Sleep and Athletic Performance

Impacts on Physical Performance, Mental Performance, Injury Risk and Recovery, and Mental Health: An Update

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KEYWORDS

• Sleep • Sport • Insomnia • Performance

KEY POINTS

- Insufficient sleep and poor sleep quality are prevalent among athletes, potentially due to time demands, physical demands, and developmental needs.
- Sleep disturbances among athletes have adverse impacts on physical performance, mental performance, injury risk and recovery, medical health, and mental health.
- Sleep interventions among athletes have been shown to improve physical strength and speed, cognitive performance and reaction time, mental health, and other domains.
- Sport organizations should incorporate sleep health promotion programs at individual, team, and system levels.

INTRODUCTION

Scope of the Problem

In recent years, there has been increased attention toward the importance of sleep and its essential role in athletic performance, cognition, health, and mental well-being. Many of these studies examine elite athletes (eg, Olympians, professionals, and/or players recruited to national and varsity teams), and some focus on athletes in general. Despite all the efforts expended, by any definition, numerous athletes still experience inadequate sleep.[1–3] Compared with nonathletes, athletes tend to sleep less on average.[4] Furthermore, athletes' quality of sleep seems lower than their nonathlete peers.[5–7] In addition, it has been suggested that certain types of athletes are more prone to developing sleep difficulties, such as sleep apnea. For example, according to George and colleagues[8] and Albuquerque and colleagues[9] National Football League (NFL) players have higher rates of obstructive sleep apnea (OSA), which have tremendous deleterious impacts on health and daytime sleepiness. There is increasing evidence that poor sleep is a good predictor for injuries and, more importantly, concussion.[10]

Position Statements

Recently, the International Olympic Committee (IOC) has addressed, for the first time, sleep as a major contributor to athletic performance and as a fundamental feature of athlete mental health.[11,12] In addition, the National Collegiate Athletics Association (NCAA)[13–17] included sleep health as part of their published mental health best practices[18]

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as well as their more recently published official position statement on the importance of sleep health for student-athletes.[18] These position statements from the NCAA and IOC represent the increased awareness of the importance of sleep health among organizations of elite athletes. Both these documents were the result of a literature review, Delphi process of iterative consensus building, and subsequent revision, after exhaustive reviews of the available literature. In addition to the NCAA and IOC position statements, 2 expert consensus documents were also produced that support the importance of sleep in athletes.

The first[19] was the result of a narrative review of sleep in athletes and suggests several recommendations for different challenges faced by athletes and their support team. Alongside 5 key recommendations, the investigators also provide an expert review of athlete sleep assessment tools and a flow diagram for practitioners to optimize and manage sleep for athlete and referral. The second is the result of 26 researchers and/or clinicians who formalized a review and a consensus document on the management of travel fatigue and jet lag in athletes.[20] This document recommends and suggests ways to manage travel fatigue and jet lag in athletes pretravel, during travel, and posttravel. Suggestions include behavioral and pharmacologic management within different possible scenarios faced by athletes.

The IOC mental health document[11] considers sleep health in terms of sufficiency (ie, at least 7 hours for adults), proper circadian alignment, good overall perceived sleep quality, and absence of sleep disorders, including insomnia disorder and sleep apnea. The document recommends that these dimensions of sleep be considered important for mental health as well as physical health and functioning. Furthermore, the document recommends education, proper assessment and screening, and treatment using evidence-based strategies—given the consideration that some treatments may have an impact on safety and/or performance.

The NCAA document focused on sleep as an important aspect of health, performance, and mental functioning in collegiate student-athletes.[18] This document addresses many identified barriers to sleep, including academic, athletic, and social time demands. Similarly, this document defines sleep health in terms of duration (at least 7 hours in adults), timing, overall quality, and absence of disorders, including insomnia and sleep apnea. Particular attention also is paid to the role of tiredness, fatigue, and/or sleepiness as consequences of sleep loss and/or disturbances. The NCAA makes 5 recommendations in this document:

1. Conduct a collegiate athlete time demands survey annually.
2. Ensure that consumer sleep technology, if used, is compliant with Health Insurance Portability and Accountability Act and Family Educational Rights and Privacy Act laws.
3. Incorporate sleep screening into the preparticipation examination.
4. Provide collegiate athletes with evidence-based sleep education that includes (a) information on sleep best practices, (b) information about the role of sleep in optimizing athletic and academic performance and overall well-being, and (c) strategies for addressing sleep barriers.
5. Provide coaches with evidence-based sleep education that includes (a) information on sleep best practices, (b) information about the role of sleep in optimizing athletic and academic performance and overall well-being, and (c) strategies to help optimize collegiate athlete sleep.

These efforts specifically recommend that sleep-related education should be provided, sleep difficulties and disorders should be routinely assessed and screened for, and sleep health promotion should be a goal of athletics programs.

EPIDEMIOLOGY OF SLEEP DISTURBANCES IN ATHLETES

Prevalence of Insufficient Sleep

Insufficient sleep duration can have an impact on metabolism, endocrine function, and athletic and cognitive outcomes, and, furthermore, can increase perceived effort during exercise.[21–23] When athletes are compared with nonathletes, they tend to sleep less and less efficiently. Leeder and colleagues[4] compared the habits of 47 elite athletes over a 4-day period with a group of non-athletes, using actigraphy; ages of participants were not reported, but groups were matched for age and gender. On average, athletes slept 6.55 hours $\pm$ 0.43 hours versus nonathletes who slept 7.11 hours $\pm$ 0.25 hours (P = .27). The investigators did report, however, lower sleep efficiency (80.6 hours $\pm$ 6.4 hours vs 88.7 hours $\pm$ 3.6 hours; $P < .05$), higher time spent in bed (8:07 hours $\pm$ 0:20 hours vs 8:36 hours $\pm$ 0.53 hours; $P < .05$), wake after sleep onset (0:50 hours $\pm$ 0:16 hours vs 1:17 hours $\pm$ 0:31 hours; $P < .05$), sleep-onset latency (5.0 hours $\pm$ 2.5 hours vs 18.2 hours $\pm$ 16.5 hours; $P < .05$), and sleep fragmentation (29.8 hours $\pm$ 9.0 hours vs 36.0 hours $\pm$ 12.4 hours; $P < .05$) in athletes. Furthermore, Lastella and colleagues[24] reported insufficient sleep duration among athletes, with

6.8 hours on average. Sargent and colleagues[25,26] also reported that over 14 nights assessed with actigraphy, athletes recorded an average of 6.5 hours of sleep per night.

