

## Review

# Optimizing sleep to maximize performance: implications and recommendations for elite athletes

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Despite a growing body of literature demonstrating a positive relationship between sleep and optimal performance, athletes often have low sleep quality and quantity. Insufficient sleep among athletes may be due to scheduling constraints and the low priority of sleep relative to other training demands, as well as a lack of awareness of the role of sleep in optimizing athletic performance. Domains of athletic performance (e.g., speed and endurance), neurocognitive function (e.g., attention and memory), and physical health (e.g., illness and injury risk, and weight maintenance) have all been shown to be

negatively affected by insufficient sleep or experimentally modeled sleep restriction. However, healthy adults are notoriously poor at self-assessing the magnitude of the impact of sleep loss, underscoring the need for increased awareness of the importance of sleep among both elite athletes and practitioners managing their care. Strategies to optimize sleep quality and quantity in athletes include approaches for expanding total sleep duration, improving sleep environment, and identifying potential sleep disorders.

In recent years, increased attention has been paid to the essential role of sleep in health and well-being. However, like numerous other important health-related behaviors, many athletes still experience inadequate sleep (Samuels, 2009; Silva et al., 2012). Compared with non-athletes, athletes tend to sleep less (6.5–6.7 h per night) and the quality of their sleep is lower (Fietze et al., 2009; Mah et al., 2011; Leeder et al., 2012; Hausswirth et al., 2014; Sargent et al., 2014). Limited additional research suggests that some athletes, in particular National Football League (NFL) players, have higher rates of obstructive sleep apnea/sleep disordered breathing, a sleep disorder that reduces night time sleep quality and often results in high levels of daytime sleepiness (George et al., 2003; Albuquerque et al., 2010).

We now know the consequences of inadequate sleep are especially important for athletes given the relationship between sleep and athletic performance.

Athletes face a unique set of constraints in their efforts to sleep well. Training schedules, available practice times, lengthy travel to competitions, jet lag, and pre-competition anxiety can all impact the quality and quantity of sleep prior to performance (Mah et al., 2011; Sargent et al., 2014; Juliff et al., 2015).

Several studies have documented a competitive advantage for West Coast-based teams in evening games, ostensibly due to the impact of circadian misalignment (Jehue et al., 1993; Smith et al., 2013). Circadian rhythms can also result in variations in peak performance based on the time of day and typical training schedules, both of which can have an effect on performance in competitions (Drust et al., 2005).

Among athletes, sleep may be deprioritized relative to other training needs. A pervasive attitude in our modern culture has been that the ability to tolerate insufficient sleep is a strength and is perceived as a badge of honor (e.g., Adler, 2009). More recently, however, several high profile athletes have identified the importance of sleep as a means to improve performance (Schultz, 2014). However, it is likely that these recent public statements remain the exception rather than the rule when it comes to prioritizing the importance of sleep among athletes on a night-to-night basis.

Further, an individual's ability to self-assess their level of sleep impairment is poor (Van Dongen et al., 2003), making it difficult for athletes to gauge the impact of potential insufficient sleep on

performance. Research has shown that objective performance becomes impaired in a dose-dependent manner (greater sleep loss equates to greater performance impairment); however, subjective assessments show a leveling of perceived sleepiness (impairment) that persists as sleep loss accumulates (Van Dongen et al., 2003). A useful comparison for the impact of sleep loss equates the degree of impairment to the effects of alcohol. Strikingly, performance impairments equivalent to those of 0.05% blood alcohol content (BAC) are found after only 17–19 h of wakefulness, and 28 h of wakefulness is equivalent to 0.10% BAC (Williamson & Feyer, 2000).

The goal of this article is to increase awareness of the importance of sleep for maximum athletic performance, as well as to provide strategies for athletes to optimize their own sleep patterns. This review is organized into three sections: (1) the impact of sleep on athletic and neurocognitive performance, (2) the relationship between sleep and physical health, and (3) strategies to optimize sleep in athletes.

## Methods

A literature search on empirical articles published before October 2015 on sleep and performance in athletes was conducted on Web of Science. Initial search terms were ["sleep quality" OR "sleep duration"] OR ["sleep deprivation" OR "sleep restriction" OR "sleep extension"] AND ["athletics" OR "athletes"] AND "athletic performance." A more expanded search for individual domains of performance (e.g., endurance, speed) was also conducted. All articles that contained quantitative assessment of performance and a standardized assessment of sleep (including both objective measures and validated self-report questionnaires assessing duration or quality) were included. Targeted literature searches were then conducted in neurocognitive domains and physical health/injury risk, with a focus on outcome measures of particular relevance to athletes and athletic performance (e.g., risk of illness, executive functioning, attention-related performance).

## Results

### Effects of sleep loss on athletic performance

There are multiple overlapping areas of performance that are substantially affected by inadequate sleep, including speed, endurance, strength, attention, executive function, and learning. This section reviews these findings, broadly categorized into the domains of physical and neurocognitive performance.

