Sleep and Athletic Performance

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Abstract

Sleep is an essential component of health and well-being, with significant impacts on physical development, emotional regulation, cognitive performance, and quality of life. Along with being an integral part of the recovery and adaptive process between bouts of exercise, accumulating evidence suggests that increased sleep duration and improved sleep quality in athletes are associated with improved performance and competitive success. In addition, better sleep may reduce the risk of both injury and illness in athletes, not only optimizing health but also potentially enhancing performance through increased participation in training. Despite this, most studies have found that athletes fail to obtain the recommended amount of sleep, threatening both performance and health. Athletes face a number of obstacles that can reduce the likelihood of obtaining proper sleep, such as training and competition schedules, travel, stress, academic demands, and overtraining. In addition, athletes have been found to demonstrate poor self-assessment of their sleep duration and quality. In light of this, athletes may require more careful monitoring and intervention to identify individuals at risk and promote proper sleep to improve both performance and overall health. This review attempts to highlight the recent literature regarding sleep issues in athletes, the effects of sleep on athletic performance, and interventions to enhance proper sleep in athletes.

Introduction

The recommended amount of sleep to achieve optimal health and quality of life varies across the lifespan, with a gradual decrease from birth to older adulthood. According to the American Academy of Sleep Medicine, adults require between 7 and 9 h of sleep for optimal performance and health, while adolescents require additional sleep, ideally between 8 and 10 h (9,30). The necessary amounts of sleep will vary widely between individuals and may differ day to day for the same individual based on a number of factors including illness, sleep debt, and physiologic or psychologic stress (9,30). Duration is only one component of sleep, however, and the importance of sleep quality has been increasingly recognized as a vital element of overall health and well-being (3). Although a specific evaluation of each component is beyond the scope of this article, recent guidelines from the National Sleep Foundation suggest that sleep quality is improved at all ages by sleep continuity (decreased sleep latency, nighttime awakenings, and wake after sleep onset) and sleep efficiency, while the roles of sleep architecture and naps are less clear (27). It has been suggested that athletes may require more sleep than nonactive individuals to allow for adequate recovery and adaptation between bouts of exercise, perhaps requiring closer to 9 or 10 h of sleep instead of the 7- to 9-h general recommendation for adults (3). Despite this, there are currently no specific guidelines regarding sleep duration or quality for athletes.

The majority of the available evidence seems to suggest that athletes exhibit similar or perhaps slightly better sleep duration and quality than sedentary counterparts, and an active lifestyle that includes moderate exercise is consistently recommended as an effective means to improve sleep (13). Nonetheless, with respect to the current adult and adolescent sleep recommendations, athletes have been consistently shown to average less than 8 h of sleep per night across a variety of adult and youth sports without any clear difference between sexes (16). In a study of more than 800 elite South African athletes, nearly three quarters reported sleeping less than 8 h, while 11% reported sleeping less than 6 h (51). A study of precompetitive sleep behavior in 103 athletes found that the majority slept less than 8 h, and 70% reported worse sleep quality than usual, largely attributable to mood and anxiety disturbances before competition (22). In addition, Olympic athletes demonstrated poorer sleep quality in terms of sleep efficiency and sleep fragmentation compared with age and sex-matched controls (23). In a systematic review regarding elite athletes and sleep quality, poor sleep quality was reported in 38% to 57% of participants and may be more prevalent among female athletes and participants in aesthetic sports (16).

Barriers to Sleep in Athletes

There are a number of obstacles to proper sleep in athletes that should be considered when attempting to optimize

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sleep and improve performance. Importantly, athletes have been found to demonstrate poor self-assessment in terms of sleep need, duration, and quality, potentially making them less likely to seek guidance or medical help when needed (50). In addition, certain cultures appear to idealize the ability to function with minimal sleep, potentially further inhibiting athletes from obtaining adequate sleep or seeking help. Training volume and schedules exert important, potentially negative effects on sleep. In a study of 27 adult athletes assigned to control (normal training), acute fatigue, and functional overreaching groups, those nine athletes in the functional overreaching group exhibited significant reductions in sleep time (17). Increases in acute training load also have been shown to be associated with decreased sleep duration and quality in female youth soccer players (54) and Australian rules football players (31). Sleep duration also has been found to be significantly affected by training schedule, with decreased sleep and increased pretraining fatigue before days with early morning training, (37) as well as nighttime competition (38). On the other hand, despite worse sleep quality, no change in sleep duration was identified with increased training load among elite adult male athletes during a residential camp (31). Given the important implications for health and performance, further efforts to define the relationship between training and sleep constitute an important area for future research.

