowing, of whom 92.6% provided data for all 52 weeks. The risk of new injuries increased significantly with a 14-day lag of <7 hours of sleep per night (hazard ratio [HR] = 1.51, 95% CI: 1.13-2.02, p < 0.01) [4]. In contrast, sleep lasting more than 7 hours per day greatly reduced the risk of new injuries (HR = 0.63, 95% CI: 0.45-0.87, p < 0.01) [4]. Johnston and his colleagues analysed

general health problems and sleep among endurance athletes in a prospective study, confirming the relationship between sleep and the risk of new injuries [24].

Studies have shown a clear correlation between sleep duration and the incidence of sports injuries – the risk of injury increased gradually as sleep duration fell below 8 hours per day. The critical level appears to be 7–8 hours and under this level the risk of injury increases significantly.

### 3.2 Sleep Quality and Injury Risk

Numerous studies have shown that, in addition to the amount of sleep, its quality is an independent risk factor for injuries.

*Subjective Sleep Quality:* Hamlin et al. studied 82 young, elite academic athletes (aged 18–23) during 2020. Athletes who slept ≥8 hours had an odds ratio of 0.8 for sports injuries, while those with better sleep quality had an even lower odds ratio of 0.6 (95% CI: 0.5–0.7). Regression analysis showed that higher perceived sleep quality was strongly associated with a decrease in number of injuries and illnesses [2].

*Sleep Quality Extremes:* A retrospective study of 536 elite and pre-elite netball players was conducted, which showed that short sleep duration in the 48 hours prior to injury was associated with an increased risk of injury. Interestingly, ‘very poor’ sleep quality and extremes of both too little (<5 hours) and too much (>10 hours) sleep were associated with a bidirectional relationship with an increased risk of injury ($p<0.001$) [5].

*Sleep Disorders:* Butovskiy's study demonstrated that sleep problems, assessed using accepted questionnaires (PSQI and ASBQ), had a significant impact on injuries in young, elite footballers. The prevalence of sleep problems increased with age, highlighting the need for screening for sleep disorders at different stages of life [19].

### 3.3 Sleep Patterns and Injury Outcomes

Other studies have focused on sleep patterns that go beyond basic measures of length and quality.

*Sleep Consistency:* Senbel and his colleagues discovered that athletes with poor sleep habits (unstable sleep and wake times, frequent awakenings) were more prone to injuries compared to those with regular, high-quality sleep. Greater heart rate variability, indicating better sleep quality and recovery, was associated with better performance and a lower risk of injury [1].

*Temporal Relationships:* Use of advanced lag analysis to examine temporal associations between sleep and injuries. It was found that sleep deprivation in the previous 14 days (14-day lag) had the strongest association with the risk of new injuries, suggesting a cumulative effect of sleep deprivation on injury susceptibility [4].

*Sleep Disturbances:* Gao reports that regular sleep interruptions during the night, regardless of total sleep time, were associated with an increased risk of sports injuries in adolescents. This indicates that sleep fragmentation and poor sleep structure may increase the risk of injury to a greater extent than sleep duration alone [10].

### 3.4 Population-Specific Findings

*Sex Differences:* Abrahamson identified female sex as a risk factor for sports-related injuries in young elite athletes with sleep duration interacting with sex to influence injury risk [18]. Many analyses focused exclusively on female athletes [5, 9, 15, 27], while others examined only male athletes [12, 19], indicating possible sex-specific vulnerabilities. However, the precise nature of this interaction requires further investigation.

*Sport-Specific Patterns:* Basketball players demonstrated consistent associations between sleep and injury across numerous studies [1, 3, 12], which likely reflects the high-intensity, contact nature of the sport and demanding competition schedules. Soccer players showed strong associations between sleep during the off-season and injury risk during the competitive season [8, 19, 27, 28, 29], highlighting the importance of recovery periods in injury prevention. Endurance athletes exhibited distinct patterns, with both insufficient sleep (<7 hours) and potentially excessive sleep (>10 hours) being associated with a higher risk of injuries and health problems [4, 5, 24].

*Competitive Level:* Findings were consistent across different levels of athletic participation—from youth athletes [10, 16, 18], through collegiate athletes [1, 3, 12], to elite and professional athletes [5, 7, 8], suggesting that the relationship between sleep and injury is fundamental rather than level-specific.