#### Physical performance

Treadmill tests have been used to assess the impact of experimental sleep loss on speed and endurance. Two studies found that shorter distances were covered during timed tests following one night of total sleep deprivation (Oliver et al., 2009; Skein et al., 2011), with one documenting participants reporting similar effort on both rested and sleep-deprived trials (despite impaired performance) (Oliver et al., 2009). This finding complements the observation that increased compensatory

effort is needed under conditions of sleep loss in order to "remain behaviorally effective" (Goel et al., 2009). Thus, sleep loss appears to reduce athletic performance despite equivalent applied effort and may relate to observed reductions in glycogen stores in muscles *even prior to performance* following just one night of total sleep deprivation (Skein et al., 2011). One night of sleep loss has also been shown to reduce time to exhaustion and increase resting oxygen uptake and resting carbon dioxide production (Azboy & Kaygisiz, 2009). Even a single night of partial sleep loss has been shown to increase heart rate and oxygen consumption, as well as higher lactate levels during a cycling test (Mougin et al., 1990). Together, these findings demonstrate that sleep loss has a direct physiologic effect that translates into reduced speed and endurance.

Studies examining strength/lifting performance impairments following sleep restriction report mixed results. One study of 10 collegiate male weightlifters observed no significant difference in lifting performance after a night of total sleep deprivation, despite increases in negative affect, fatigue, and sleepiness (Blumert et al., 2007), while another found that anaerobic performance (power) was not significantly affected after one night of sleep loss (Taheri & Arabameri, 2012). A third weightlifting study found that sleep restriction over 3 days was associated with a lower maximum weight lifted in tasks that required the largest muscle groups (Reilly & Piercy, 1994). These studies are small and have used several strategies to assess power. More research is needed to better understand how inadequate sleep may affect this performance domain.

Even mild sleep restriction can affect accuracy in athletic performance. In a study of tennis players, reducing sleep duration to 5 h for a single night impaired serving accuracy from an average of 53–37% (Reyner & Horne, 2013). Sleep loss also has been shown to impair dart throwing accuracy following a night of sleep restricted to 4–5 h when compared with a full night's sleep (Edwards & Waterhouse, 2009). This study also demonstrated decrements in throwing accuracy as a function of chronobiological factors (i.e., time of day) (Edwards & Waterhouse, 2009).

While the studies described above document the negative impact of inadequate sleep on athletic performance, there are limited data assessing the impact of extending sleep on performance—either via increasing nocturnal sleep duration or use of daytime naps. Two studies have demonstrated the beneficial effects of *increasing* sleep duration. In one study, college men's basketball players were encouraged to obtain as much nocturnal sleep as possible and were able to increase objectively measured average sleep durations from an average of 6.6 h/night to 8.5 h/night (Mah et al., 2011). Compared with baseline, performance following the 5- to 7-week sleep extension period reflected a 5% increase in speed, 9% increase in free throw accuracy, 9% improved free-throw percentage, and 9.2% increase in three-point field goal percentages (Mah et al., 2011). Another study found that expanding sleep duration by an estimated 2 h per night improved the serving accuracy of college tennis players from 36% to 41% (Schwartz & Simon, 2015). The available data on the impact of daytime naps are mixed. One small study ( $n = 10$  men) found that a 30-min nap following a night of partial sleep restriction improved alertness and sprint times, among other domains (Waterhouse et al., 2007). Another larger observational study of ultra-endurance cyclers found that sleep time during the an 600-km race (e.g., nap periods) had no impact on race time, although the duration of performance in this study may be longer than the competition periods faced by most athletes (Knechtel et al., 2012). While these studies are preliminary in nature, overall, they provide encouraging data that improving sleep can be an effective performance enhancement strategy.

In summary, athletic performance deteriorates with even mild sleep loss (sleeping 4–5 h compared with 7–8 h) across a number of domains including speed, endurance, and performance accuracy. While these performance metrics are interrelated, the consistency of significant findings suggest that adequate sleep plays an integral role in peak physiological performance. More recent data also suggest that extending (increasing) total sleep time can significantly improve performance on these metrics.

### *Neurocognitive performance*

Peak athletic performance, particularly during competition, requires optimal neurocognitive functioning. Insufficient sleep has been shown in multiple studies to erode neurocognitive function in several domains central to athletic performance, including attention, executive functioning, and learning.

**Attention.** Numerous studies show that sleep loss negatively impacts attention (Dinges et al., 1997; Vgontzas et al., 2004). There is also mounting evidence that “catching up” on sleep following chronic sleep restriction does not immediately restore full performance (Belenky et al., 2003). This finding is particularly important for athletes, who may undergo a period of mild sleep restriction during intense pre-competition training with the false expectation that they can “catch up” on sleep in the night or two before a big event and erase any performance deficits. While there are inter-individual differences in susceptibility to the effects of sleep loss, with some individuals being more resilient to the effects of sleep loss than others (Van Dongen et al., 2004), to date there is no accurate way to identify vulnerable individuals outside of laboratory testing, and, as described earlier, self perception of sleep-related impairment is poor (Van Dongen et al., 2003).