Sleep in athletes also can be undermined by competition, not only due to the potentially increased physiologic loads but also due to the consequences of long-distance travel and the associated disturbances in mood, stress, and anxiety (16). Studies of athletes have repeatedly demonstrated increased levels of stress and anxiety around competition which are thought to impair sleep quality and duration, with a recent review reporting a prevalence of precompetition insomnia symptoms between 37% and 78% in elite athletes (16). In a study of 652 elite male and female German athletes, 66% admitted to a sleep problem before competition at least once in the prior year, primarily due to difficulty falling asleep and anxiety about the competition (11). Similarly, Juliff et al. (21) identified a high prevalence of sleep disturbance before competition in a large group of Australian elite athletes, highlighted by the fact that 59% of team sport athletes and 33% of individual athletes reported having no strategy to deal with poor sleep. Interestingly, the likelihood of poor sleep decreased with age in team sport athletes, but increased with age in individual sport athletes.

Travel for competition also may directly interfere with performance due to alterations in sleep schedules and dissociation with circadian rhythms. In addition to anxiety and stress related to travel itself, transmeridian travel and the associated jet lag are associated with fatigue, disorientation, impaired sleep, and general discomfort, all of which are a threat to athletic performance (53). Performance decrements after travel across time zones also can be compounded by training or competition times that do not align with the typical circadian rhythms based on the athletes' home time zone. Jehue et al. (18) initially identified a disproportionately higher winning percentage for west coast-based teams in the National Football League during night games when playing central or east coast-based teams, felt to be attributable to the misalignment of evening game times and the normal circadian rhythms of the visiting athletes. This finding has been supported by a subsequent study of 40 yr of evening and daytime games which found a higher success rate for west coast-based NFL teams during evening competitions (42).

Youth and collegiate athletes also may experience additional threats to sleep duration and quality as a function of concomitant academic pressures (47). While academic pressures are not unique to athletes, they must be managed alongside the additional time constraints of the simultaneous training and competition schedules. Unfortunately, this often means that athletes are required to sacrifice sleep time to fully accommodate academic and athletic commitments, such that younger athletes may be at an even greater risk of sleep deprivation (47). This can not only undermine athletic performance but also threaten classroom performance potentially increasing an athlete's stress, anxiety, and perceived pressure, resulting in further sacrifice of sleep duration and quality.

Athletes also may be at increased risk for certain medical conditions associated with impaired sleep. Although it is estimated to affect only 4% of the general population, sleep-disordered breathing has been estimated to be present in 14% of professional football players (15). Given the detrimental effects that sleep-disordered breathing and obstructive sleep apnea can have on both health and athletic performance, a high index of suspicion should exist, particularly among athletes with increased body mass and large neck circumference. Restless legs syndrome is increasingly recognized as an important cause of poor sleep, perhaps more so in athletes than previously suspected. Although moderate exercise is recommended for individuals with restless legs syndrome, a single survey of 61 marathon runners found that 13% met the criteria for restless legs syndrome, suggesting that this may be a more prevalent condition among athletes than previously suspected (12).

Sleep and Performance

Several previous studies in team sports have demonstrated that competitive success in competition is related to increased sleep duration and quality. In a recent study, 576 elite male and female Brazilian athletes were asked to describe their sleep quality and mood immediately before a national or international competition (5). While the majority of participants rated their sleep quality as normal or good, poor sleep quality was an independent predictor of lost competition, even after accounting for the effects of anger, vigor, and tension. A study of 42 adult netball athletes used a combination of wrist actigraphy and sleep journals before, and during, a national tournament to evaluate the relationship between sleep and competitive success. The two teams with the highest placement in the tournament demonstrated significantly greater sleep duration and subjective ratings of sleep quality compared with the two last place teams, and a strong inverse correlation ($r = -0.62$) was identified between sleep duration during the competition and final tournament position (lower position being better) (20). While this seems to suggest that improved sleep duration and quality are associated with increased chances of competitive success, this has only been investigated in team sports, and there may be considerable variation in this effect between individuals.

