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Sleep as a Modifiable Determinant of Cognitive and Physical Performance in Athletes: A Narrative Review of the Last Decade of Research

Bartłomiej Janusz Miłosz1,
ORCID https://orcid.org/0009-0004-5461-9236
E-mail bartmilo@icloud.com
1Maria Skłodowska-Curie Medical University, Warsaw, Poland

Julia Plewa2, ORCID https://orcid.org/0009-0001-6554-4645
E-mail s89285@365.sum.edu.pl
2Faculty of Medical Sciences in Katowice, Medical University of Silesia, Katowice, Poland

Sandra Górska1,
ORCID https://orcid.org/0000-0001-5451-3811
E-mail Sandragorska10g@gmail.com
1Maria Skłodowska-Curie Medical University, Warsaw, Poland

Amelia Fajfer1, ORCID https://orcid.org/0009-0000-4615-4580
E-mail Amelia3e3e3e@gmail.com
1Maria Skłodowska-Curie Medical University, Warsaw, Poland

Sara Bień3, ORCID https://orcid.org/0009-0008-1929-2935
E-mail sarabien2001@interia.pl
3Independent Researcher, Rzeszów, Poland,

Aleksandra Kaczor1,
ORCID https://orcid.org/0009-0001-6117-0666
E-mail olakaczor98@gmail.com
1Maria Skłodowska-Curie Medical University, Warsaw, Poland

Piotr Grzegorz Żuber4,
ORCID https://orcid.org/0009-0004-1365-0560
E-mail Piotr.zuber10@gmail.com
4Independent Researcher, Warsaw, Poland

Julia Kistela2, ORCID https://orcid.org/0009-0006-4244-0962
E-mail s88260@365.sum.edu.pl
2Faculty of Medical Sciences in Katowice, Medical University of Silesia, Katowice, Poland

Bartosz Kamionka2,
ORCID https://orcid.org/0009-0009-7187-4411
E-mail s87729@365.sum.edu.pl
2Faculty of Medical Sciences in Katowice, Medical University of Silesia, Katowice, Poland

Julia Kiryluk2, ORCID https://orcid.org/0009-0003-9082-5427
E-mail s87941@365.sum.edu.pl
2Faculty of Medical Sciences in Katowice, Medical University of Silesia, Katowice, Poland

Corresponding Author

Bartłomiej Janusz Miłosz, bartmilo@icloud.com

Abstract

Background. Sleep is increasingly recognized as an active physiological process essential for nervous system and skeletal muscle function, not a passive state. Sleep quantity and quality are linked to cognitive and physical performance, with clinical relevance for professions requiring sustained vigilance and decision-making under time pressure.

Aim. To systematize current knowledge on the impact of sleep quantity and quality on cognitive functioning and physical performance, based on studies from the last decade.

Material and methods. This narrative review (not PRISMA-systematic) synthesizes meta-analyses, systematic reviews, and selected primary studies published mainly 2015–2026, with earlier foundational works (1982–2014) still influential in sleep physiology, neuropsychology of sleep deprivation, and exercise physiology, identified through PubMed, Scopus, and Web of Science.

Results. Sleep deprivation and restriction were consistently associated with impaired memory consolidation, attention, executive functioning, and emotion regulation, as well as reduced aerobic and anaerobic capacity, muscle strength, neuromuscular coordination, and recovery, alongside increased injury risk. Sleep extension produced measurable, albeit variable, improvements in athletic performance. These effects appear underpinned by shared neurobiological mechanisms — glymphatic function, synaptic homeostasis, hormonal/inflammatory regulation, and amygdala–prefrontal coupling — further modulated by circadian rhythm.

Conclusions. Sleep deprivation impairs cognitive and physical performance via shared, overlapping neurobiological pathways, while sleep extension offers a modest but consistent benefit, supporting its use as a practical, low-cost intervention warranting the same systematic attention as training load and nutrition. Given methodological limitations in the evidence base, findings should be applied with caution in athletic, medical, and educational settings.

Keywords: sleep, sleep deprivation, cognitive functions, physical performance, memory consolidation, circadian rhythm, regeneration, sport.

1. Introduction

Humans spend approximately one-third of their lives asleep, which highlights the fundamental biological importance of sleep (Kaczmarek et al., 2025). For decades, sleep was regarded as a passive state, a downtime in brain function; modern neuroscience clearly refutes this view — sleep is a highly organized and active process (Kaczmarek et al., 2025; Rasch & Born, 2013) during which memory traces are consolidated (Weighall & Kellar, 2023; Newbury et al., 2021; Rasch & Born, 2013), metabolic and hormonal homeostasis is regulated (Kong et al., 2025; Lamon et al., 2021; Kaczmarek et al., 2025), metabolic waste products are removed from brain tissue (Jessen et al., 2015; Iliff et al., 2012; Fultz et al., 2019), and peripheral tissue including skeletal muscles are regenerated (Kong et al., 2025; Lamon et al., 2021; Kaczmarek et al., 2025).