**Executive function.** Arguably, executive function is the most important domain for athletic performance during competition. Executive functioning encompasses the higher level thinking required to apply strategy, make decisions, and manage attention. Sleep loss erodes executive functioning, particularly on tasks requiring flexible thinking and learning (Goel et al., 2009). Inhibitory control, or the ability to refrain making impulsive or risky decisions, is also critical to athletic performance and is negatively affected by even one night of sleep loss (Harrison & Horne, 2000; Killgore et al., 2006; Killgore et al., 2011; Anderson & Platten, 2011; Rossa et al., 2014). These studies collectively suggest that insufficient sleep may have a significant negative impact on athletes’ ability to make a game time decision, read, and react to an opposing defense or implement a specific competition strategy.

**Learning.** The ability to learn new skills is also essential to high-level athletic performance. Sleep fosters increased consolidation of memories and allows for faster and better performance on learned tasks requiring physical execution. One landmark study demonstrated that a night of sleep results in a 20% increase in motor speed without the loss of accuracy, compared to a similar amount of time awake (without incurring sleep loss) (Walker et al., 2002). There is also evidence that sleep and dreaming is critical to off-line memory re-processing/consolidation (Stickgold et al., 2001) and visual discrimination (Stickgold et al., 2000). For a full review of sleep-dependent learning findings, the reader is referred to the

review by Walker and Stickgold (2004). The relationship between learning and sleep is of particular relevance to collegiate athletes, who are faced with meeting multiple academic and athletic demands. See Curcio et al. (2006) for a review of sleep loss, learning capacity, and academic performance.

### Effects of sleep loss on physical health

Maintaining and optimizing physical health is essential for peak athletic performance. From a most basic level, the ability to stay healthy and avoid illness and injury is critical for athletes’ ability to perform. This includes maintaining an ideal body mass and the ability to tolerate the discomfort of physical training. These aspects of physical health directly relevant to athletic performance are nested within a much broader literature documenting links between sufficient sleep and risk for diabetes, cardiovascular diseases, and mortality among others (Ayas et al., 2003; Gangwisch et al., 2007; Grandner et al., 2010).

#### *Injury risk*

There is accumulating evidence that insufficient sleep increases risk of injury. Adolescents sleeping less than 8 h/night were found to be 1.7 times more likely to experience a significant injury than those who slept more than 8 h (Milewski et al., 2014). The impact of inadequate sleep on reaction time and cognitive abilities (see performance section above) is likely to contribute to this increased injury risk. Data drawn from other fields (e.g., insufficient sleep and motor vehicle accidents and medical errors) also show striking increases in risk of accidents and injury with sleep loss (Lyznicki et al., 1998; Barger et al., 2005; Centers for Disease Control & Prevention, 2015). Young adults, the prime age for most athletes, have been shown to be at even greater risk for sleepiness-related errors or accidents (under simulated conditions) compared with older adults (Cappuccio et al., 2010; Filtz et al., 2012).

#### *Illness susceptibility*

Maintaining a state of physical well-being is essential for optimal athletic performance, and increasing evidence suggests that sleep is protective against illness risk. Among the most powerful evidence for this comes from a study conducted by Cohen et al. (2009). In this study, participants tracked their sleep and then were inoculated with a dose of active cold virus (Cohen et al., 2009). Individuals sleeping less than 7 h/night prior to the inoculation were three times more likely to develop a cold after a direct application of cold virus than those sleeping 8 h or more (Cohen et al., 2009). A follow-up study by this research team found a significant increase in risk of developing a cold with less than 6 h of sleep per night (Prather et al., 2015) compared with sleeping 7 or more hours. Observational data from adolescents also showed that longer sleepers reported fewer illnesses than shorter sleepers (Orzech et al., 2014). Sleep also helps support a healthy adaptive immune response to vaccinations (Benedict et al., 2012; Prather et al., 2012), another effective method of reducing illness risk.

#### *Weight maintenance*

Maintaining an ideal body mass can help optimize performance and, in some sports, determines if an athlete is able to



compete in a particular weight class (e.g., rowing or wrestling). There is a wealth of data showing a relationship between sleep duration and body mass index (BMI), with short sleep durations in particular associated with higher BMIs. These associations have been observed in epidemiological studies both cross-sectionally (Taheri et al., 2004) and prospectively (Chaput et al., 2008). Further, short sleep durations are associated with changes in metabolic hormones related to appetite and food consumption in both epidemiological (Taheri et al., 2004) and experimental sleep restriction (Spiegel et al., 2004; Simpson et al., 2010) studies. These changes in hormone patterns can help explain changes in food intake patterns that follow sleep restriction, with a shift towards increased carbohydrates and snacks (Nedeltcheva et al., 2009), increased portion sizes (Hogenkamp et al., 2013), and a decreased ability to process glucose (Schmid et al., 2011). There are also limited data suggesting that poor sleep quality (either observed or reduced through experimental manipulation) is associated with reduced glucose metabolism (Stamatakis & Punjabi, 2010; Byberg et al., 2012), suggesting that sleep quality, as well as quantity, may be important for optimal health maintenance. Together, these data demonstrate that obtaining adequate sleep can be an important behavioral strategy for developing and maintaining an ideal weight and body composition for athletic performance.