Taken together, these studies have investigated a total of 241 elite athletes and, documented actigraphically, determined sleep durations of approximately 6.5 hours in most cases. Recently, Mah and colleagues[27] indicated that 39.1% of athletes reported insufficient sleep (<7 hours) by self-report. And, among a large sample of collegiate athletes in the United States (N = 8312), Turner and colleagues[28] reported that the mean number of nights per week that athletes did not think they got enough sleep was 3.8.

A recent review highlighted the insufficient sleep patterns of young athletes and compared them with those of nonathletes, finding conflicting results.[29] Based on 2 studies[30,31] with sleep diaries, young athletes reported sleeping longer than nonathletes by 66 and 25 minutes, respectively. However, a subsequent study with objective sleep measurement (ambulatory polysomnography) showed that young athletes reported a shorter total sleep time by approximately 36 minutes.[32] In addition, training and competition schedules may also decrease the total sleep time, thereby increasing the prevalence of insufficient sleep in athletes. For example, it has been demonstrated that sleep is impacted differently following a day or night game. In elite Australian rugby players, following a day game (15:45–17:45 PM) total sleep time averaged 7.7 ± 0.8 versus 5.3 ± 0.6 hours following an evening game (19:10–21:10 PM).[33] Likewise, in Australian female basketball players, following a double header compared with regular game, total sleep time, measured by actigraphy, was reduced by 11%.[34]

Prevalence of Poor Sleep Quality

Hoshikawa and colleagues[35] investigated the quality of sleep of 817 Japanese elite athletes with the Pittsburgh Sleep Quality Index (PSQI), showing that 28% of the participants exhibited a score greater than 5, suggesting poor quality of sleep. Mah and colleagues[27] reported that 42.2% of the 629 athletes in that study experienced poor sleep quality, also using the PSQI. In 2019, Turner and colleagues[28] examined data from 8312 collegiate student-athletes and found that 19.8% reported that “sleep difficulties” were particularly “traumatic or difficult to handle” over the past 12 months and that 21.8% reported extreme difficulty falling asleep at least 3 nights per week. Bleyer and colleagues[5] reported that 38% of their 452 participants reported poor sleep.

Findings from a study conducted among elite rugby and cricket players (n = 175) showed that 50% of their participants’ PSQI score were greater than 5 and that 9% scored greater than 10.[3] Tsunoda and colleagues[7] reported the PSQI scores of 14 wheelchair basketball athletes (mean = 5.8 ± 3.0) and compared their results with those of 103 nonathletes from the general population (mean = 4.51 ± 2.14). Regardless of total sleep time, the wheelchair athletes reported lower sleep quality and lower sleep efficiency than matched nonathletes.

In a cohort of 317 athletes from the Rio de Janeiro 2016 Summer Olympics from 11 different sports, poor sleep quality (as assessed by the PSQI) was prevalent in more than 50% of the athletes after the Olympic Games.[36] This research recapitulates the earlier results with a similar cohort, in which up to 83% of athletes reached the cutoff, indicating poor sleep.[37] The higher proportion with a score greater than 5 occurred in the lead-up to the Olympics and the lower figure was recorded at the games. Consequently, regardless of the type of sports, these results highlight the prevalence of poor sleep quality among athletes.

Prevalence of Daytime Sleepiness

Few studies have examined the prevalence of general fatigue and/or sleepiness among athletes. Turner and colleagues[28] reported that 60.9% of collegiate athletes report that they experience feeling “tired, dragged out, or sleepy during the day” at least 3 days per week (as measured by self-report). Furthermore, 32.75% of these collegiate student-athletes reported an inability to maintain wakefulness at least 3 times per week (by self-report). Mah and colleagues[27] reported that 51% of student-athletes in their study reported high scores (≥10) on the Epworth Sleepiness Scale. Last, among 190 NCAA division 1 student-athletes, 60% reported daytime sleepiness or sleepiness on 2 or more days per month.[10] These findings indicate high levels of sleepiness in elite athletes.

Prevalence of Circadian Preferences and Disruption

Data exploring chronotype among the general population suggest that approximately 25% are morning types, 50% are intermediate types, and approximately 25% are evening types.[38] Few studies have explored the chronotype distribution among athletes. Two studies[2,39] indicated that 51% of athletes were classified as morning types, 40% as intermediate types, and only 9% as evening types. One study examined athletes in wheelchairs, and the other examined school-aged athletes and may not be representative of the elite athlete population. Lastella and colleagues[40] investigated 114 elite athletes emerging from 5 different sports. Their results indicated that 28% were morning types, 65% were intermediate types, and only 6% were evening types, supporting previous findings that athletes tend to pursue and excel in sports that match their chronotype.[41] Circadian rhythms can influence variations in performance, depending on the time of day and typical training schedules, which ultimately can affect competitive performance.[42] When athletes experience disturbances in their environments or routines, such as overnight travel, repetitive time zone changes, evening training, or late-night competition, endogenous circadian rhythms and normal sleep patterns may be out of synchrony.[43,44] Such disruptions in circadian and sleep patterns can increase homeostatic pressure and thus influence the regulation of emotions, body temperature, and circulation of melatonin and cause a significant increase in sleep latency.[45] The sleep/wake behavior of athletes often is governed by their training schedules.[46] Therefore, the role of chronotype among athletes may interact with a training schedule and should be considered to optimize training and performance[42] and reduce the prevalence of chronobiologic disturbances. Circadian variation, such as timing of the day of competition or game have, been demonstrated to have considerable impact on performance.[47] Olympic swim times between 2004 and 2016 have demonstrated that late afternoon competition around 17:12 PM improved performance by 0.32% relative to 8:00 AM competition. Moreover, the time-of-the-day effect exceeded the difference between first and second and second and third places in 40% and 64% of the races, respectively. Despite the elaborate preparation of each Olympic athlete, circadian rhythms and time of the day still represent a major factor in human performance.