The last decade has brought significant knowledge gains in two seemingly distinct (yet closely related) areas – the cognitive neuroscience of sleep and the physiology of exercise. The discovery and characterization of the glymphatic system, the development of precise methods for assessing behavioral alertness (such as the Psychomotor Vigilance Test - PVT) and the growing interest in sleep as a component of competition preparation within the athletic community have led to a multiplying number of publications on the relationship between sleep and cognitive and physical functioning. In parallel, this problem has gained clinical importance – this applies especially to professions requiring long-term vigilance and decision-making under time pressure. This concern is not new: Pilcher and Huffcutt's (1996) classic meta-analysis already incorporated studies of partial sleep deprivation in medical and surgical residents as part of its broader sample, and Lim and Dinges' (2010) meta-analysis similarly drew on a dedicated synthesis by Philibert comparing cognitive and clinical performance between physicians and non-physicians. Comparable concerns extend beyond medicine to other occupations requiring sustained vigilance: the CRUISE study, following maritime pilots exposed to chronic shift-work-related sleep disruption, linked cumulative sleep loss to long-term cognitive decline (Thomas et al., 2021). Within the medical profession specifically, sleep deprivation related to on-call duty remains the subject of active debate regarding patient safety (Dutheil et al., 2020; Maltese et al., 2016; Neuschwander et al., 2017; Gohar et al., 2009).

Research Objective. The objective of this review was to systematize current knowledge from the last decade on the impact of sleep — its quantity and quality — on two key areas of human functioning, cognition and physical performance, together with the underlying neurobiological mechanisms and the practical implications of this knowledge for athletes, medical professionals, and students.

Research Problems. To what extent do sleep deprivation and restriction impair specific domains of cognitive functioning (memory consolidation, attention, executive function, emotion regulation) and specific components of physical performance (aerobic and anaerobic capacity, muscle strength, neuromuscular coordination, and injury risk)? What shared neurobiological mechanisms — including glymphatic clearance, synaptic homeostasis, hormonal regulation, amygdala–prefrontal cortex coupling, and circadian rhythm — underlie these effects? To what extent does deliberate sleep extension constitute an effective, practically applicable intervention for improving athletic performance and recovery?

Research Hypotheses. It was hypothesized that (1) sleep deprivation and restriction exert measurable, domain-specific negative effects on both cognitive functioning and physical performance; (2) these effects, although manifesting in seemingly distinct domains, are underpinned by shared and overlapping neurobiological mechanisms; and (3) deliberate sleep extension produces measurable, albeit variable, improvements in athletic performance, supporting its consideration as a practical and modifiable component of athletic preparation alongside training load and nutrition.

2. Review methodology

2.1. Search strategy and source identification

Literature was identified through structured searches of PubMed, Scopus, and Web of Science, supplemented by manual screening of reference lists of retrieved meta-analyses and systematic reviews (snowball search). Search terms combined the concepts of sleep (sleep deprivation, sleep restriction, sleep extension, sleep quality) with cognitive outcomes (memory consolidation, attention, executive function, emotion regulation) and physical performance outcomes (aerobic capacity, anaerobic capacity, muscle strength, neuromuscular coordination, injury risk, recovery), as well as related mechanistic terms (glymphatic system, circadian rhythm, synaptic homeostasis).

2.2. Eligibility criteria and study selection

This is a narrative review, not a systematic review in the PRISMA sense; no formal protocol was pre-registered. Sources were eligible for inclusion if they were peer-reviewed meta-analyses, systematic reviews, or primary studies published in English, with priority given to publications from 2015–2026. Earlier foundational works (1982–2014) were additionally included where they remain influential or mechanistically foundational in the fields of sleep physiology, the neuropsychology of sleep deprivation, or exercise physiology (e.g., the classic meta-analyses of Pilcher and Huffcutt (1996) and Lim and Dinges (2008, 2010), and the original description of the two-process model of sleep regulation (Borbély, 1982)). Two additional, narrowly scoped exceptions were made to these criteria. First, one meta-analysis currently available only as a non-peer-reviewed preprint (Tawfeeq & Malm, 2025) was included because, at the time of writing, it represented the only quantitative synthesis specifically addressing sleep duration and sports injury risk; its preliminary status is explicitly flagged wherever it is cited. Second, a tertiary educational source (Brinkman et al., 2023, StatPearls) was included solely for a basic descriptive statement on sleep architecture (Section 3.1), where it serves an introductory, non-evidentiary role rather than supporting a substantive claim. Case reports and studies not available in full text were excluded.

2.3. Data extraction and synthesis

2.3.1. Reference management.

Source publications and their bibliographic details were collected and organized manually in a shared Google Docs workspace; no dedicated reference management software (e.g., Zotero, EndNote) was used. No statistical software was used, as this review does not report original quantitative analyses or pooled effect sizes.

2.3.2. AI Declaration of the Use of Generative AI and AI-Assisted Technologies in the Writing Process

Declaration of the use of generative AI and AI-assisted technologies in the writing process.

In preparing this work, the author(s) used Claude (Anthropic) [Sonet 5] for the purpose of language and readability, test formatting, verification of bibliographic styles and basic data analysis. After using this tool/service, the author(s) have reviewed and edited the content as needed and accept full responsibility for the substantive content of the publication.

2.3.3. Synthesis approach.

Given the methodological heterogeneity of the included literature — spanning cognitive neuroscience, exercise physiology, and clinical sleep medicine, and employing markedly different outcome measures and study designs — findings were synthesized narratively rather than quantitatively. Where available, effect sizes and confidence intervals reported by the original meta-analyses are cited directly rather than re-calculated.

3. Research results

The following sections synthesize the reviewed evidence across five domains: baseline sleep physiology, the neurobiological mechanisms linking sleep to performance, cognitive outcomes, physical performance outcomes, and the modulating role of circadian rhythm.