Endurance Performance and Anaerobic Power

The specific mechanisms responsible for the association between sleep and performance are not well defined, but the effects may vary depending on the task involved. With respect to endurance performance, most previous research has demonstrated that sleep deprivation inhibits performance, perhaps through an increase in perceived exertion (14). In a study of 11 male subjects who completed a 30-min self-paced treadmill test after a normal night sleep and after 30 h of sleep deprivation in a randomized order, Oliver et al. (28) found that distance covered was decreased after sleep deprivation, without differences in thermoregulatory function or oxygen consumption. One night of sleep loss also has been shown to decrease time to exhaustion in progressive testing in volleyball players (2). In addition, a single night of restricted sleep after a heavy exercise bout was found to result in a 4% decrease in 3-km time trial performance the following morning among adult cyclists, suggesting that restricted sleep may impair recovery between bouts of strenuous exercise (7). The effect of sleep deprivation on anaerobic power is less clear, however. Mean and peak power outputs during a Wingate Test have been found to decrease significantly after 36 h of sleep deprivation (43), as well as after a night of sleep restriction in athletes (1). On the other hand, no differences in mean or peak power were identified with Wingate testing after complete sleep deprivation in student athletes (45), or after sleep restriction of 4 h in highly trained athletes (26).

Preexercise muscle glycogen stores have been found to be decreased after sleep deprivation, suggesting an alteration in substrate availability that could translate into impaired performance in endurance efforts (41). In addition, decrements in time to exhaustion after sleep deprivation in laboratory testing conditions have been associated with an increased rating of perceived exertion, and improvements in time to exhaustion after sleep extension appear to be related to a decrease in perceived exertion at comparable workloads, suggesting that a central fatigue mechanism may be responsible (49). Neuromuscular fatigue has been found to only partly explain changes in perceived exertion in endurance exercise after sleep deprivation (49), however, and the interaction of these mechanisms remains an important area of future investigation.

Sprint Performance

The effect of sleep deprivation on performance in speed and strength-based activities is conflicting. With respect to sprint performance, Skein et al. (41) found slower mean sprint times during an intermittent sprinting protocol in male team sport athletes after 30 h of sleep deprivation. Similarly, after a 5- to 7-wk period of 2-h sleep extension in male collegiate basketball players, Mah et al. (24) identified significant improvements in sprint test times, as well as improved self-ratings of fatigue, vigor, and performance during practices and games. On the other hand, Takeuchi et al. (46) found no difference in 40-m sprint performance in a group of 12 healthy young, recreationally active adult males after 64 h of total sleep deprivation. A single study of eight young adult men found that maximal weights lifted in bench press, leg press, and dead lift all decreased after three consecutive nights of only 3 h of sleep (34). However, one night of total sleep deprivation was not found to significantly affect lifting performance in male collegiate weightlifters despite worse ratings of sleepiness, fatigue, confusion, mood, and affect (4). It has been suggested that sleep loss may have a smaller effect on performance during shorter, maximal events when the effects of increased perceived exertion or muscle glycogen deficits would be less impactful than during prolonged submaximal or progressive efforts (14,28). The available studies are small and have used different methods to measure strength and sprint performance, however, suggesting that further research is needed to better define this relationship.