## Pain tolerance

Increased pain tolerance can allow athletes to train more intensely, compete with greater focus, and engage more fully in rehabilitation after injury. Sleep is intimately involved in pain regulation, with one study finding an 8% decrease in pain threshold tolerance after a single night of total sleep deprivation (Onen et al., 2001), and others showing small but significant increases (5–10%) in spontaneously reported generalized pain after both total and partial sleep restriction (Haack et al., 2007, 2009). Interestingly, one study of mildly sleepy but otherwise healthy adults (reflective of inadequate habitual sleep duration) found that extending sleep opportunities for four nights increased pain tolerance by 20% (Roehrs et al., 1989).

## Strategies to optimize sleep in athletes

This section reviews approaches to improving sleep duration and sleep quality and suggests countermeasures to offset the negative impact of insufficient sleep and jet lag. Recommendations for identification and referrals for treatment of potential sleep disorders are also discussed (Table 1). It is important to consider that “sleep symptoms” are a common symptom of overtraining syndrome (Mackinnon, 2000); as such, the presence of sleep disturbances should also prompt a review of overtraining symptoms among at-risk athletes and addressed as appropriate.

### Improving total sleep duration

The amount of sleep needed varies based on age, physical activity, and a range of other individual factors; however, most adults need between 7 and 9 h of sleep per night (Hirshkowitz et al., 2015). The most recent consensus statement of the American Academy of Sleep Medicine and Sleep Research Society states that adults should sleep 7 or more hours per night and that sleeping more than 9 h/night may be appropriate for young adults (Watson et al., 2015). While not yet

Table 1. Recommendations for Improving Sleep in Athletes

### Obtain adequate total sleep duration

**Strategy 1:** Track sleep for 2 weeks using a self-report sleep diary (example: <http://yoursleep.aasmnet.org/pdf/sleepdiary.pdf>).

Gradually increase sleep duration by 15 min every few nights, until athlete feels well rested and alert during the day. Consider increasing nighttime sleep by 30–60 min/night; this is particularly important if average sleep duration is <7 h/night

**Strategy 2:** Consider implementing regular naps, beginning on weekends or off-days if needed. Allow adequate time to return to full alertness after daytime naps

### Maintain healthy sleep habits

**Strategy 1:** Develop a good sleep environment: the ideal room is cool, dark, and comfortable. Avoid having/using electronics or personal devices in bedroom

**Strategy 2:** Avoid alerting factors in the evening. Reduce ambient light exposure in late evening hours as possible, limit electronic device use at least 1 h prior to bedtime, allow for a 30–60 min relaxing wind-down period before bed. Ideally, consume no caffeine after lunch; limit alcohol use in late evening

### Minimizing impact of travel

**Strategy 1:** Factor-in time needed to adjust to new time zone; as a rule of thumb, the body can adjust to 1 h of time zone difference each day. Consider starting to shift body clock prior to departure or during flight; personalized travel planners (available online) may be helpful

**Strategy 2:** Reduce impact of non-jet lag travel effects: dehydration, acoustic stress, low physical activity, changes in food/drinking patterns

### Identify/address possible sleep disorders

**Strategy 1:** Consider referral to sleep clinic if athlete has difficulty sleeping or is experiencing high levels of daytime sleepiness despite adequate opportunity

**Strategy 2:** Athletes with insomnia but limited access to a sleep clinic may benefit from online treatment with cognitive behavioral therapy for insomnia (CBTI)

### Assess impact of improved sleep on athletic performance

Consider conducting pre- and post-assessment of a relevant performance metric for the athlete (e.g., sprint times) after implementation of sleep improvement strategies. Conduct post-assessment after 2–4 weeks of improved sleep to best assess the effects of behavioral changes

tested empirically, it has been suggested that athletes need comparably more sleep than non-athletes to ensure adequate physiological and psychological recovery from training (Bird, 2013). Other proponents of increased sleep time in athletes suggest that athletes should obtain 80 h of sleep total per week, including nightly sleep duration and naps (Samuels, 2009). While sleeping an average of 11.4 h per 24 h period (the equivalent of 80 h/week) may not be necessary or even feasible for most athletes, there are data supporting the idea that athletes may benefit from more than an “average” amount of sleep for recovery from athletic training as well as to maintain peak performance (Mah et al., 2011).

As a first step to optimizing sleep, we recommend that athletes track their sleep patterns for 2 weeks, using either a basic self-report diary or a personal sleep monitor. It should be cautioned that personal sleep monitors may have limited accuracy, particularly those that assess sleep while placed on the bed and not worn on the body. If sleep duration is below 7 h/night on average, athletes should be encouraged to engage in a “behavioral experiment” in which they test the effects of extending their sleep duration (initially by 30–60 min/night) on a desired performance metric (e.g., sprint times) before and after a 2- to 4-week period of increased sleep. Athletes already sleeping greater than 7 h may also benefit from a trial of increased sleep duration. Strategies to increase sleep duration

include increasing nighttime sleep duration and implementing (or increasing) daytime naps. To date, there are no available data on the relative benefit of increasing total sleep duration (e.g., nighttime sleep duration plus naps) relative to nighttime sleep duration alone, or when it may be optimal to add sleep time to receive maximum athletic performance benefit. Guiding principles suggest adding sleep time when feasible based on scheduling limitations, and also at times of day in which the athlete will be able to sleep more easily (e.g., moving bedtime earlier for a “morning person” or waking later for a person with night owl tendencies). Strategies for implementing naps are described in the napping section below. It should be noted that while protecting/increasing sleep opportunity can be beneficial for increasing sleep duration, “trying to sleep,” or exerting effort to sleep once in bed, may create sleep problems and result in decreased total sleep time. This is particularly important for athletes who have insomnia or other difficulties in sleeping (Broomfield & Espie, 2005).