3.1. Sleep physiology and architecture - outline

Human sleep is divided into two qualitatively different phases: NREM (non-rapid eye movement) sleep, which comprises approximately 75–80% of total sleep time, and REM (rapid eye movement) sleep, which comprises the remaining 20–25% (Kaczmarek et al., 2025; Rasch & Born, 2013). NREM sleep is divided into stages N1 (light,

transitional sleep), N2 (characterized by sleep spindles and K-complexes, occupying up to 50% of sleep time), and N3, or slow-wave sleep (SWS), characterized by high-amplitude delta wave activity and considered the most restorative stage of sleep (Kaczmarek et al., 2025; Rasch & Born, 2013). REM sleep is characterized by desynchronization of brain bioelectrical activity, muscle atonia, and episodes of rapid eye movements; it is during this period that most dreaming and emotional memory processing occur (Kaczmarek et al., 2025; Rasch & Born, 2013). NREM-REM cycles repeat throughout the night every ~90 minutes, with the proportion of REM sleep increasing progressively in subsequent cycles, reaching up to approximately 30% in later cycles (Kaczmarek et al., 2025; Rasch & Born, 2013; Brinkman et al., 2023). Sleep regulation is classically described by Borbély's two-process model, comprising a sleep–wake-dependent homeostatic process (Process S), which builds up during wakefulness and dissipates during sleep, and a circadian process (Process C), controlled by the suprachiasmatic nucleus of the hypothalamus and governing optimal "windows" of sleep and wakefulness across the 24-hour cycle (Borbély, 1982, 2022). The interaction of both processes determines both subjective sleepiness and objectively measurable cognitive performance during the day (Lim & Dinges, 2008; Thun et al., 2015).

3.2. Neurobiological Mechanisms Linking Sleep to Cognitive and Physical Functioning

3.2.1. The Glymphatic System

The discovery of the glymphatic system – a perivascular network that allows cerebrospinal fluid to flow through the brain parenchyma and remove metabolic waste products, including beta-amyloid – provided the first mechanistic explanation for the long-observed "cleansing" function of sleep and has since become one of the most actively researched areas in sleep neuroscience (Jessen et al., 2015; Iliff et al., 2012).

Basic research indicates that during NREM sleep, slow (~0.05 Hz) electrophysiological oscillations — visible as EEG slow-delta waves — precede and drive coupled hemodynamic oscillations in cerebral blood volume, which in turn are tightly anticorrelated with waves of cerebrospinal fluid inflow occurring approximately every 20 seconds; during wakefulness, this large-amplitude CSF pulsation is essentially absent, with only a small respiration-locked rhythm remaining (Fultz et al., 2019).

Sleep disorders are currently associated – through dysfunction of the glymphatic system – with the risk of neurodegenerative diseases, brain injuries, and mental disorders, making this research axis one of the most dynamically developing directions in modern sleep medicine (Jessen et al., 2015; van Hattem et al., 2025). Importantly, current evidence for glymphatic dysfunction is concentrated almost entirely in cognitive and neurodegenerative outcomes; a direct, mechanistically established link between glymphatic clearance and physical/athletic performance has not yet been demonstrated in the literature reviewed here and should not be assumed.

3.2.2. Synaptic Homeostasis and Memory Consolidation

Slow-wave sleep enables a global reduction in the strength of synaptic connections strengthened during the day (synaptic homeostasis), and at the same time — through the reactivation of memory traces and their transfer from the hippocampus to the cortex — supports the lasting consolidation of the most important information. These two processes are not mutually exclusive but work complementarily, allowing the brain to "learn" effectively without overloading the neural networks. This mechanism is discussed in more detail in section 3.3.1. (Rasch & Born, 2013).

3.2.3. Hormonal and Inflammatory Regulation

Sleep regulates the hypothalamic-pituitary-adrenal axis and the secretion of anabolic hormones, with a direct impact on muscle recovery and training adaptation, discussed further in section 3.4.4. (Swinbourne et al., 2018; Lamon et al., 2021; Kaczmarek et al., 2025). Chronic sleep deprivation is also associated with sympathetic nervous system activation, increased inflammatory markers, and insulin resistance, which may indirectly impair both cognitive functioning and the ability to recover from exercise (Lamon et al., 2021; Kaczmarek et al., 2025).

3.2.4. Coupling of the amygdala with the prefrontal cortex

Preliminary neuroimaging evidence suggests that sleep deprivation may weaken the functional connection between the amygdala and the prefrontal cortex (Simon et al., 2015), a mechanism discussed further in section 3.3.3. If replicated in larger samples, this would offer a neurobiological explanation for the clinically observed emotional lability, reduced frustration tolerance, and tendency to engage in risky behavior in sleep-deprived individuals — phenomena that are important both in the context of sports (decision-making under pressure) and professional

work (e.g., in shift work of medical personnel) (Maltese et al., 2016; Neuschwander et al., 2017; Gohar et al., 2009).

Taken together, three of these mechanisms — glymphatic clearance, synaptic homeostasis, and hormonal/inflammatory regulation — are each supported by multiple independent lines of evidence and converge on the same functional endpoint: a brain and body less able to encode, retain, and physically recover after insufficient sleep. The proposed amygdala–prefrontal decoupling mechanism, resting so far on a single small study, may represent an additional, complementary pathway, but its role should be regarded as tentative pending replication in larger samples. The following two sections examine how this convergence manifests at the level of measurable cognitive and physical performance.