Prevalence of Sleep Disorders

Insomnia

Gupta and colleagues[48] demonstrated that the relation between elite sport participation and insomnia symptoms is poorly systematized. Daytime impairment—a key part of insomnia diagnosis—can reflect a wide variety of experiences, including fatigue, emotional fluctuation, and psychomotor and/or neuropsychological performance, which are all important for elite athletes. Given this particular sensitivity to performance impairment and high levels of sleepiness (which is not common in insomnia), there arise some challenges in insomnia assessment among elite athletes. Traditional insomnia models might poorly discriminate insomnia per se in this nontraditional population.[49] The multifaceted demands of elite sport, including a high level of training volume,[50,51] precompetition anxiety,[24,46,52] and circadian challenges (jet lag),[53] all can predispose and precipitate sleep disturbance, thus leading to or facilitating symptoms of insomnia.

Given the absence of a validated sleep questionnaire specifically for athletes before the creation of the Athlete Sleep Screening Questionnaire (ASSQ),[54] it is difficult to precisely indicate the insomnia prevalence in elite athletes. The systematic review conducted by Gupta and colleagues,[48] however, reported that sleep disturbance complaints range from 13% to 70% of the athletes and that overall, on average, 26% of the athletes significantly scored for insomnia symptoms using the Insomnia Severity Index and PSQI. Supporting the previous review, of 111 professional soccer players in Qatar, 27% reported subthreshold insomnia based on an Insomnia Severity Index (ISI) score of greater than 11 and 68.5% reported poor sleep.[55] Notwithstanding the popularity of these 2 questionnaires, neither of them is specifically validated in an elite athlete population. Elite athletes are selected primarily based on not only physiologic predisposition but also psychological attributes.[56,57] It is possible that personality traits that include a focus on success (eg, perfectionism) also may predispose an elite athlete to insomnia.[58] Furthermore, the demands of elite sports, including an elevated frequency, intensity, and volume of activity and scheduling challenges,[25,51] coupled with precompetition anxiety[52] and jet lag/travel,[59,60] may all lead an individual toward sleep difficulties. Given that these challenges are uncommon among the general population and the relationship between risk factors and sleep may be fundamentally different in this group (eg, distribution of muscle mass), tools not specifically validated in athletic populations should be used somewhat cautiously.

Sleep apnea

The prevalence of sleep apnea may be high in certain type of sports, such as strength, power, and high-contact sports, where athletes often present with a large body mass and neck circumference.[3,61,62] In the NFL and National Hockey League, 2 high-speed and high-contact sports, an elevated body mass index and a large neck circumference are considered protective assets, making athletes less injury prone.[3] These specific body traits, however, unfortunately, also predispose these athletes to an increased risk of OSA.[62–64] Two studies carried out among NFL players illustrated that players with these specific physical traits seemed to have a higher incidence of OSA.[8,65] In addition, in line with the previous football studies, Dobrosielski and colleagues[66] illustrated that approximately 8% of the NCAA division I football players were at risk for OSA. Moreover, in professional hockey players, OSA was present in approximately 10% of athletes.[67] It is reported that, in most cases, the OSA severity was mild but even mild OSA might cause major disturbances in sleep,[68] potentially having an impact on athletic performance. In a study involving 25 elite rugby union players, 24% were diagnosed with sleep apnea after an overnight polysomnography.[69] These results demonstrate that sleep apnea is a prevalent disorder in certain types of sports and, given its potentially harmful impact on health,[70,71] it would justify a process for identifying those at risk and a plan for care.

Other disorders

Few studies have been conducted on restless legs syndrome (RLS) among athletes. Findings from a study assessing a population of runners indicate that prevalence is suggested at approximately 13%.[72] Among hockey players, prevalence is suggested at approximately 5%[67]; finally, within a sample of rugby players, no participants reported RLS but 12% reported periodic limb movements (PLMs).[69] These 2 studies have shown that sleep disorders, such as RLS and PLMs, are relatively common among elite athletes from a variety of sports.