Accuracy and Reaction Time

Sleep deprivation and even minimal amounts of sleep restriction have been consistently shown to impair accuracy in athletic events, whereas accuracy has been found to improve after sleep extension. Compared with after a full night's sleep, dart throwing accuracy was found to decrease significantly after a single night of 4 to 5 h of sleep (10). Similarly, a single night of 5 h of sleep in tennis players was associated with a decrease in serving accuracy of up to 53% compared with after a normal night's sleep (35). A study of 29 adolescent student-athletes found decreased sleep time on weekdays than weekends, with accumulated sleep debt through the week that was associated with worsening reaction times by the end of the week (44). On the other hand, in the study of collegiate male basketball players mentioned above, an increase of objectively measured sleep from 6.6 to 8.5 h per night over a 5- to 7-wk period was associated with a 9% increase in free-throw accuracy, a 9.2% increase in three-point field goal percentage, and significant improvements in a psychomotor vigilance task (24). In collegiate tennis players, 1.6-h sleep extension was associated with a 36% to 41% increase in serving accuracy (39). Together, these studies suggest that sleep deprivation and sleep restriction are associated with impairments in reaction time and accuracy, while sleep extension appears to have a beneficial effect on performance of these tasks.

Learning and Executive Function

The capacity to learn is essential to athletic development and performance, and sleep is critical for memory consolidation. This has important implications for tactical development in athletic training and may be particularly important among youth and collegiate athletes who must concomitantly attend to both academic and athletic demands (47). For example, a study of adolescent male soccer players identified a steeper learning curve for the performance of sport-specific tasks after habitual sleep than after a period of sleep deprivation (29). Although there are large interindividual differences in the effects of sleep loss on executive function, sleep deprivation is associated with cognitive lapses and may significantly undermine tasks that require flexible thinking. One night of sleep deprivation also has been found to have significant negative effects on inhibitory control (36), potentially undermining decision-making during athletic competition. Finally, sleep loss has been found to have a negative effect on a number of measures of subjective well-being, including fatigue, mood, soreness, depression, and confusion (54). Impairments in neurocognitive performance may be the most critically important effect of impaired sleep on athletic performance in

competition, particularly in athletic events with large elements of quick decision-making.

Sleep, Injury, and Illness

Recent evidence suggests that training availability is a primary determinant of athletic success, and injuries and illnesses represent the greatest obstacle to training participation in athletes. Although prior research has focused almost exclusively on youth athletes, the available evidence suggests that impaired or decreased sleep is associated with an increased risk of injury. In a study of middle and high school athletes, Milewski et al. (25) found that those individuals who slept less than 8 h per night on average were 70% more likely to report an injury than those who slept more than 8 h. In addition, a recent study of 496 adolescent athletes from 16 different individual and team sports found that increased training load and decreased self-reported sleep duration were independently associated with an increased risk of injury. In fact, the greatest risk for injury resulted when training load increased and sleep duration decreased simultaneously, as is often seen in competitive travel and training camps (52). The underlying mechanism for the relationship between sleep loss and injury is unclear, but may be related to resulting impairments in reaction time and cognitive function after sleep deprivation that could predispose to acute injury (52). On the other hand, impaired sleep may contribute to higher levels of fatigue that can similarly contribute to injury risk in athletes.

Decreased sleep has been shown to be immunosuppressive and increases susceptibility to upper respiratory infections in particular (8,32). In a study of 154 adult men and women, Cohen et al. (8) monitored sleep duration and efficiency over a 14-d period, after which participants were administered nasal drops containing rhinovirus and monitored for symptom development over 5 d. Those individuals who slept less than 7 h were nearly three times as likely to develop an infection compared with those who slept 8 h or more. In a similar study of 164 adults monitored for 7 d with wrist actigraphy before nasal rhinovirus administration, those who slept less than 5 h were 4.5 times more likely to develop a subsequent infection than those that slept more than 7 h (32). It has been suggested that increased perceived stress and depressive symptoms may contribute to an increased risk of illness around athletic competition, which may be exacerbated by impairments in sleep duration and quality often seen at the same time (21).

Interventions to Promote Sleep in Athletes

Given the significant implications for performance, health and general well-being, a number of recommendations have been suggested to monitor and improve sleep in athletes (14,40,47). Athletes with complaints of poor sleep or excessive daytime fatigue should be screened for medical conditions that could be contributing, such as insomnia, sleep disordered breathing, restless legs syndrome, depression, anxiety, or concomitant illness. Athletes may experience stress from a number of sources both in and out of sport, and this may be especially true of adolescent athletes who are attempting to manage academic and athletic demands within an already highly pressurized social environment (47). Early identification and management of mental health issues in athletes is critical for improved sleep, health, and performance.