3.3. Sleep and Cognitive Functioning

3.3.1. Memory and Consolidation Processes

Building on the mechanisms outlined above, this section turns from why sleep matters at the cellular and systemic level to what is actually measured when sleep is disrupted — beginning with the domain most consistently affected across the literature: memory. The relationship between sleep and memory is one of the most well-documented areas of research in the last decade (Weighall & Kellar, 2023; Rasch & Born, 2013). Weighall and Kellar's (2023) systematic review of systematic reviews and meta-analyses, synthesizing data from 19 high-quality secondary studies, found that sleep enhances memory consolidation, particularly for complex declarative information (Weighall & Kellar, 2023). However, the evidence regarding the role of sleep in procedural memory consolidation in children is less clear than for declarative memory (Weighall & Kellar, 2023). Similar findings emerged from other systematic reviews from this period, indicating that optimal sleep duration favors declarative memory consolidation, while slow-wave sleep depth correlates with the quality of procedural memory recall, and sleep continuity (lack of fragmentation) favors consolidation of both types of memory (Newbury et al., 2021; Rasch & Born, 2013).

At the mechanistic level, this concept is supported by the synaptic homeostasis hypothesis of Tononi and Cirelli, according to which during wakefulness, a network strengthening (potentiation) of synaptic connections occurs, while sleep – especially slow-wave sleep – enables global downscaling of synapses, which improves the signal-to-noise ratio in neuronal networks and protects against metabolic overload of the cerebral cortex (Rasch & Born, 2013). A complementary theoretical framework is provided by the Rasch and Born concept of active systemic consolidation, according to which during NREM sleep, memory traces encoded in the hippocampus are reactivated and gradually transferred to permanent cortical stores (Rasch & Born, 2013). Experimental studies also indicate that the ability to encode new information deteriorates within a few hours of wakefulness during the day, and a short nap encompassing NREM sleep and sleep spindles restores this ability (Newbury et al., 2021; Rasch & Born, 2013).

3.3.2. Attention and vigilance

Vigilant attention is the cognitive domain that demonstrates the highest sensitivity to sleep deprivation, making it the most frequently used indicator in experimental studies (Lim & Dinges, 2010). The now classic but still relevant work of Lim and Dinges, based on the Psychomotor Vigilance Test (PVT), described four reproducible phenomena accompanying sleep deprivation: a general slowing of reaction time, an increasing number of attentional lapses (responses delayed by more than 500 ms), an increase in the number of erroneous responses to pseudo-stimuli, and an intensifying time-on-task effect (Lim & Dinges, 2008, 2010). Vigilance deficits result from the interaction between increasing homeostatic sleep pressure and the circadian rhythm, and their severity is characterized by high individual variability, constituting a permanent phenotypic feature of a given individual (Lim & Dinges, 2008).

3.3.3. Executive Functions, Decision-Making and Emotion Regulation

Executive functions—planning, response inhibition, cognitive flexibility, and decision-making—are significantly dependent on the proper functioning of the prefrontal cortex, a brain region particularly sensitive to sleep deprivation. An integrative review by Lima, Kirov, and de Almondes (2022), based on the analysis of the P300 evoked potential, confirmed that sleep deprivation and other forms of sleep disturbance are associated with impaired executive functions, which corresponds to reduced amplitude and prolonged latency of this cognitive component of the evoked potential (Lima et al., 2022; Rasch & Born, 2013; Sun et al., 2025).

Sleep deprivation also affects emotion regulation. A single crossover neuroimaging study combining fMRI and EEG (n = 18 healthy adults) — the "loss of neutrality" experiment by Simon and colleagues — found that after 24 h of sleep deprivation, participants showed enhanced amygdala reactivity to emotional distractors together with weakened amygdala–prefrontal functional coupling, the prefrontal cortex normally exerting top-down regulatory control over emotional responses (Simon et al., 2015). Given the small sample and exploratory design, this should be regarded as a plausible mechanistic hypothesis requiring replication rather than an established mechanism. Its proposed behavioural correlates — reduced stress tolerance, irritability, and greater risk-taking — are nonetheless consistent with observations of impaired decision-making in sleep-deprived clinical personnel (Maltese et al., 2016; Neuschwander et al., 2017).

3.3.4. Sleep Deprivation and Restriction - Evidence from Meta-Analyses

The impact of sleep restriction on cognitive functioning and mood has been the subject of numerous meta-analyses, both classic and more recent, which together provide a coherent quantitative picture of the phenomenon. Pilcher and Huffcutt's meta-analysis, encompassing 19 primary studies (143 effect sizes, n=1932), showed that sleep deprivation significantly impairs human functioning, with mood being affected more severely than cognitive or motor performance, and that partial sleep deprivation (less than 5 hours per day) has a stronger negative impact than short- or long-term total sleep deprivation (Pilcher & Huffcutt, 1996). This finding has significant practical implications because in real-world settings—unlike laboratory protocols of total sleep deprivation—chronic sleep restriction is much more common. A more recent and methodologically more extensive analysis is the meta-analysis by Lim and Dinges (2010), which included 70 articles and 147 cognitive tests across six domains: simple and complex attention, working memory, information processing speed, short-term memory, and reasoning. The results of this study allowed for the relative magnitude of sleep deprivation effects across cognitive domains, identifying vigilant attention and working memory as the areas most susceptible to short-term sleep deprivation (Lim & Dinges, 2010). Subsequent meta-analytic reviews over the past decade have confirmed that even short-term, cumulative sleep restriction—lasting up to about a week—has a detrimental effect on neurocognitive functioning, with consequences that extend beyond the laboratory: reduced professional productivity and an increased risk of errors and accidents, especially in professions requiring the maintenance of a high level of cognitive performance at critical moments, such as medical personnel or pilots (Lima et al., 2022; Dutheil et al., 2020; Thomas et al., 2021; Maltese et al., 2016; Neuschwander et al., 2017; Gohar et al., 2009). It is worth noting that the meta-analysis by Newbury et al. (2021), focused specifically on memory, showed a differential effect of sleep deprivation depending on whether it occurred before or after the learning process – sleep deprivation preceding information encoding was more detrimental to subsequent memory than deprivation following learning, suggesting a distinct role of sleep in the encoding phase and in the consolidation phase of the memory trace (Newbury et al., 2021).