IMPACT OF SLEEP ON PHYSICAL PERFORMANCE

Adverse effects of sleep restriction on athletic performance have been documented for many years, including cardiorespiratory and psychomotor effects, which require sustained and stable performance over time.[73–78] Mougin and colleagues[78] observed 7 participants on a cycle ergometer, in a study that included a 10-minute warm-up and then a 20-minute steady exercise corresponding to 75% of the predetermined maximal oxygen consumption and was followed by an increased-intensity exercise until exhaustion; this was done along with sleep restriction (3 hours of wakefulness in the middle of the night). In this study, physiologic demands were significantly higher during the submaximal effort compared with a baseline night (10:30 PM to 7:00 AM).[78] Heart rate was significantly higher when measured after 9 minutes (167.1 $\pm$ 2.0 bpm vs 171.3 $\pm$ 2.5 bpm) and after 20 minutes (176.0 $\pm$ 2.6 bpm vs 179.1 $\pm$ 2.4 bpm). Also, ventilation (141.0 $\pm$ 5.7 bpm vs 157.5 $\pm$ 6.4 bpm) and respiratory frequency (43.0 $\pm$ 1.6 bpm vs 44.7 $\pm$ 1.7 bpm) were both altered after a sleep restriction compared with baseline. Similarly, these same variables were significantly higher after the sleep restriction condition when performing a graded exercise stress test, until exhaustion, whereas the volume of maximal oxygen uptake decreased. Lactate accumulation was also greater at the ninth minute ($P < .01$), at the twentieth minute ($P < .05$) of the steady power exercise, and at maximal exercise ($P < .05$) after sleep restriction. These results from Mougin and colleagues[78] elegantly demonstrated that after a sleep restriction, physical performances require a higher physiologic demand, ultimately leading the athletes to exhaustion faster than he should have been. In a separate study, however, there was no significant change in mean or maximal power in anaerobic tests after a 3:00 AM bedtime compared with a 10:30 PM bedtime.[79] Subsequent studies by Mougin and colleagues[80] showed that after 4-hour sleep restriction, the maximum work rate developed by the participants was reduced by 15 W for cyclists in a 30-minute exercise at 75% of maximum power. In agreement with some of the previous results, the average and maximum powers of an anaerobic test decrease among students,[81] football players,[82] and judokas[83] after a single 4-hour sleep restriction. The reasoning behind the decrease in resistance to exercise is the alteration of the aerobic pathways[77] or in the perceptual change (impression of a longer effort), because the physiologic aspects remain predominantly unchanged.[75,76] The increase in perceived effort accompanied by a reduction in generated power supports the theory of neuromuscular fatigue,[84] possibly indicating a combination of central nervous system response and neural theory of sleep.[75,85,86]

Other studies also have shown adverse impacts of sleep restriction on athletes' anaerobic power,[87] tennis serving accuracy,[88] isometric force,[89] and cortisol levels.[90] In addition, the average distance traveled by elite runners decreases (6.224–6.037 miles) in a treadmill exercise (30 minutes) at their own pace.[91] Skein and colleagues[92] reported lower average sprint times, reduced glycogen concentration in the muscles, and decreased strength and activation during an isometric force test after a 30-hour total sleep deprivation, with 10 athletes from team sports, compared with a normal 8 hours of sleep. Submaximal-effort sports, such as running, might be more likely affected by total sleep deprivation than maximum-effort sports, such as weightlifting, because they require more time and, therefore, have a negative impact on the perception of effort throughout time perhaps due to the higher physiologic demand required.[78] After sleep restriction, the perception of effort increases exponentially increased completion time of the test.[91] The differences in muscle contraction results (voluntary activation), however, can probably be explained by the sensitivity and accuracy of the electromyography equipment used. For example, previous studies probably have been limited in this aspect contrary to recent studies due to the technological advancement of equipment.[92,93] In summary, although the effects of sleep deprivation on exercise are not completely understood, many converging results imply adverse effects of sleep deprivation on athletic performance.

Moreover, the balance of the energy substrate seems vulnerable to sleep deprivation. For instance, a 30-hour sleep deprivation compared with an 8-hour sleep opportunity demonstrated the inability of the human body to fully recover (24 hours) muscle glycogen in an athletic population, as shown by the muscle glycogen concentration before exercise (310 $mmol \cdot kg^{-1}$ dry weight [dw] $\pm$ 67 $mmol \cdot kg^{-1}$ dw vs 209 $mmol \cdot kg^{-1}$ dw $\pm$ 60 $mmol \cdot kg^{-1}$ dw).[92] Inadequate glucose intake would hinder athletes' ability to compete for extended periods, because glycogen shortage is known to reduce muscle function and athletic stamina.[94,95] It seems that a large energy imbalance leads to a deterioration in both aerobic and anaerobic power production when activity is sustained over several days and sleep is reduced.[93–100] Prolonged periods of sleep deprivation are associated with increased sympathetic nervous system activity and decreases in parasympathetic nervous system activity as well as altered spontaneous baroreflex sensitivity during vigilance testing in healthy adults.[101] Because disturbances of sympathetic and parasympathetic equilibrium are associated with overtraining,[102] it is possible that these disturbances of the autonomic nervous system after sleep deprivation may promote the development of a state of overtraining in athletes.[95,103] Despite these nervous system disturbances, several studies have reported that sleep deprivation has minimal impact on the cardiorespiratory variables during exercise,[75,79,104] as opposed to the previous finding of Mougin and colleagues.[78] Differences probably are more attributable to the protocols administered and the exercise mode used (running, cycling, and time of exhaustion) throughout these different studies. In addition to these results, there were no significant effects on cardiorespiratory or thermoregulatory function in athletes despite a reduction in the distance run for 30 minutes on a treadmill after sleep deprivation.[91] Oliver and colleagues[91] hypothesized that the minimal effects on cardiorespiratory function could be due to the influence of perceived effort during the final stages of prolonged high-intensity exercise (described previously).

Furthermore, several performance aspects also lie in tactical and technical outcomes.[105] In 10 elite rugby players, 10 single-passing skill trials were investigated under normal sleep (7–9 hours) and restricted sleep (3–5 hours).[106] Following a period of familiarization with the dominant and nondominant side for passing, the players performed significantly worse under sleep restriction compared with normal sleep. In 11 collegiate athlete basketball players, following a sleep extension, shooting accuracy improved by 9.0% in free throw and by 9.2% for 3-point attempts.[27] Similarly, in 12 collegiate athlete tennis players, following a sleep extension to at least 9 hours, participants improved their serving accuracy compared with their normal sleep from 35.7% to 41.8%.[107] Last, the sleep of 17 elite Australian female basketball players was monitored with actigraphy over the course of 2 seasons.[34] The study investigated the sleep patterns of their players for game at home, on the road, and double headers alongside basketball efficiency statistic (EFF). Results reported a small correlation between total sleep time at prematch for regular game (r = −0.25; P = .430; n = 12) and double header (r = −0.22; P = .484; n = 12).