Barring the presence of an underlying medical condition, a sleep monitor or daily sleep journal for at least 2 wk can be used to quantify sleep duration (40). Identifying the optimal amount of sleep on an individual basis may be difficult, but at a minimum, adult and youth athletes who demonstrate an average sleep of less than 7 or 8 h, respectively, likely warrant additional evaluation to identify their specific sleep barriers. Those individuals felt to demonstrate negative effects of insufficient sleep duration should be encouraged to use the sleep hygiene techniques listed below and gradually extend their sleep by 30 to 60 min per night, monitoring for improvements in daytime energy and alertness (16). Longitudinal monitoring of training load, sleep, fatigue, stress, and mood may not only help identify individuals at risk but also can help monitor for improvements in sleep, well-being, and performance after interventions and aid in the development of individualized sleep recommendations in athletes (40).

Proper sleep hygiene is important for all athletes, including a proper sleep environment and schedule. Sleeping environments should be comfortable, cool, dark, without electronic devices, and with minimal ambient noise or distraction. To the extent that training and competition schedules allow, athletes should establish consistent sleep and wake times and incorporate a 30- to 60-min period of quiet relaxation before bedtime that can help facilitate sleep onset. Although studies in athletes have not identified a performance detriment from the nighttime use of portable electronic devices (19), they may suppress natural melatonin production and interfere with sleep, such that restriction for at least 1 h before bedtime may be reasonable (40). Intake of caffeine or other stimulants (*e.g.*, medication for attention deficit disorder) should be limited to the morning hours, and alcohol and nicotine should be avoided due to their disruptive effects on sleep. Over-the-counter sedating medications, such as antihistamines and melatonin, are widely used but have not been shown to benefit sleep or subsequent performance in athletes (48). Sedating medications, such as benzodiazepines, should be avoided given their addictive potential without proven performance benefit (33).

Efforts should be made to limit the effects of training and competition on sleep schedules to reduce the risk of sleep restriction in athletes. Variation in training times should be minimized and early morning and late evening training and competitions should be avoided. When possible, transmeridian travel should be limited to two to three time zones, and travel should allow for 1 d in the destination before competition per time zone crossed to adjust properly. Adjusting training, sleep and wake times before departure to mimic the destination time zone can aid in the adjustment and potentially shorten the adjustment time after arrival.

The role of daytime naps on performance is unclear. There is no available data comparing the effects of sleep extension through nighttime sleep extension alone versus combined naps and nighttime sleep. Those studies that have evaluated the effect of naps while attempting to control for nighttime sleep duration have demonstrated equivocal results, but naps may provide an additional performance benefit

during periods of unavoidable sleep restriction (6). Naps should be relatively brief (~30 min) to avoid sleep inertia and avoided late in the day to prevent any disruption of nighttime sleep. While further research is needed to clarify the role of naps in athletic performance, the available evidence seems to suggest that naps could be a useful way to increase total sleep duration during periods when sleep restriction is not avoidable, but not necessarily as a substitute for nighttime sleep.

Future Areas of Research

Between-Sport Differences in the Effect of Sleep on Performance

Sleep may exert different effects on different sports as a result of the differential effect on the specific tasks involved. While the evidence regarding sleep and endurance performance, reaction time, and accuracy are consistent, the effects on strength, sprint, and power are less clear, with obvious implications for performance in sports that significantly incorporate these elements.

Mechanisms Responsible for Relationship Between Sleep and Performance

Although the relationship between impaired sleep and performance decrements is considerable, the underlying mechanisms are poorly defined. The pathway between sleep and performance may be task-specific, potentially incorporating alterations in substrate availability, perceived exertion, reaction time, cognitive speed, and/or executive function. Future research should be aimed at identifying the biomechanical, psychologic, and physiologic mechanisms that mediate the influence of sleep on performance in athletes in different sports.