### *Improving sleep quality/healthy sleep habits*

Healthy sleep habits can help athletes develop the highest quality sleep possible and obtain the most restorative benefit from their sleep. These habits fall into two main categories: sleep environment factors and pre-sleep behaviors.

**Sleep environment.** The ideal sleeping environment is cool, dark, quiet, and comfortable (like “sleeping in a cave”). Sleeping in conditions that are too warm or light can disrupt the body clock and lighten sleep (Lack et al., 2008; Dijk & Archer, 2009). Ambient noise can also disrupt sleep through full or partial arousals from sleep. A comfortable sleep environment is also essential with respect to both physical comfort (e.g., appropriate mattress firmness) and also feeling safe and secure in the bedroom. The majority of strategies to improve athletes’ sleep environments rely on practical solutions: use of a room fan to cool temperatures; an eye mask or light-blocking window shades to reduce light; and earplugs, fan, white noise machine, or white noise “app” to block or reduce disruptive noise. Comfort with the sleep environment may require a new mattress or a mattress topper or adjustments to roommate arrangements.

**Pre sleep behaviors.** An athlete’s daytime routine can also impact their nighttime sleep. The main areas to consider are substances, light, and schedule.

**Substance use:** Athletes should be encouraged to end caffeine use (outside of strategic use for performance—see below) after lunchtime given its long half-life (3–7 h for most adults) (Fredholm et al., 1999). Alcohol consumption should also be avoided or limited for 3–4 h prior to sleep onset. While the initial effects of alcohol are sedating and are sometimes thought to be helpful for sleep, as alcohol is processed by the body it can have a significant disruptive effect on sleep (Roehrs & Roth, 2001). Use of other substances (e.g., nicotine, Adderall) with stimulant effects is also cautioned in the evening hours; the exact timing of the suggested cut-off point depends on the half-life of the individual substance. While there is increasing evidence for the use of herbal substances or nutraceuticals to improve athletic performance and recovery (e.g., Bell et al., 2015), to date, there is limited available empirical support for use of these substances to improve sleep in athletes or the general population (Halsom, 2014; Yurchesha et al., 2015).

**Exposure to light** during the daytime can also impact sleep quality and quantity. Exposure to bright light in the late evening can have an alerting effect and may result in difficulty falling asleep at the desired time through reducing or delaying the release of melatonin (a natural sleep regulating hormone) (Duffy & Czeisler, 2009). To avoid this, lights should be lowered and use of personal devices with LED screens should be avoided for several hours prior to bedtime. Data suggest that even 1–2 h of tablet use before bed can impact melatonin release (Figueiro et al., 2011). Seeking bright light exposure in the morning, however, is recommended as it can increase alertness and help set or maintain the desired biological sleep/wake rhythm (Duffy & Czeisler, 2009; Wood et al., 2013).

**Establishing a sleep/wake routine:** Maintaining a regular sleep schedule helps to optimize circadian (biological) effects on sleep/wake cycles (Manber & Carney, 2015). Contrary to what is commonly believed, the most effective way to stabilize a circadian rhythm is by anchoring the wake time, rather than the bedtime. As it is often difficult for athletes with early morning competition or travel schedules to maintain a regular sleep schedule, trade-offs with respect to the amount of sleep maintained must be balanced with implementing a regular schedule. Finally, as higher levels of cortical arousal can interfere/delay sleep onset, athletes who have difficulty sleeping should additionally build in a 30- to 60-min wind down routine before bed in order to transition into a more relaxed brain state before bedtime (Manber & Carney, 2015). The content of the wind down is flexible, but the individual should be engaging in relaxing, pleasant, non-productive activities (e.g., reading, taking a bath, stretching).

**Countermeasures:** In an ideal world, athletes will approach key performances fully rested; however, this is often not feasible. In these situations, “countermeasures” can help buffer the negative effects of insufficient sleep. The main countermeasure approaches are naps and caffeine.

**Naps.** While the majority of the sleep period should occur at night in order to best align with the normal circadian rhythm, daytime naps can increase overall sleep duration. They also provide a short-term general performance boost under conditions of sleep restriction (Brooks & Lack, 2006). A caution is that longer naps (e.g., greater than 30 min) may lead to a period of lingering “sleep inertia,” or grogginess, and impaired performance after waking (Brooks & Lack, 2006). The timing of naps is also important to consider, as it may be relatively easier for the athlete to fall asleep at different times of the day; additionally, naps taken late in the day may have a negative impact on nighttime sleep (Borbely, 1982). Athletes may more easily be able to initiate sleep during daytime hours by taking advantage of circadian alerting rhythms, which generally demonstrate a slight afternoon “dip” (making sleep initiation easier) (Borbely, 1982). For a more extensive description of impacts of nap length, time of day, and age on general performance and well-being, please refer to the review by Milner and Cote (2009). Effects of naps on physical performance mixed, but to date few have examined the impact of naps when controlling for nighttime sleep duration (Waterhouse et al., 2007; Knechtle et al., 2012; Petit et al., 2014). Thus, the available data suggest that naps may be a useful way to increase habitual sleep duration, general performance, and feelings of alertness, more so than as a day-of-performance improvement strategy.