IMPACT OF SLEEP ON INJURY RISK AND RECOVERY

Sleep and Concussions

It is estimated that as many as 3.8 million concussions are sustained in the United States during competitive sports per year.[108] Regrettably, approximately 50% of concussions may go unreported.[108] As many as 1 million student-athletes reported having 2 or more concussions during a period of 12 months.[109] A study indicated that 40% of athletes with a concussion reported that their coaches were not aware of their symptoms.[110] Moreover, it is suggested that athletes involved in team sports have significantly higher risk for 1 or more concussions than athletes in individual sports.[109]

Sleep may play an important role as a risk factor for concussions. Participants were given sleep screening questionnaires and followed over a 1-year period. Predictors of incident concussions included clinically moderate to severe insomnia (relative risk [RR], 3.13; 95% confidence interval

[CI], 1.320–7.424; P = .015) and excessive daytime sleepiness (RR, 2.856; 95% CI, 0.681–11.977; P = .037), in a study of 190 NCAA athletes,[10] and these risk factors outperformed more traditional risk factors (eg, high-risk sport and history of concussions) as predictors.

Postconcussion sleep also is important. Recently, a meta-analysis reported that sleep disturbances were reported after a concussion approximately 50% of the time.[111] The most common sleep disturbances reported after a concussion are daytime sleepiness and insomnia, 50% and 25%, respectively.[112] In addition, sleep disturbance may be a prominent contributor to exacerbate comorbid features of depression, fatigue, and pain after a concussion[111] and worsen recovery because normal recuperative functions of sleep are altered.[113]

A return to baseline cognition and self-reported symptoms are key priorities that could be adopted to ensure player safety.[114,115] It has been demonstrated, however, that athletes sleeping fewer than 7 hours the previous night of testing would perform worse.[116] Considering that the decision of allowing a player back to play results from a comparison of preconcussion and postconcussion performances, a valid neurocognitive baseline is needed. In that sense, sleep should be monitored throughout the year to obtain an adequate neurocognitive performance and, therefore, a valid baseline. Moreover, the difference in symptomatic presentation after a concussion is highly divergent between male and female athletes,[117] which highlights the existing gap between the type of athletes and the consideration that should be directed toward an individualized baseline assessment to better detect the symptoms of a concussion.

Concussion, regardless of severity, is an injury to the brain, and athletes who are suspected of such an injury should be monitored carefully.[118,119]

An increase in awareness has directly led to more interest into postconcussion symptoms.[120,121] Research has specifically pointed out that the continuation of poor sleep symptoms after a concussion was a reliable predictor of prolonged recovery.[122–124] In addition, Kostyun and colleagues[125] demonstrated that during recovery, adolescents who reported greater sleep disturbance performed worse on neurocognitive testing.

Insufficient Sleep as a Risk Factor for Injury

Athletes aim to achieve peak performance for as long as possible, given typically short careers with high stakes. An online study of adolescent students (12–18 years old) reported that students sleeping less than 8.1 hours a night were 1.7 times more likely to have had an injury than their peers who slept more than 8.1 hours.[126,127] Furthermore, the same study also indicated that for each additional grade in school, students were 1.4 times more likely to have had an injury. Taken together, insufficient sleep duration may increase the risk of injury. In addition, the summation of years of (accumulated) sleep debt may play a role in risk injury outcomes.

Nutrition plays a fundamental role in recovery and injury prevention,[37,128–130] and nutrition and sleep have a bidirectional relationship.[131–135] There is an association between the number of hours slept and the intake of dietary nutriment categories.[133] Furthermore, individuals who have a later bedtime tend to consume a higher percentage of carbohydrates, fat, and protein than the average sleepers.[136] On the other hand, some nutriment categories may have a positive effect on sleep, such as tart cherries and kiwis, which are believed to reduce the number of awakening and increasing the sleep time.[137] Although nutritional knowledge is assumed to be high among athletes,[138] data are sparse on the number of athletes who are following their diets on a regular basis, and this may be impacted by poor sleep, which influences food intake.[139]

Adolescents sleeping fewer than 8 hours per night were more likely to sustain an injury[140] compared with students sleeping greater than 8 hours. These results are in line with the conclusions of Milewski and colleagues,[127] which is interesting given that the results are replicated in a population of athletes. In additional, Von Rosen and colleagues[140] found that the recommended intake of fruits, vegetables, and fish was not met for 20%, 39%, and 43% of their athletes, respectively. Therefore, the hypothesis of combined effect of poor sleep and a poor nutrition needs to be further explored to better understand the mechanisms underlying injuries in athletes.

Moreover, lack of sleep and poor sleep quality exacerbate depression and anxiety symptoms,[141] which also may increase injury risk. In a study of 958 athletes, 40.6% experienced an injury of various nature.[142] At preseason, 28.8% of the 958 enrolled athletes in this study reported anxiety symptoms and 21.7% reported depressive symptoms. Those with anxiety symptoms were 2.3 times more likely to have had an injury.[142] Given the strong association between poor sleep, anxiety, and depression symptoms,[143,144] it can be speculated that insufficient sleep may indirectly lead to an injury.

Insufficient Sleep and Recovery

Poor sleep quality and sleep deprivation impair brain functions that affect a wide array of cognitive functions,[145] which may directly or indirectly facilitate recovery from mental effort and/or physical injury. Furthermore, sleep-deprived individuals might increase their intake of unhealthy foods, which ultimately impairs glycogen repletion and protein synthesis,[146] which are critical for recovery in athletes. In addition, impaired sleep directly affects growth hormone release and alters cortisol secretion,[80] having an impact on recovery from exercise and stress. Sleep deprivation also increases proinflammatory cytokines, such as interleukin-6 and C-reactive protein levels, which are pain-facilitating agents,[147] ultimately affecting the immune system; hinders muscle recovery and repair from damages sustained in high-intensity training; and leads toward an imbalance of the autonomic nervous system.[148,149] Moreover, athletes who feel the need to push the boundaries of their capabilities may tend to develop poor sleep patterns, increasing their chances of illness (ie, medical symptoms), and this has an impact on their performance and recovery.[97] In addition to the aforementioned studies, others have also pointed out the association of insufficient sleep with higher symptoms both subjectively and objectively. In 545 adolescent athletes treated for sports-related concussion, Kostyun and colleagues[125] reported that subjectively sleeping fewer than 7 hours per night correlated with higher complaints of concussion symptoms during their recovery. In another study, Sufrinko and colleagues[150] investigated 670 student-athletes with a diagnosis of sport-related concussion. Those with a history of sleep disturbance before the injury performed worse on the Post-Concussion Symptom Scale and Verbal Memory and reported a higher number of total symptoms.[150] Ultimately, preinjury sleep disturbances may exacerbate neurocognitive symptoms and alter the recovery trajectory following a sports-related concussion.