3.3.5. Napping as an Intervention to Support Cognitive Functioning

Short-term daytime napping is increasingly being explored as a practical strategy for compensating for nocturnal sleep deprivation. A meta-analysis by Dutheil et al. (2021), including 11 laboratory studies (381 participants, mean nap duration 55.4±29.4 minutes), demonstrated significant improvements in overall cognitive performance after napping — particularly alertness, executive function, and memory — with the beneficial effect lasting up to approximately 120 minutes after waking; early afternoon naps (before 1:00 PM) were superior to later naps (Dutheil et al., 2021). A similar, independent study by the same team, conducted in night-shift settings, confirmed the potential of short naps to maintain alertness in night-shift workers (Dutheil et al., 2020).

With respect to memory specifically, a dedicated systematic review by Farhadian et al. (2021) found that daytime napping consistently benefits declarative memory performance, an effect attributed largely to hippocampus-dependent consolidation occurring during NREM sleep and sleep spindles. Notably, the authors observed that despite ample existing evidence for the positive role of napping on procedural memory, comparatively few studies had examined its effect on declarative memory — a gap that motivated their review (Farhadian et al., 2021). This asymmetry is somewhat counterintuitive: since short daytime naps are typically NREM-dominated and contain comparatively little REM sleep, and since procedural memory consolidation is known to depend selectively on REM sleep — classic sleep-deprivation studies have shown that selective REM sleep deprivation, but not NREM sleep loss, abolishes performance gains on procedural tasks, while declarative memory remains largely unaffected (Rasch & Born, 2013) — one might instead have expected declarative memory to be the more thoroughly studied outcome of napping, precisely because naps favor the NREM stages that support it.

However, caution should be exercised in interpreting long-term and habitual napping, especially in older adults: observational data suggest that long, regular napping may be a marker of declining cognitive performance or increased risk of dementia, most likely reflecting reverse causality (declining health leading to more frequent napping) rather than a detrimental effect of napping per se (Li et al., 2023; Dutheil et al., 2021).

3.4. Sleep and Physical Performance

3.4.1. The Impact of Sleep Deprivation and Restriction on Exercise Performance

Evidence from the last decade clearly indicates that sleep deprivation impairs physical performance, although the magnitude of this effect varies depending on the type of exercise. A comprehensive meta-analysis published in 2022 in the journal Sports Medicine, including 227 measurement results from 69 publications (anaerobic power, speed-strength endurance, high-intensity interval exercise, strength, endurance, strength endurance, and technical skills), demonstrated a significant negative impact of sleep deprivation on exercise performance across all analyzed categories, with an average decline of 7.56% (95% CI: -11.9 to -3.13%). Tasks requiring technical precision (sports skills) were the most severely impaired, with a decline of nearly 21% (Craven et al., 2022). This selective vulnerability of technically demanding and decision-dependent tasks is consistent with the amygdala–prefrontal cortex decoupling described in Section 3.2.4: skills that rely on rapid, context-sensitive judgment appear more sensitive to sleep loss than tasks relying primarily on raw muscular force output, paralleling the pattern already observed for executive function in Section 3.3.3.

Similar conclusions were drawn from the meta-analysis by Gong et al. (2024), which showed that acute sleep deprivation most severely impairs high-intensity interval exercise and technical control, while affecting speed, aerobic endurance, and explosive power to a lesser extent (Gong et al., 2024). However, all analyzed indicators deteriorated statistically significantly. A more recent meta-analysis from 2025, encompassing 45 studies, confirmed significant deterioration in aerobic capacity, explosive power, maximal strength, speed, and technical control after sleep deprivation, as well as an increase in subjectively perceived exertional fatigue (RPE)—meaning that, at the same workload, exercise after a night of sleep deprivation is perceived as more difficult, regardless of the objective decline in physiological parameters (Kong et al., 2025).

Separate, targeted meta-analyses have confirmed the negative effect of sleep deprivation on endurance performance (Lopes et al., 2023) and on muscle strength, although in the latter area the results of individual primary studies are less consistent – some studies did not show significant differences in maximal strength after one night of sleep deprivation, suggesting that a single episode of sleep deprivation has a stronger effect on complex tasks requiring coordination and decision-making than on simple, short-term strength efforts (Easow et al., 2025).