**Caffeine.** It is well known that strategic use of caffeine can improve athletic performance (for review, see Sökmen et al.,

2008) and that caffeine is helpful in minimizing the effects of sleep loss/sleep inertia on general performance (Van Dongen et al., 2001). The broader literature on the effects of caffeine on performance following sleep loss is complex, for example, suggesting that caffeine may buffer an individual against sleep-related impairments in risk taking (Killgore et al., 2011) but not decision making (Killgore et al., 2012). Few well-controlled studies examine the impact of caffeine on athletic performance following sleep loss. In one small study of tennis players, caffeine had no beneficial effect on serving accuracy in sleep-deprived participants (Reyner & Horne, 2013). Together, these studies suggest that caffeine may not universally counter performance deficits related to sleep loss.

## Minimizing impact of travel on sleep

*Jet lag* occurs when there is a misalignment between an individual's internal sleep/wake rhythm and the new (local) time zone and can have a significant negative impact on both nighttime sleep quality/quantity and daytime alertness. A rule of thumb is that it takes approximately 1 day to adjust to each time zone crossed. Athletes who need to maximize their performance upon arrival may consider either attempting to avoid synchronization to the local time zone if the new time zone is out of phase with their normal performance rhythm (as hypothesized by Youngstedt & O'Connor, 1999) or beginning to transition their sleep/wake schedule before traveling to minimize the effects of jet lag on performance upon arrival. Specifically timed light exposure, melatonin supplements, and other environmental cues, such as physical activity, can all minimize the impact of jet lag (Sack, 2010). Jet lag management programs (available online) can create an individual plan for travel based on destination and habitual sleep patterns. Additionally, air travel frequently results in dehydration, stress from noise and physical crowding, and changes in physical activity and eating/drinking patterns. Increasing fluid intake, use of earplugs and eye masks, and planned stretching breaks during flight can minimize these symptoms. While there is limited research on adjusting to jet lag specifically in athletes, several recent position papers describe how the effects of jetlag on athletic performance can be mitigated (Forbes-Robertson et al., 2012; Samuels, 2012).

*Altitude:* Sleeping at altitude or simulated altitude is a widely used training strategy for athletes (Kinsman et al., 2005), despite a lack of well-controlled studies supporting its utility (Lundby et al., 2012). In the general population, sleeping at altitude has been shown to negatively affect sleep architecture and quality (Latshang et al., 2013). There are little available data examining the relative trade-offs of impaired sleep vs potential performance gains obtained by training at altitude. This need for additional research is reflected in a recent review of sleep altitude training, which stated that the research is not sufficiently advanced to make specific recommendations for athletes at this time (Lundby et al., 2012).

## References

Adler M. In today's world, the well-rested lose respect. *Morning edn.* Washington, DC: National Public Radio, 2009.

Albuquerque FN, Kuniyoshi FH, Calvin AD, Sierra-Johnson J, Romero-Corral A, Lopez-Jimenez F, George CF, Rapoport DM, Vogel RA, Khandheria B, Goldman ME, Roberts A, Somers VK. Sleep-

disordered breathing, hypertension, and obesity in retired National Football League Players. *JACC* 2010; 56: 1432–1433.

Anderson C, Platten CR. Sleep deprivation lowers inhibition and enhances impulsivity to negative stimuli. *Behav Brain Res* 2011; 217: 463–466.

Ayas NT, White DP, Manson JE, Stampfer MJ, Speizer FE, Malhotra A, Hu FB. A prospective study of sleep duration and coronary heart disease in women. *Arch Intern Med* 2003; 163: 205–209.

Azboy O, Kaygisiz Z. Effects of sleep deprivation on cardiorespiratory functions of the runners and

## Identifying/treating sleep disorders and other contributing disorders

If sleep difficulties or excessive daytime sleepiness are experienced even with sufficient time allowed for sleep, a sleep disorder may be present and a referral for further evaluation at a sleep disorder clinic is appropriate. Insomnia, obstructive sleep apnea, and circadian rhythm disorders (mismatches between internal body clock rhythms and desired sleep/wake schedules) are relatively common in adults and are treatable medical conditions. Contrary to public opinion, athletes experience disrupted or poor quality sleep at higher rates than non-athletes and may have higher rates of sleep disorders [particularly among professional football players (Samuels, 2009; George et al., 2003)]. For insomnia disorder, online treatments (e.g., cognitive behavioral therapy for insomnia) are also available if face-to-face treatment is inaccessible. In addition, mental health disorders, such as depression and anxiety, often have symptoms of disrupted sleep, so it is important to consider sleep disturbances within an overall assessment of athlete well-being and make referrals to appropriate mental health services as needed.