Training Load and Sleep Interaction

It remains unclear how fluctuations in training load influence sleep in athletes. While higher chronic loads are associated with physiologic adaptations that are beneficial to performance, large fluctuations in acute training load may have a negative impact on sleep. While sleep appears to be impaired in overtrained athletes, these impairments may accumulate over several weeks and understanding the acute interactions between training load and sleep may help identify individuals at higher risk to facilitate individualized exercise prescription, improve performance, and reduce injury risk in athletes.

Sleep and Injury Risk

Initial research appears to suggest that reduced sleep duration is associated with increased injury risk, but the majority of these studies have been retrospective and conducted in youth athletes. In addition, the underlying mechanisms for this suggested relationship are unclear. It seems plausible that impairments in the same constructs that influence performance, such as cognition, reaction time, or fatigue, resulting from poor sleep could increase injury risk, but these relationships have not been fully explored. An increased understanding of these effects may help facilitate the real-time identification of athletes at risk for injury and allow for individualized intervention to reduce the risk of injury.

Conclusions

The available evidence suggests that sleep optimization can have a significant influence on performance across a range of athletic activities. Improvements in sleep duration and quality appear to improve reaction time, accuracy, and endurance performance, while the effects on anaerobic power, strength, and sprint performance are less clear and remain an important area of further study. In addition, poor sleep may increase the risk of injury and illness, reducing training availability and undermining overall health. Athletes consistently demonstrate insufficient sleep and poor sleep quality, and experience a number of unique obstacles to proper sleep, including training and competition schedules, travel, fluctuations in training load, anxiety or stress associated with sporting events, and competing scholastic demands in younger athletes. Sports medicine professionals and coaching staff should prioritize proper scheduling, travel protocols, time management, stress management, and sleep hygiene in athletes to improve overall health and performance.

References

1. Abedelmalek S, Chtourou H, Aloui A, *et al*. Effect of time of day and partial sleep deprivation on plasma concentrations of IL-6 during a short-term maximal performance. *Eur. J. Appl. Physiol*. 2013; 113:241–8.
2. Azboy O, Kaygisiz Z. Effects of sleep deprivation on cardiorespiratory functions of the runners and volleyball players during rest and exercise. *Acta Physiol. Hung*. 2009; 96:29–36.
3. Bird SP. Sleep, recovery, and athletic performance: a brief review and recommendations. *Strength Cond. J*. 2013; 35:43–7.
4. Blumert PA, Crum AJ, Ernsting M, *et al*. The acute effects of twenty-four hours of sleep loss on the performance of national-caliber male collegiate weightlifters. *J. Strength Cond. Res*. 2007; 21:1146–54.
5. Brandt R, Bevilacqua GG, Andrade A. Perceived sleep quality, mood states, and their relationship with performance among Brazilian elite athletes during a competitive period. *J. Strength Cond. Res*. 2017; 31:1033–9.
6. Brooks A, Lack L. A brief afternoon nap following nocturnal sleep restriction: which nap duration is most recuperative? *Sleep*. 2006; 29:831–40.
7. Chase JD, Roberson PA, Saunders MJ, *et al*. One night of sleep restriction following heavy exercise impairs 3-km cycling time-trial performance in the morning. *Applied physiology, nutrition, and metabolism = Physiologie appliquee, nutrition et metabolisme*. 2017: 1–7.
8. Cohen S, Doyle WJ, Alper CM, *et al*. Sleep habits and susceptibility to the common cold. *Arch. Intern. Med*. 2009; 169:62–7.
9. Consensus Conference, Watson NF, Badr MS, *et al*. Joint Consensus Statement of the American Academy of Sleep Medicine and Sleep Research Society on the recommended amount of sleep for healthy adult: methodology and discussion. *Sleep*. 2015; 38:1161–83.
10. Edwards BJ, Waterhouse J. Effects of one night of partial sleep deprivation upon diurnal rhythms of accuracy and consistency in throwing darts. *Chronobiol. Int*. 2009; 26:756–68.
11. Erlacher D, Ehrlenspiel F, Adegbesan OA, El-Din HG. Sleep habits in German athletes before important competitions or games. *J. Sports Sci*. 2011; 29:859–66.
12. Fagundes SB, Fagundes DJ, Luna AA, *et al*. Prevalence of restless legs syndrome in runners. *Sleep Med*. 2012; 13:771.
13. Fullagar HH, Duffield R, Skorski S, *et al*. Sleep and recovery in team sport: current sleep-related issues facing professional team-sport athletes. *Int. J. Sports Physiol. Perform*. 2015; 10:950–7.
14. Fullagar HH, Skorski S, Duffield R, *et al*. Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sports Med*. 2015; 45:161–86.
15. George CF, Kab V, Kab P, *et al*. Sleep and breathing in professional football players. *Sleep Med*. 2003; 4:317–25.
16. Gupta L, Morgan K, Gilchrist S. Does elite sport degrade sleep quality? A systematic review. *Sports Med*. 2016.
17. Hausswirth C, Louis J, Aubry A, *et al*. Evidence of disturbed sleep and increased illness in overreached endurance athletes. *Med. Sci. Sports Exerc*. 2014; 46:1036–45.