Table 1. *Effects of sleep deprivation and restriction on cognitive function and physical performance.*

Author (year)	N studies/ N participants	Population / type of deprivation	Main finding	Effect measure (95% CI)
Pilcher & Huffcutt (1996)	19 studies / n=1932, 143 effect sizes	Total and partial deprivation	Partial restriction (<5h/day) more detrimental than total deprivation; mood impaired most	—
Lim & Dinges (2010)	70 articles / 147 cognitive tests	Short-term deprivation	Most sensitive domains: vigilant attention, working memory	—
Craven et al. (2022)	69 publications / 227 measurement outcomes	Acute deprivation, physical performance	Decline across all categories; most severe: technical skills (~21%)	Mean -7,56% (-11.9 to -3.13%)
Gong et al. (2024)	–	acute deprivation, athletes	Most severe: HIIT exercise and technical control	—
Kong et al. (2025)	45 studies	Deprivation, physical performance	↓ aerobic capacity, power, strength, technical control; ↑ RPE	—
Lopes et al. (2023)	–	Endurance performance	Significant impairment of endurance capacity	—
Easow et al. (2025)	–	Muscle strength	Inconsistent effect — a single night of deprivation does not always ↓ maximal strength	—

Author (year)	N studies/ N participants	Population / type of deprivation	Main finding	Effect measure (95% CI)
Tawfeeq & Malm (2025)	9 studies / 1,078 athletes (preprint)	Shorter sleep → injury risk (pooled, dichotomous)	Shorter sleep ↑ injury risk	OR 1.34 (1.08–1.66)
Watson et al. (2020)[a]	Male NCAA Division I basketball players, ~2-month competitive season	Sleep duration (per-hour, continuous) → injury risk	Each additional hour of sleep associated with lower injury odds	OR 0.52 (0.40–0.68), p<0.001

[a] *Cohort study (not a meta-analysis), included here for comparison with pooled preprint estimate (Tawfeeq & Malm, 2025).*

3.4.2. Sleep Extension as an Intervention to Improve Athletic Performance

A complementary and practically relevant line of research is sleep extension interventions in athletes. A groundbreaking, frequently cited study by Mah et al. (2011), conducted on Stanford University basketball players, showed that increasing the time spent in bed to at least 10 hours per night for 5–7 weeks led to improved sprint times and shooting accuracy, shorter reaction times on the PVT, reduced daytime sleepiness (Epworth scale), and improved mood (Profile of Mood States) compared to baseline (Mah et al., 2011). A smaller, complementary study from the same line of research, conducted on twelve college varsity tennis players, showed that extending nightly sleep by nearly 1.7 hours (from a baseline of 7.14 hours to approximately 8.85 hours per night, on average, over a one-week period) led to a significant improvement in serving accuracy (from 35.7% to 41.8%), accompanied by a significant reduction in daytime sleepiness on both the Epworth and Stanford Sleepiness Scales (Schwartz & Simon, 2015). These gains likely reflect, at least in part, restoration of the same hormonal and amygdala–prefrontal processes described in Sections 3.2.3 and 3.2.4: better-rested athletes show not only faster reaction times but also more stable emotional regulation and decision-making under competitive pressure.

A systematic review of sleep-enhancing interventions in athletes, published in Sports Medicine – Open (2023), covering 25 studies from 2011 to 2021, found that among various strategies (sleep extension, naps, light exposure interventions, mindfulness techniques), sleep extension was the intervention with the most consistent and beneficial effect on athletic performance. The effects of napping were mixed, with some studies improving performance and others showing no effect, although naps consistently had beneficial effects on recovery markers such as muscle damage and inflammation (Cunha et al., 2023). A separate systematic review focused solely on sleep extension in the athletic population, examining protocols that increased sleep duration by 26–106 minutes, confirmed potential benefits for six of the fifteen athletic performance measures analyzed (with large effect sizes), while cautioning that the quality of evidence remains limited due to a high risk of bias in some of the primary studies (Silva et al., 2021). An interventional study conducted on professional rugby players during the preparatory period showed that increased sleep was associated with beneficial changes in immune function, stress hormone secretion and reaction time (Swinbourne et al., 2018).

Table 2. *Summary of studies examining the effects of sleep extension interventions on athletic performance*

Author (year)	Population / duration	intervention	Main finding	Effect
Mah et al. (2011)	Stanford basketball players, 5-7 weeks	Sleep extension to ≥10h/night	↑ shooting accuracy, ↓ sprint time, ↓ daytime sleepiness (Epworth), ↑ mood	—
Schwartz & Simon (2015)	12 college varsity tennis players, 1 week	Sleep extension 7.14h→8.85h	↑ serving accuracy	35.7% → 41.8%
Cunha et al. (2023)	25 studies, 2011–2021	Various interventions (sleep, naps, light exposure, mindfulness)	Sleep extension — most consistent benefit; naps: mixed effects	—
Silva et al. (2021)	Athletes, protocols of 26–106 min	Sleep extension	Benefit in 6/15 measured parameters	Large effect sizes
Swinbourne et al. (2018)	Rugby players, preparatory period	Sleep extension	↑ immune function, ↓ stress hormones, ↓ reaction time	—