IMPACT OF SLEEP ON MENTAL AND COGNITIVE PERFORMANCE

Vigilance and Reaction Time

Sleep restriction has been demonstrated to have a negative impact on attention and reaction times.[151–154] Furthermore, it has been demonstrated that reaction times are adversely impacted after only a 1-night, complete sleep deprivation.[87] In 12 healthy handball goalkeepers, it was demonstrated that following a partial sleep restriction, athletes were significantly slower on the reaction time test compared with normal sleep.[155]

Sleep extension, conversely, has been shown to improve reaction times by 15% and also improve objective daytime sleepiness,[156] in a study of student-athletes. Mah and colleagues[157] extended the sleep of a college basketball team during a 5- to 7-week period. The average total sleep time increased from 7.50 hours to 10.25 hours of sleep over this period. Student-athletes improved their reaction time scores ($P < .001$) in morning and evening testing sessions. Given that athletes often experience at least mild sleep restriction (especially during intense periods of training or competition), sleep management becomes a priority to maximize reaction time. Consistent with the findings on sleep extension, there is evidence that sleep can be banked to optimize vigilance and reaction time.[158–160]

Executive Function and Decision Making

Executive functions are one of the cornerstones of athletic performance.[161,162] These functions include the highest levels of thinking required to engineer a strategy, make a fast decision, demonstrate cognitive flexibility, and manage the prioritization of attention. Deep sleep/slow wave sleep seems to have different restorative functions both at the neurophysiologic and phenomenological levels. Deep sleep seems to have a beneficial impact on the prefrontal cortex, which also has a positive impact on the functions directed by this cerebral region.[163,164] Prioritization or inhibitory control ensures the control of the athlete's concentration, attention, and thoughts and suppresses the cognitive and behavioral external and internal distractions.[165,166] Cognitive flexibility is vital for athletes by ensuring efficiency and adaptation in changing tasks.[165,167] Adaptation is key in athletics; it prevents athletes from making a bad or a risky decision, and this inhibitory control is highly linked to sleep deprivation.[168,169] As sleep restriction is a common feature and reflects of the reality of the athletic population, studies have focused on its impact on decision making.[170,171] Demos and colleagues[171] demonstrated that sleep restriction had no impact statistically on decision making. However, participants were 30% more likely to make inhibition errors.[171] Officials represent a crucial part of sport, and they are subject to the same sleep challenges as athletes.[172] Although they may have a direct impact on the outcome of certain sports, the effect of sleep on decision making has yet to be adequately investigated among the population of sports officials.[172]

These studies underscore the deleterious effects of lack of sleep on executive functions. Too little sleep may alter an athlete's ability to make a good decision versus a risky one in a split second, during the course of a game or event. Caffeine has been suggested as a countermeasure to protect against effects on risk taking or poor decision making.[173] It has been demonstrated, however, that caffeine does not replace a proper night of sleep for these functions.[88,174–176]

Learning and Memory

Learning new skills is crucial for every athlete. The roots of memory consolidations are found in sleep.[85,177–179] The ability to recall information[180] is inevitably of interest for athletes. For example, the NFL requires emphasis on the playbook, and the ability to recall complex plays is essential for participation in football. Moreover, learning and improving a motor skill are known to continue 24 hours after training.[181] In healthy young adults, non–rapid eye movement (NREM) stage 2 sleep typically represents approximately 45% to 55% of total sleep time.[182] It has been demonstrated that the duration of sleep stage 2 (NREM) is strongly correlated with the consolidation of motor skills.[183–185] Arguably, the sleep period following learning a new skill is crucial, and it has been shown that sleep restriction can have an adverse impact on the memory consolidation.[186]

Although it is true to a certain point that practice makes perfect, the results of several studies indicated that sleep after learning improves performance significantly, relative to sleep deprivation.[187–189] So perhaps sleep makes perfect. Also, sleep restriction also has a negative impact on the academic performance of student-athletes.[190] Fifty-six students were either assigned to a 5 hours' or 9 hours' time in bed for 14 consecutive days, in which participants had to study for the Graduate Record Examination. Results showed that the sleep-restricted group was significantly impacted for the recall of massed item, which is fundamental in academic success.

Another group of elite athletes, student-athletes, need to be prepared not only for their competitions but also for academics. Turner and colleagues[28] found that general sleep difficulty, initial insomnia, daytime tiredness, daytime sleepiness, and insufficient sleep all were associated with decreased academic performance among student-athletes. It is partially a coach's responsibility to mentor the student-athletes to be ready for any kind of test, either athletic or academic. Ultimately, assessing sleep on a regular basis could provide crucial information for the coaching members and the athletes.[191] Furthermore, having a clear idea of how an athlete sleeps may help a team medical specialist prevent injuries, such as concussion.[10]

Creativity and Thinking

Through sleep, the consolidation theory suggests that learning and memory consolidation benefit creativity.[192] The relationship between sleep and creativity stems from the direct influence of sleep on learning and formation of new concepts, ideas, solutions, and, ultimately, the genesis of creativity.[193] It was demonstrated that rapid eye movement (REM) sleep can improve creative problem solving.[194] REM sleep, according to Cai and colleagues,[194] enhanced creativity for items that are primed before sleep by more than 40%. Another study showed that stage 1 sleep was associated with fluency and flexibility, and slow wave sleep and REM sleep were associated with originality and global measure of figural creativity.[195] Furthermore, in a Remote Associates Test study, participants were faced with different levels of difficulty and the unsolved problems were presented again after a period of sufficient sleep, wake, or no delay.[196] The sleep group solved a greater number of difficult Remote Associates Test items than the other groups. These findings suggest that sleep facilitates creative thinking for harder problems. Creative problem solving is essential for elite athletes. During every game and every competition, elite athletes are faced with decisions that either can improve or lessen their chances of winning. Therefore, it is essential to investigate how sleep can enhance problem solving within an environment filled with distractions, coupled with the rapidity of execution, which is more typical for elite athletes than nonathletes.