18. Jehue R, Street D, Huizenga R. Effect of time zone and game time changes on team performance: National Football League. *Med. Sci. Sports Exerc*. 1993; 25:127–31.
19. Jones MJ, Peeling P, Dawson B, *et al*. Evening electronic device use: the effects on alertness, sleep and next-day physical performance in athletes. *J. Sports Sci*. 2017; 1–9.
20. Juliff LE, Halson SL, Hebert J, *et al*. Longer sleep durations are positively associated with finishing place during a national multi-day netball competition. *J. Strength Cond. Res*. 2017.
21. Juliff LE, Halson SL, Peiffer JJ. Understanding sleep disturbance in athletes prior to important competitions. *J. Sci. Med. Sport*. 2015; 18:13–8.
22. Lastella M, Lovell GP, Sargent C. Athletes' precompetitive sleep behaviour and its relationship with subsequent precompetitive mood and performance. *Eur. J. Sport Sci*. 2014; 14(Suppl 1):S123–30.
23. Leeder J, Glaister M, Pizzoferro K, *et al*. Sleep duration and quality in elite athletes measured using wristwatch actigraphy. *J. Sport Sci*. 2012; 30:541–5.
24. Mah CD, Mah KE, Kezirian EJ, Dement WC. The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep*. 2011; 34:943–50.
25. Milewski MD, Skaggs DL, Bishop GA, *et al*. Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. *J. Pediatr. Orthop*. 2014; 34:129–33.
26. Mougin F, Bourdin H, Simon-Rigaud ML, *et al*. Effects of a selective sleep deprivation on subsequent anaerobic performance. *Int. J. Sports Med*. 1996; 17:115–9.
27. Ohayon M, Wickwire EM, Hirshkowitz M, *et al*. National Sleep Foundation's sleep quality recommendations: first report. *Sleep Health*. 2017; 3:6–19.
28. Oliver SJ, Costa RJ, Laing SJ, *et al*. One night of sleep deprivation decreases treadmill endurance performance. *Eur. J. Appl. Physiol*. 2009; 107:155–61.
29. Pallesen S, Gundersen HS, Kristoffersen M, *et al*. The effects of sleep deprivation on soccer skills. *Percept. Mot. Skills*. 2017; 124:812–29.
30. Paruthi S, Brooks LJ, D'Ambrosio C, *et al*. Consensus statement of the American Academy of Sleep Medicine on the recommended amount of sleep for healthy children: methodology and discussion. *J. Clin. Sleep Med*. 2016; 12:1549–61.
31. Pitchford NW, Robertson SJ, Sargent C, *et al*. Sleep quality but not quantity altered with a change in training environment in elite Australian Rules football players. *Int. J. Sport Physiol*. 2017; 12:75–80.
32. Prather AA, Janicki-Deverts D, Hall MH, Cohen S. Behaviorally assessed sleep and susceptibility to the common cold. *Sleep*. 2015; 38:1353–9.
33. Reilly T, Atkinson G, Budgett R. Effect of low-dose temazepam on physiological variables and performance tests following a westerly flight across five time zones. *Int. J. Sports Med*. 2001; 22:166–74.
34. Reilly T, Piercy M. The effect of partial sleep deprivation on weight-lifting performance. *Ergonomics*. 1994; 37:107–15.
35. Reyner LA, Horne JA. Sleep restriction and serving accuracy in performance tennis players, and effects of caffeine. *Physiol. Behav*. 2013; 120:93–6.
36. Rossa KR, Smith SS, Allan AC, Sullivan KA. The effects of sleep restriction on executive inhibitory control and affect in young adults. *J. Adolesc. Health*. 2014; 55:287–92.