*Case Study Insights:* Allen presented a compelling case study of a Division I NCAA athlete in whom medial tibial stress syndrome was associated with severe sleep deprivation (<3 hours per night), leading to bilateral stress reactions of the tibial and fibular bones. Sleep-focused interventions increased total body bone mineral density and resolved the bilateral stress reactions, providing direct evidence of the role of sleep in bone health and injury recovery [9].

## 4. DISCUSSION

This systematic review provides strong evidence that sleep is a significant, modifiable risk factor in preventing sports injuries. The consistency of findings across populations, sports disciplines, competition levels, and geographic regions supports the strong evidence for a relationship between sleep and injury.

This study suggests that 7–8 hours of sleep appears crucial for injury prevention. The risk of injury is significantly higher below this level [4]. Regardless of sleep duration, sleep quality also impacts frequency of injuries, with high sleep quality providing a protective effect for athletes [2, 3, 5]. This review demonstrates an important dose-response relationship, with injury risk increasing progressively with decreasing sleep duration. This confirms that sleep is a continuous, rather than categorical, risk factor [4, 16]. Furthermore, sleep deprivation in the 14 days preceding injury shows the strongest association, suggesting a cumulative effect of sleep deprivation on injury susceptibility [4]. The results are consistent among adolescents, collegiate athletes, and professional athletes, indicating underlying biological relationships rather than population-specific ones.

Many biological and physiological processes illustrate the relationship between sleep deprivation and a higher risk of sports injuries. Sleep deprivation impairs cognitive abilities, including focus, decision-making, and reaction time [1, 4, 12]. In sports requiring rapid decision-making and precise motor control, these cognitive deficits increase the risk of injury-prone situations [3]. Sleep deprivation impairs neuromuscular control and proprioception, which reduces the body's ability to respond to unexpected disturbances and maintain joint stability [12]. Sleep is also crucial for tissue repair and regeneration. During deep sleep, growth hormone production peaks, which supports muscle protein synthesis, bone reconstruction, and connective tissue regeneration [9]. Sleep deprivation disrupts these anabolic processes, which can increase the risk of tissue injury during exercise and competition [5, 15]. The case study by Allen provides direct evidence of sleep’s role in bone health, demonstrating that severe sleep deprivation (<3 hours/night) contributed to stress reactions and that sleep interventions improved bone mineral density [9]. What is more, sleep deprivation increases systemic inflammation and impairs immune function [2, 5]. Increased inflammatory markers can slow recovery of micro-injuries accumulated during training, increasing the risk of overuse injuries [4]. Insufficient sleep also impairs immune surveillance, potentially increasing the risk of disease and thus contributing to injury susceptibility by impairing training quality and altering biomechanics [5, 27]. Additionally, sleep regulates essential hormones such as cortisol,

testosterone, and growth hormone [2]. Sleep deprivation increases cortisol levels, leading to catabolism and potentially compromising tissue integrity [9]. Dysfunction in testosterone and growth hormone secretion impairs recovery and adaptation to exercise [1]. Senbel's study demonstrates that higher heart rate variability (HRV), a sign of parasympathetic nervous system dominance, and better sleep quality were associated with higher performance and a reduced risk of injury [1]. Sleep deprivation shifts the autonomic balance toward sympathetic nervous system dominance, which may impede recovery and increase the risk of injury [2]. Lastly, sleep deprivation exacerbates stress, anxiety, and mood disorders [2, 3]. These psychological factors may influence injury risk by altering pain perception, reducing motivation to prevent injury, and decreasing adherence to rehabilitation regimens [15].