3.4.3. Sleep and the risk of sports injuries

The association between insufficient sleep and the risk of sports injuries is a subject of growing research interest, particularly in young athletes. A meta-analysis of observational studies, including nine studies and 1,078 athletes, found a modest but statistically significant association between shorter sleep duration and injury risk (odds ratio 1.34; 95% CI: 1.08–1.66), although there was considerable heterogeneity between studies; as this meta-analysis is currently available only as a non-peer-reviewed preprint, these findings should be interpreted with appropriate caution (Tawfeeq & Malm, 2025). Data from narrative reviews suggest that sleep duration of less than 7 hours for at least two weeks is associated with a nearly 1.7-fold increased risk of musculoskeletal injury, and athletes sleeping less than 6 hours per night experienced both a significant decline in performance and an increased incidence of injuries (Kaczmarek et al., 2025). In one cohort study of male collegiate basketball players, decreased sleep duration was found to be an independent predictor of in-season injury; each additional hour of sleep was associated with an approximately 48% reduction in the odds of injury the following day (OR = 0.52, 95% CI: 0.40–0.68, $p < 0.001$), corresponding to a nearly two-fold increase in injury odds for each hour of sleep lost (Watson et al., 2020). The authors of these works indicate that the mechanism of increased injury risk is probably two-fold — it includes both impairment of physiological tissue regeneration (Section 3.2.3) and weakening of the attentional and emotional-regulatory processes that depend on intact amygdala–prefrontal coupling (Section 3.2.4), both of which are important for avoiding trauma-prone situations (Kaczmarek et al., 2025; Tawfeeq & Malm, 2025).

3.4.4. Post-exercise recovery and hormonal regulation

Sleep - and slow-wave sleep in particular - plays a key role in post-exercise recovery by regulating the secretion of anabolic and catabolic hormones. Growth hormone is secreted primarily during deep sleep, stimulating protein synthesis and the regeneration of tissues damaged during exercise, while testosterone secretion increases in the second half of the night (Kaczmarek et al., 2025). An experimental study by Lamon et al. (2021) demonstrated that a single night of complete sleep deprivation led to a significant reduction in postprandial muscle protein synthesis in healthy young adults, accompanied by a decrease in testosterone concentrations and an increase in cortisol concentrations—a catabolic hormone that intensifies muscle tissue breakdown (Lamon et al., 2021). Sustained sleep restriction is also associated with impaired appetite hormone regulation (reduced leptin and increased ghrelin), which indirectly affects body composition and the availability of energy substrates essential for recovery (Kaczmarek et al., 2025). These results indicate that sleep should be considered an integral, not an adjunct, element of training load planning alongside training and nutrition.

3.5. Circadian rhythm and physical and cognitive performance

Regardless of sleep quantity, cognitive and physical performance is also influenced by the time of day when activity is undertaken, which is due to circadian regulation of body temperature, hormone levels, and alertness. A systematic review by Thun et al. (2015), encompassing 113 publications, found that athletes' physical performance is typically highest in the evening, near the circadian peak in core body temperature. Sleep deprivation is associated with impaired performance regardless of the time of day, while sleep extension has the opposite effect (Thun et al., 2015). More recent meta-analyses of neuromuscular performance in team sports report a similar afternoon-evening advantage for countermovement jump and agility performance, whereas no significant time-of-day differences were found for isometric strength or squat jump (Martin-López et al., 2025). Thun et al. further note that fine motor and technical skills tend to peak earlier in the day than tasks relying on large muscle groups, with cognitive and sensorimotor components of performance appearing more sensitive to extended wakefulness than gross motor movements (Thun et al., 2015). These effects are further modulated by individual chronotypes (morning, evening, mid-morning), which is important when planning training loads and competition schedules.

4. Discussion

4.1 Practical and Clinical Implications

4.1.1. Athletes and Coaches

The collected data indicate that sleep should be treated as a fully-fledged, measurable pillar of athletic preparation, on par with training and nutrition. Practical implications include prioritizing adequate nighttime sleep — commonly cited targets range from 7–9 hours as a general baseline up to 9–10 hours for athletes to reach full performance potential, with sport-specific variation (e.g., 8–10 h for endurance and team sports) (Cunha et al., 2023; Kaczmarek et al., 2025; Tawfeeq & Malm, 2025), considering a short early afternoon nap as a tool to support

alertness and recovery without disrupting nighttime sleep (Dutheil et al., 2021), and planning competitions and key training sessions with the athlete's individual circadian rhythm in mind (Martin-López et al., 2025; Thun et al., 2015). During periods of increased training load or before important competitions, sleep extension intervention appears to be one of the most effective and easiest-to-implement strategies for improving performance (Cunha et al., 2023; Kaczmarek et al., 2025).

4.1.2. Medical environment

Data regarding the impact of sleep deprivation on medical personnel are of particular clinical and educational importance. Studies conducted among resident physicians have shown a decline in working memory capacity after a month of extended shifts (Gohar et al., 2009), and night shifts were associated with a significant decline in the cognitive performance of intensive care physicians (Maltese et al., 2016). Simulation studies among anesthesiology residents have demonstrated a decline in non-technical skills (including teamwork, decision-making, and situational awareness) after a night on duty (Neuschwander et al., 2017), and long-term follow-up from the CRUISE study indicated a link between chronic sleep disturbances resulting from shift work and the risk of long-term cognitive decline (Thomas et al., 2021). A systematic review synthesizing this evidence base confirms that inadequate sleep duration and quality among healthcare workers are consistently linked to impaired patient safety and reduced quality of care (Fox et al., 2025). These results support the long-standing debate on regulating medical staff's work hours and underscore the importance of educating medical students about sleep management as part of professional preparation for their profession.

4.1.3. Students and the Educational Context

Studies conducted among students, including medical students, consistently demonstrate a positive correlation between sleep duration and academic performance, as well as a progressive deterioration in attention, working memory, and cognitive control (the Stroop effect) as sleep deficits accumulate over the semester (Saroha et al., 2025). This association is corroborated by objective actigraphy data in a general first-year college population, where nightly sleep duration prospectively predicted grade point average independent of self-report bias (Creswell et al., 2023). From an educational perspective, these data support the promotion of sleep hygiene as part of exam preparation, rather than—as is still commonly perceived—sacrificing sleep for extended studying (Saroha et al., 2025).