IMPACT OF SLEEP ON MENTAL HEALTH

Previous studies have pointed out the bidirectional associations between sleep, daily stressors, and poor mood states.[197,198] Moreover, poor sleep quality and short sleep duration were significantly associated with cognitive interferences related to stress the next day, such as the experience of intrusive, unwanted, off-task, and potentially ruminated thoughts.[144] In addition, associations in the opposite direction were found, such as stressful and cognitive interferences throughout the day, which would lead to an earlier bedtime and earlier wake time.[144]

Prevalence of anxiety symptoms in adult athletes ranges from 7.1% to 26%.[199,200] Student-athletes report higher rates of anxiety, up to 37%.[142,201] In a study by Lastella and colleagues,[202,203] 21% of the athletes reported that anxiety was the primary reason for their awakening during the night. Additionally, Savis and colleagues[204] reported, among student-athletes, a lower sleep quality the night before a competition. Student-athletes reported that the primary reason for their sleep difficulty was anxiety and that this greatly affected their performance the following day.[144,205,206] Moreover, Davenne[207] reported that continuously being in a new sleep environment exacerbated the anxiety, thus having a negative impact on sleep and therefore performance.

Worldwide, depression may affect close to 300 million individuals across all ages.[208] Sleep and depression are interrelated, because sleep represents a core component of depression.[209] Awareness of mental health issues among high-performance athletes has grown. However, the evidence varies considerably regarding the prevalence of depression in the athletic population. In 2016, a systematic review indicated that more than 1 in 3 athletes (34%) had reported symptoms of depression based on a clinical interview.[210] A subsequent systematic review in 2020 reported a prevalence of depression ranging from 6.7% and 34% among high-performance athletes aged 17 years and older.[211] In the pursuit to investigate the prevalence of mental health problems, including depressive disorder, eating disorders, and stress-related disorders, among elite athletes, another study found that women (37.8%) were more likely than men (16.8%) to seek for help.[212] The lifetime prevalence of mental health problems is reported by almost half of the elite athlete population,[212] which coincides with the reported prevalence of insufficient sleep and poor sleep quality. To support the closely knitted relationship between sleep difficulties and mental health problems, a study with outpatient polysomnography showed that athletes with clinical sleep difficulties were more likely to report depressive symptoms.[213] Last, a large study reported that 7.4% had had suicide ideation within the past year,[214] which was significantly associated with sleep distress, sleep onset insomnia, as well as insufficient sleep.

Athletes not getting sufficient sleep consistently show higher rates of anxiety and depression, leading to increased difficulty in coping with new environmental challenges and stressors, a key component of performance for every athlete.[184,185] Altogether, these studies underlined the crucial role of sleep in mental health, and adequate sleep has always been recognized to positively influence mental health and well-being in different populations, including athletes. Further studies are needed to clarify this bidirectional relation in athletes to develop appropriate plans of action and adaptative strategies to optimize performance and mental health.

INTERVENTIONS AT THE TEAM LEVEL

Promoting a Culture of Healthy Sleep

Prioritizing sleep in athletes' preparation and recovery routines is not an easy task. There is an omnipresent attitude in society toward sleep that has been put forward where being able to tolerate insufficient sleep is a sign of mental strength and a badge of honor.[215] This attitude may influence young elite athletes who are trying to reach the highest-level performance in their respective sports. To counter this, teams can promote a culture of healthy sleep as a performance enhancer. This culture includes embracing the idea that sleep is essential to athletic performance and recovery and counteracting the perception that getting sufficient sleep should produce a feeling of guilt. Several high-profile athletes have now publicly discussed the importance of sleep in their preparation and recovery.[216] Unfortunately, these athletes' habits are not yet the norm and, throughout the sports literature and culture, sleep is not yet a priority among elite athletes and professional team sports, although this may be changing.

Systematically Screening for Sleep Problems

Systematically screening for sleep problems is required to understand the scope of a problem, identify areas that need improvement, and identify individuals at risk for sleep problems.[18,19] Ideally, teams need to screen athletes at the beginning of a season and follow-up with prospective sleep assessment. Challenges include integrating sleep assessments into existing programs, decisions about what tools to use, implementing sleep assessment at multiple time points, and strategies for assessing sleep disorders. In addition, developing collaborative relationships with sleep providers should be a priority.[217,218] It should be noted that if athletes are not adequately screened for sleep disturbances, most sleep recommendations would be undermined and ineffective.[19] The recent expert consensus on sleep and athletes recommends a sleep toolbox for practitioners that includes screening sleep disturbances in all types of sports with the appropriate tools.

To date, only 1 sleep questionnaire has been validated in athletes, the ASSQ.[54] Another promising tool is the Athlete Sleep Behavioral Questionnaire,[219] which addresses mainly poor sleep behavior.