## Perspectives

An increasing body of research documents the negative impact of sleep loss on human performance across a range of domains. While the literature on sleep patterns in athletes and the impact of insufficient sleep on athletic performance are in their nascentcy (Fullagar et al., 2015), there is a robust body of evidence documenting global performance impairments (e.g., on attention) and negative health effects following sleep loss, which can directly affect athletic performance potential. Increasing awareness of the broad range of consequences of inadequate sleep is one way to encourage elite athletes to prioritize obtaining optimal sleep. Drawing from the clinical sleep literature, additional strategies of increasing sleep duration/improving sleep quality and quantity and assessing impact on performance are essential, as is the identification/treatment of common sleep disorders. Implementing these effective strategies to optimize their own sleep patterns give athletes an additional tool in their arsenal to maximize athletic performance.

**Key words:** Athletic performance, cognitive function, sleep restriction, insufficient sleep.



- volleyball players during rest and exercise. *Acta Physiol Hung* 2009; 96: 29–36.
- Barger LK, Cade BE, Ayas NT, Cronin JW, Rosner B, Speizer FE, Czeisler CA. Extended work shifts and the risk of motor vehicle crashes among interns. *N Engl J Med* 2005; 352: 125–134.
- Belenky G, Wesensten NJ, Thorne DR, Thomas ML, Sing HC, Redmond DP, Russo MB, Balkin TJ. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. *J Sleep Res* 2003; 12: 1–12.
- Bell PG, Walshe IH, Davison GW, Stevenson EJ, Howatson G. Recovery facilitation with Montmorency cherries following high-intensity, metabolically challenging exercise. *Appl Physiol Nutr Metab* 2015; 40: 414–423.
- Benedict C, Brytting M, Markstrom A, Broman J-E, Schiöth HB. Acute sleep deprivation has no lasting effects on the human antibody titer response following a novel influenza A H1N1 virus vaccination. *BMC Immunol* 2012; 13: 1.
- Bird SP. Sleep, recovery, and athletic performance: a brief review and recommendations. *Strength Cond J* 2013; 35: 43–47.
- Blumert PA, Crum AJ, Ernsting M, Volek JS, Hollander DB, Haff EE, Haff GG. 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: 1146–1154.
- Borbely AA. A two process model of sleep regulation. *Human Neurobiol* 1982; 1: 195–204.
- Brooks A, Lack L. A brief afternoon nap following nocturnal sleep restriction: which nap duration is most recuperative? *Sleep* 2006; 29: 831–840.
- Broomfield NM, Espie CA. Towards a valid, reliable measure of sleep effort. *J Sleep Res* 2005; 14: 401–407.
- Byberg S, Hansen ALS, Christensen DL, Vistisen D, Aadahl M, Linneberg A, Witte DR. Sleep duration and quality are associated differently with alterations of glucose homeostasis. *Diabet Med* 2012; 29: E354–E360.
- Cappuccio FP, D'Elia L, Strazzullo P, Miller MA. Sleep duration and all-cause mortality: a systematic review and meta-analysis of prospective studies. *Sleep* 2010; 33: 585–592.
- Centers for Disease Control & Prevention. Insufficient sleep is a public health epidemic, 2015. Available at: <http://www.cdc.gov/features/dssleep/> (accessed February 9, 2016).
- Chaput JP, Despres JP, Bouchard C, Tremblay A. The association between sleep duration and weight gain in adults: a 6-year prospective study from the Quebec Family Study. *Sleep* 2008; 31: 517–523.
- Cohen S, Doyle WJ, Alper CM, Janacki-Deverts D, Turner RB. Sleep habits and susceptibility to the common cold. *Arch Int Med* 2009; 169: 62–67.
- Curcio G, Ferrara M, De Gennaro L. Sleep loss, learning capacity and academic performance. *Sleep Med Rev* 2006; 10: 323–337.
- Dijk DJ, Archer SN. Light, sleep, and circadian rhythms: together again. *PLoS Biol* 2009; 7: e1000145.
- Dinges DF, Pack F, Williams K, Gillen KA, Powell JW, Ott GE, Aptowicz C, Pack AI. Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. *Sleep* 1997; 20: 267–277.
- Drust B, Waterhouse J, Atkinson G, Edwards B, Reilly T. Circadian rhythms in sports performance – an update. *Chronobiol Int* 2005; 22: 21–44.
- Duffy JF, Czeisler CA. Effect of light on human circadian physiology. *Sleep Med Clin* 2009; 4: 165–177.
- 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: 756–768.
- Fietze I, Strauch J, Holhausen M, Los M, Theobald C, Lehnkering H, Penzel T. Sleep quality in professional ballet dancers. *Chronobiol Int* 2009; 26: 1249–1262.
- Figueiro MG, Wood B, Plitnick B, Rea MS. The impact of light from computer monitors on melatonin levels in college students. *Neuroendocrinol Lett* 2011; 32: 158–163.
- Filtness AJ, Reyner LA, Horne JA. Driver sleepiness—comparisons between young and older men during a monotonous afternoon simulated drive. *Biol Psychol* 2012; 89: 580–583.
- Forbes-Robertson S, Dudley E, Vadgama P, Cok C, Drawer S, Kilduff LP. Circadian disruption and remedial interventions effects and interventions for jet lag for athletic peak performance. *Sports Med* 2012; 42: 185–208.
- Fredholm BB, Bättig K, Holmén J, Nehlig A, Zvartau EE. Actions of caffeine in the brain with special reference to factors that contribute to its widespread use. *Pharmacol Rev* 1999; 51: 83–133.
- Fullagar HHK, Skorski S, Duffield R, Hammes D, Coutts AJ, Meyer T. Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sports Med* 2015; 45: 161–186.
- Gangwisch JE, Heymsfield SB, Boden-Albala B, Buijs RM, Kreier F, Pickering TG, Rundle AG, Zammitt GK, Malaspina D. Sleep duration as a risk factor for diabetes incidence in a large US sample. *Sleep* 2007; 30: 1667.
- George CF, Kab V, Levy AM. Increased prevalence of sleep-disordered breathing among professional football players. *N Engl J Med* 2003; 348: 367–368.
- Goel N, Rao H, Durmer JS, Dinges DF. Neurocognitive consequences of sleep deprivation. *Semin Neurol* 2009; 29: 320–339.
- Grandner MA, Hale L, Moore M, Patel NP. Mortality associated with short sleep duration: the evidence, the possible mechanisms, and the future. *Sleep Med Rev* 2010; 14: 191–203.
- Haack M, Lee E, Cohen DA, Mullington JM. Activation of the prostaglandin system in response to sleep loss in healthy humans: potential mediator of increased spontaneous pain. *Pain* 2009; 145: 136–141.
- Haack M, Sanchez E, Mullington JM. Elevated inflammatory markers in response to prolonged sleep restriction are associated with increased pain experience in healthy volunteers. *Sleep* 2007; 30: 1145–1152.
- Halsal SL. Sleep in elite athletes and nutritional interventions to enhance sleep. *Sports Med* 2014; 44: S13–S23.
- Harrison Y, Horne JA. The impact of sleep deprivation on decision making: a review. *J Exp Psychol Gen* 2000; 6: 236–249.
- Hausswirth C, Louis J, Aubry A, Bonnet G, Duffield R, Le Meur Y. Evidence of disturbed sleep and increased illness in overreached endurance athletes. *Med Sci Sports Exerc* 2014; 46: 1036–1045.
- Hirshkowitz M, Whiton K, Albert SM, Alessi C, Bruni O, DonCarlos L, Hazen N, Herman J, Katz ES, Kheirandish-Gozal L, Neubauer DN, O'Bonnell AE, Ohayon M, Peever J, Rawding R, Sachdeva RC, Setters B, Vitiello MV, Ware JC, Adams Hillard PJ. National Sleep