The results of this systematic review are consistent with extend previous systematic reviews examining the association between sleep and injury. Clemente conducted a systematic review focusing specifically on the relationships between sleep, sport and match performance, training load, and injuries in soccer players. Their findings support the crucial role of sleep in reducing injuries in soccer, which is consistent with the findings of this review [29]. On the other hand, Dobrosielski and his team conducted a systematic review of 12 prospective cohort studies examining the association between poor sleep and sports and physical activity-related injuries in adult athletes. They found limited evidence supporting an association between poor sleep and injury in adult athletes, with insufficient evidence for specific groups, including elite athletes, collegiate athletes, and endurance athletes. They indicated that the current evidence does not support poor sleep as a distinct risk factor for increased injury risk in adult athletes [30]. The alleged difference between the conclusions of Dobrosielski's study and the present review may reflect differences in selection criteria, search methods, and literature search time. This review examines more recent studies published since 2020, which provide stronger evidence for a relationship between sleep and injury. Furthermore, this review includes adolescent groups, where the evidence is particularly strong. These observations are supported by evidence highlighting that insufficient sleep duration is a critical risk factor for musculoskeletal injuries, as athletes who fail to achieve adequate sleep volume are significantly more vulnerable to injury [17].

This study expands the evidence base by including latest, high-quality prospective studies with sophisticated statistical approaches [1, 3, 4], synthesizing evidence from different populations and sports which reveals consistent patterns, analysing both sleep duration and quality as an independent predictors, identifying temporal dynamics and dose-response relationships and highlighting biological mechanisms supported by empirical evidence.

Despite the consistency of the results, several limitations are worth considering. Studies used different methods for assessing sleep (subjective self-report, validated questionnaires, objective actigraphy, sleep monitoring devices) and defining injuries (time-loss injuries, injuries requiring medical intervention, all injuries). This heterogeneity limits direct comparisons and meta-analytic analyses [1, 2, 3, 4, 5, 30]. Most studies relied on subjective sleep reports, which may be subject to recall and social desirability bias [3, 16]. Objective sleep assessment via actigraphy or polysomnography was rarely used, limiting the accuracy of quantifying sleep parameters [1]. Injury definitions varied across studies – some only considered time-loss injuries, while others included all injuries requiring medical intervention [5, 27]. This variability impacts injury prevalence estimates and comparability across studies. Sleep is strongly associated with other injury risks, such as training load, stress, diet, and recovery techniques [2, 4, 5]. While some studies considered these confounding factors [12], others ignored them, potentially overestimating the independent effect of sleep on injury risk. Most studies have examined sleep as a predictor of future injury, but some cross-sectional designs do not allow for establishing a temporal precedence [16]. Additionally, injury itself can disrupt sleep, creating bidirectional associations that complicate causality [5]. Also, studies demonstrating significant associations between sleep and injury may be more likely to be published than neutral findings, potentially leading to inflated effect size estimates [30]. Although the biological mechanisms have a solid theoretical basis, there are few studies that directly examine the suggested mediators (e.g., inflammatory markers, cognitive function, neuromuscular control) linking sleep to injury. A case study by Allen provides unique, direct evidence of the effect of sleep on bone mineral density [9]. The majority of research has focused on athletes in team sports, while little evidence exists for individual, combat, and aesthetic sports [4, 7, 9, 24]. Additionally, most studies have focused on young adult and adolescent populations, with little evidence in masters athletes or young athletes under 12 years of age.

The evidence supports several practical recommendations for athletes, coaches, and sports medicine professionals. Athletes should aim for 8-10 hours of sleep per night, recognizing that athletic demands may increase sleep needs beyond general population recommendations [1, 2, 10, 16]. In addition to sleep deprivation, athletes must focus on sleep quality by ensuring sleep-wake schedules, creating sleep environments (darkness, quiet, cool), and implementing a pre-sleep routine that promotes relaxation [2, 3]. Athletes should be assessed for both sleep duration and quality, especially during clinical periods and periods of illness. Wearable devices and sleep apps can facilitate monitoring [1, 4]. The finding that off-season sleep predicts in-season injury risk highlights the importance of recovery periods for