37. Sargent C, Lastella M, Halson SL, Roach GD. The impact of training schedules on the sleep and fatigue of elite athletes. *Chronobiol. Int*. 2014; 31:1160–8.
38. Sargent C, Roach GD. Sleep duration is reduced in elite athletes following night-time competition. *Chronobiol. Int*. 2016; 33:667–70.
39. Schwartz J, Simon RD Jr. Sleep extension improves serving accuracy: a study with college varsity tennis players. *Physiol. Behav*. 2015; 151:541–4.
40. Simpson NS, Gibbs EL, Matheson GO. Optimizing sleep to maximize performance: implications and recommendations for elite athletes. *Scand. J. Med. Sci. Sports*. 2017; 27:266–74.
41. Skein M, Duffield R, Edge J, *et al*. Intermittent-sprint performance and muscle glycogen after 30 h of sleep deprivation. *Med. Sci. Sports Exerc*. 2011; 43:1301–11.
42. Smith RS, Efron B, Mah CD, Malhotra A. The impact of circadian misalignment on athletic performance in professional football players. *Sleep*. 2013; 36:1999–2001.
43. Souissi N, Sesboue B, Gauthier A, *et al*. Effects of one night's sleep deprivation on anaerobic performance the following day. *Eur. J. Appl. Physiol*. 2003; 89:359–66.
44. Suppiah HT, Low CY, Chia M. Effects of sport-specific training intensity on sleep patterns and psychomotor performance in adolescent athletes. *Pediatr. Exerc. Sci*. 2016; 28:588–95.
45. Taheri M, Arabameri E. The effect of sleep deprivation on choice reaction time and anaerobic power of college student athletes. *Asian J. Sports Med*. 2012; 3:15–20.
46. Takeuchi L, Davis GM, Plyley M, *et al*. Sleep deprivation, chronic exercise and muscular performance. *Ergonomics*. 1985; 28:591–601.
47. Taylor L, Chrismas BC, Dascombe B, *et al*. The importance of monitoring sleep within adolescent athletes: athletic, academic, and health considerations. *Front. Physiol*. 2016; 7:101.
48. Taylor L, Chrismas BC, Dascombe B, *et al*. Sleep medication and athletic performance-the evidence for practitioners and future research directions. *Front. Physiol*. 2016; 7:83.
49. Temesi J, Arnal PJ, Davranche K, *et al*. Does central fatigue explain reduced cycling after complete sleep deprivation? *Med. Sci. Sports Exerc*. 2013; 45:2243–53.
50. Van Dongen HP, Maislin G, Mullington JM, Dinges DF. The cumulative cost of additional wakefulness: dose-response effects on neurobehavioral functions and sleep physiology from chronic sleep restriction and total sleep deprivation. *Sleep*. 2003; 26:117–26.
51. Venter RE. Role of sleep in performance and recovery of athletes: a review article. *S. Afr. J. Res. Sport Ph*. 2012; 34:167–84.
52. von Rosen P, Frohm A, Kottorp A, *et al*. Multiple factors explain injury risk in adolescent elite athletes: applying a biopsychosocial perspective. *Scand. J. Med. Sci. Sports*. 2017.
53. Waterhouse J, Reilly T, Edwards B. The stress of travel. *J. Sports Sci*. 2004; 22:946–65; discussion 65–6.
54. Watson A, Brickson S, Brooks A, Dunn W. Subjective well-being and training load predict in-season injury and illness risk in female youth soccer players. *Br. J. Sports Med*. 2016.