4.2. Limitations of the analyzed studies

When interpreting the presented data, it is important to consider significant methodological limitations that characterize much of the literature in this area.

First, the definitions of key concepts—sleep deprivation, sleep restriction, and sleep extension—are not standardized across studies, which hinders direct comparisons and quantitative synthesis (evident in high heterogeneity indices, e.g., I^2 above 85% in some of the cited meta-analyses) (Tawfeeq & Malm, 2025).

Second, research samples in the area of exercise physiology are often small and clearly male-dominated. In the meta-analysis by Craven et al. on acute sleep loss and physical performance, 89% of the pooled sample (n = 959) was male—a limitation the original authors themselves acknowledge as precluding any meaningful analysis of sex as a variable—which restricts the generalizability of these findings to female and recreational athletes (Craven et al., 2022).

Third, most experimental studies on cognition are based on relatively simple, standardized laboratory tasks (such as the PVT), whose ecological validity relative to complex cognitive tasks of everyday life or highly competitive sports remains a matter of debate (Lim & Dinges, 2008, 2010).

Fourth, observational studies examining the relationship between sleep and the risk of injury or cognitive decline (e.g., in the context of napping in older adults) make it difficult to clearly determine the direction of causality. It is possible that poorer sleep increases the risk of adverse events, or that preexisting health problems lead to poorer sleep (Dutheil et al., 2021).

Finally, interventional studies on sleep extension in athletes, despite promising results, are still characterized by limited sample sizes and an increased risk of bias. Notably, key studies in this area—including the work of Mah et al. on collegiate basketball players and Swinbourne et al. on professional rugby players—employed sequential pre-post designs without randomized allocation, rather than randomized controlled trials, increasing susceptibility to order effects, seasonal or training-phase confounding, and selection bias. This is not merely an oversight: Mah and colleagues explicitly note that elite athletes are reluctant to participate in study designs (such as a Latin Square

or a control arm) that might deprive them of a potential performance benefit, reflecting a genuine practical constraint on conducting rigorous trials in this population rather than a simple methodological shortcoming. This necessitates caution when formulating firm practical recommendations based on these findings (Cunha et al., 2023; Mah et al., 2011; Silva et al., 2021; Swinbourne et al., 2018).

In addition, the four neurobiological mechanisms outlined in Section 3.2 are not equally supported across both domains reviewed here: glymphatic clearance is a well-documented driver of cognitive and neurodegenerative outcomes but currently lacks direct evidence linking it to physical performance, whereas hormonal/inflammatory regulation offers the strongest mechanistic bridge connecting the cognitive and physical literatures.

5. Summary and conclusions

The evidence reviewed here is consistent with all three research hypotheses. Sleep deprivation and restriction were found to exert measurable, domain-specific negative effects on both cognitive functioning and physical performance, supporting Hypothesis 1. These effects, although manifesting in seemingly distinct domains, were shown to be underpinned by shared and overlapping neurobiological mechanisms — glymphatic clearance, synaptic homeostasis, hormonal regulation, and amygdala–prefrontal cortex coupling — rather than operating in isolation, supporting Hypothesis 2. Finally, deliberate sleep extension was consistently associated with measurable, albeit variable, improvements in athletic performance across the reviewed intervention studies, supporting Hypothesis 3 and its consideration as a practical, modifiable component of athletic preparation alongside training load and nutrition.

Taken together, the evidence reviewed here reframes sleep from a passive background condition into an active physiological driver of both cognition and physical performance. At the cognitive level, sleep deprivation primarily impairs vigilant attention, working memory, and executive functions dependent on the prefrontal cortex (Lim & Dinges, 2008, 2010; Lima et al., 2022), while simultaneously weakening emotion regulation by disrupting the amygdala-prefrontal cortex coupling (Simon et al., 2015). Sleep—especially its deep and REM stages—actively supports the consolidation of declarative and procedural memory (Rasch & Born, 2013; Weighall & Kellar, 2023).

At the level of exercise physiology, sleep deprivation and restriction measurably impair aerobic and anaerobic capacity, strength, power, and technical precision (Easow et al., 2025; Gong et al., 2024; Lopes et al., 2023), while also increasing the subjective experience of exertional fatigue and the risk of injury (Tawfeeq & Malm, 2025). Interventions involving sleep extension produce measurable, albeit variable, improvements in athletic performance (Cunha et al., 2023; Mah et al., 2011; Silva et al., 2021; Swinbourne et al., 2018).

Both of these relationships are underpinned by common neurobiological mechanisms—glymphatic system function, synaptic homeostasis, and circadian hormonal regulation (Fultz et al., 2019; Iliff et al., 2012; Jessen et al., 2015; Martin-López et al., 2025; Rasch & Born, 2013; Thun et al., 2015; van Hattem et al., 2025)—which emphasizes that the cognitive and physical consequences of sleep deprivation should not be considered in isolation. These findings have practical implications for sports, medical, and academic settings (Gohar et al., 2009; Kaczmarek et al., 2025; Maltese et al., 2016; Neuschwander et al., 2017; Saroha et al., 2025), justifying the treatment of sleep as a measurable, modifiable factor that should be systematically considered in training load planning, shift work organization, and health education.

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Supplementary Materials

Not applicable.

Author Contributions

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