Treating Sleep Disorders

To treat sleep disorders among elite athletes, proper sleep screening is essential. Different types of athletes may be differently susceptible to certain types of sleep disorders. For example, American football players may have a higher prevalence of sleep apnea due to their physical attributes,[220,221] and swimmers may experience circadian rhythm problems due to their early practice schedules.[51]

Sports medicine teams should be educated on diagnosing and treating sleep disorders and referring to sleep specialists when appropriate,[22] and education about sleep disorders should be provided to both athletes and staff.[18,19] Furthermore, the sports medicine specialist also should be the provider and the promoter of good sleep behavior and its beneficial effects on athletic and academic performance.

When sleep disorders are identified, appropriate evidence-based treatments should be applied, just as in nonathletes,[11,18,19] including positive airway pressure therapy and oral appliances for sleep apnea and cognitive behavioral therapy for insomnia. Sometimes, however, evidence-based treatments of sleep disorders in athletes can be problematic. For example, sedating medications may be clinically indicated but may impede athletic performance, and some empirically supported treatments actually may be banned substances in sport.[11] For this reason, clinical providers may need to be sensitive to these issues and may need to consider whether sedating treatments impair performance or whether stimulating treatments are restricted because they are performance enhancing.

Managing Training and Travel Schedules

The relationship between training loads, timing, intensity, sleep, and performance is likely complex and not entirely understood. An increase in training load and training intensity, and decrease in hours of sleep, is associated with increased injury risk.[222,223] Therefore, training more efficiently may be preferable to training longer or harder; this would be more preferable to the accumulation of training load without a profitable recovery, accompanied by a decrease in performance and need for an extended period of recovery.[224,225]

Traveling represents a crucial component of an athlete's reality. Despite considerable evidence of the inevitable impact of travel fatigue and jet lag on performance, optimal management strategies remain unclear. As mentioned earlier, a consensus statement was produced by several researchers/clinicians.[20] The consensus includes information including definitions of circadian physiology terminology, a comprehensive explanation of the human circadian system, and how time-givers affect it, and ultimately provides consensus on recommendations for the management of travel fatigue and jet lag in athletes. Similarly, another group produced an outline on how to manage travel fatigue and jet lag in athletes with 3 distinct categories[226]; they provide recommendations pretravel, during travel, and last, posttravel. These practical tips are encouraged to be implemented to reduce the potential impact of travel on performance.

SUMMARY AND FUTURE DIRECTIONS

Sleep health is an important consideration for athletic performance. Athletes are at high risk of insufficient sleep duration (ie, less than 7–8 hours per night), poor sleep quality (eg, difficulty initiating or maintaining sleep or other sleep difficulties), daytime sleepiness and fatigue, suboptimal sleep schedules (eg, too early or too late), irregular sleep schedules, and sleep and circadian disorders (especially insomnia and sleep apnea). These issues, individually and in combination, likely have an impact on athletic performance via several domains. Sleep loss and/or poor sleep quality can impair muscular strength, speed, and other aspects of physical performance. Sleep issues also can increase risk of concussions and other injuries and impair recovery after injury. Cognitive performance is also impacted in several domains, including vigilance, learning and memory, decision making, and creativity. Sleep also plays important roles in mental health, which is important not only for athletic performance but also for the well-being of athletes in general. **Fig. 1** depicts a summary of these findings. These relationships have begun to be formally incorporated into athletics organizations, with official position statements that address sleep health published by the NCAA and the IOC.[11,18]

Much future research on sleep in athletes is needed because athletes represent a diverse group of individuals, and most studies in athletes are small, confined to a single team and/or sport, and include inconsistent measurement approaches. In particular, it is not clear what the best strategy is for assessing sleep parameters in athletes, and it likely may depend on factors intrinsic to the sport or activity. In addition, it is not known if standard approaches should be adapted. There also is a lack of trials of sleep interventions thought to have a positive impact on sleep and still an insufficient number of studies describing how improving sleep can improve performance. Despite that, there is a large and growing body of evidence that clearly establishes sleep health as an important factor in sport.

Improving sleep in athletes through sleep education at every level of sports organizations has significant implications for health, athletic performance, academic performance, and beyond, given the influence each athlete has on the general

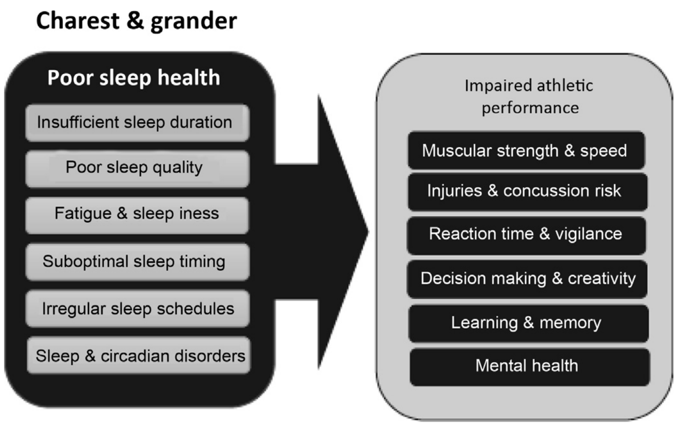

Fig. 1. Relationships between sleep health and athletic performance.

population as a role model; this not only will provide an opportunity to explore a crucial aspect of mental and physical health but also will pave the way for new interventions in the area of mental well-being. Tracking sleep through questionnaires, wearables, and other objective devices is promising, but there still are a lot of question marks remaining. It is, therefore, crucial to develop strategies to mitigate sleep difficulties, not only for physical performance but also for mental well-being, which will require additional data for a better understanding of the science of sleep.

CLINICS CARE POINTS

- Systematically screening for insufficient sleep and sleep disorder at key points during the season.
- When incorporating a plan of action to enhance sleep, consider other factors that may weight in insufficient sleep and sleep disorder (type of sports, gender, ongoing injury).
- Use adequate and validated screening tool in athletes (Athlete Sleep Screening Questionnaire - ASSQ).
- Identifiy athletes' chronotype to implement an adequate traveling plan and reduce the impact of time zone differences/jetlag.

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