building resilience [8]. Because acute sleep deprivation can negatively impact muscle protein synthesis and recovery processes after muscle-damaging training, recovery programs after matches and during intense training should clearly prioritize sleep, alongside diet and training changes [23, 31]. Training and competition schedules should accommodate adequate sleep, avoiding excessively early morning sessions or late-night competitions when possible. Additionally, travel schedules should minimize sleep disruption, with adequate time for adjustment to new time zones [1, 7]. Coaches should educate athletes about sleep's importance for injury prevention and performance, challenging cultural norms that glorify sleep deprivation [2, 3]. Pre-participation examinations and injury risk assessments should include sleep screening using validated questionnaires (e.g., PSQI, ASBQ). Athletes identified with sleep difficulties should receive targeted interventions, including sleep hygiene education, cognitive-behavioral therapy for insomnia, and referral for sleep disorders when indicated [9, 19]. Comprehensive injury prevention programs should incorporate sleep optimization alongside traditional biomechanical and training load interventions [3]. Sleep should be assessed during injury rehabilitation, as inadequate sleep may impair tissue healing and increase re-injury risk [9, 15]. Sports medicine professionals should collaborate with sleep specialists, psychologists, and nutritionists to address sleep comprehensively [2, 9].

Several research priorities emerge from this systematic review. Future studies should employ objective sleep measurement (actigraphy, polysomnography) to precisely quantify sleep parameters and validate subjective reports [1]. Large-scale prospective cohort studies with extended follow-up periods are needed to establish temporal relationships and examine cumulative effects of chronic sleep restriction [4, 24]. Randomized controlled trials examining sleep extension interventions and their effects on injury incidence would provide the strongest causal evidence [2]. Studies should directly measure proposed mediators (cognitive function, reaction time, inflammation markers, neuromuscular control) linking sleep to injury [4, 12]. Also, research examining specific sleep stages (REM, deep sleep) and their relationships to injury risk would refine understanding of critical sleep components [2]. What is more, dedicated studies examining sex-specific vulnerabilities and mechanisms are needed [5]. Additionally, studies in diverse cultural contexts would reveal whether sleep-injury relationships are universal or culturally moderated [19].

## 5. CONCLUSIONS

This systematic review provides compelling evidence that sleep represents a critical, modifiable risk factor for sports injury prevention. Athletes who sleep less than 8 hours per

night have a greater risk of injury than those who sleep adequately, and poor sleep quality independently increases the likelihood of injury. The consistency of research across populations, sports, and competitive levels, along with well-established biological mechanisms, supports the concept of sleep as an "ergogenic supplement" for injury protection.

Evidence suggests a dose-response relationship, with injury risk increasing progressively with decreasing sleep duration below 8 hours per night. Sleep quality emerges as an independent predictor beyond duration alone, highlighting the importance of both quantitative and qualitative sleep parameters. Temporal analyses reveal that sleep deficiency in the 14 days preceding injury shows the strongest associations, suggesting cumulative effects of sleep debt on injury susceptibility.

Biological mechanisms linking sleep to injury include impaired cognitive function and reaction time, compromised neuromuscular control, increased inflammation, impaired tissue repair, hormonal dysregulation, and autonomic nervous system imbalance. These mechanisms are supported by empirical evidence, including a compelling case study illustrating the direct effect of sleep on bone mineral density and the healing process of stress fractures.

Healthcare professionals, coaches, and athletes should prioritize sleep hygiene as part of comprehensive injury prevention plans. Practical recommendations include targeting 8-10 hours of sleep per night, optimizing sleep quality through consistent schedules and optimal sleep environments, monitoring sleep patterns during high-training-load periods, and screening for sleep disorders. Institutional policies should support adequate sleep through appropriate scheduling and facility design.

Future research priorities include employing objective sleep measurement, conducting randomized controlled trials of sleep interventions, examining mechanistic pathways through mediator analysis, investigating understudied populations and sports, and evaluating implementation strategies for real-world athletic settings.

In conclusion, sleep should be recognized as a fundamental pillar of athletic health and injury prevention, deserving equal attention to traditional biomechanical and training load interventions. The evidence supports sleep as an ‘ergogenic supplement’—a performance-enhancing and injury-protective intervention that is safe, accessible, and cost-effective. Optimizing sleep represents a high-yield strategy for reducing sports injury burden and enhancing athlete health and performance.

## DISCLOSURE

**Authors Contributions:** Conceptualization: O.B. and E.D.; Methodology: A.D., A.W. and G.Ł.; Formal analysis: H.B. and J.D.; Investigation: J.B., K.B. and S.C.; Data curation: O.B., K.B. and J.B.; Writing - original draft preparation: J.D., E.D. and A.W.; Writing - review and editing: G.Ł. and A.D.; Supervision: O.B. and S.C.; Project administration: O.B.
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