- Foundation's sleep time duration recommendations: methodology and results summary. *Sleep Health* 2015; 1: 40–43.
- Hogenkamp PS, Nilsson EM, Nilsson VC, Chapman CD, Vogel H, Lundberg LS, Zarei S, Cedernaes J, Rangtell FH, Broman JE, Dickson SL, Brunstrom JM, Benedict C, Schioth HB. Acute sleep deprivation increases portion size and affects food choice in young men. *Psychoneuroendocrinology* 2013; 38: 1668–1674.
- Jehue R, Street D, Huizenga R. Effect of time zone and game time changes on team performance. *Med Sci Sports Exerc* 1993; 25: 127–131.
- Juliff LE, Halson SL, Peiffer JJ. Understanding sleep disturbance in athletes prior to important competitions. *J Sci Med Sport* 2015; 18: 13–18.
- Killgore WDS, Balkin TJ, Wesensten NJ. Impaired decision making following 49 h of sleep deprivation. *J Sleep Res* 2006; 15: 7–13.
- Killgore WDS, Grugle NL, Balkin TJ. Gambling when sleep deprived: don't bet on stimulants. *Chronobiol Int* 2012; 29: 43–54.
- Killgore WDS, Kamimori GH, Balkin TJ. Caffeine protects against increased risk-taking propensity during severe sleep deprivation. *J Sleep Res* 2011; 20: 395–403.
- Kinsman TA, Gore CJ, Hahn AG, Hopkins WG, Hawley JA, McKenna MJ, Clark SA, Aughey RJ, Townsend NE, Chow CM. Sleep in athletes undertaking protocols of exposure to nocturnal simulated altitude at 2650 m. *J Sci Med Sport* 2005; 8: 222–232.
- Knechtle B, Wirth A, Knechtle P, Rüst CA, Rosemann T, Lepers R. No improvement in race performance by naps in male ultra-endurance cyclists in a 600-km ultra-cycling race. *Chin J Physiol* 2012; 55: 125–133.
- Lack LC, Gradsar M, Van Someren EJW, Wright HR, Lushington K. The relationship between insomnia and body temperatures. *Sleep Med Rev* 2008; 12: 307–317.
- Latshang TD, Lo Cascio CM, Stöwhas AC, Grimm M, Stadelmann K, Tesler N, Achermann P, Huber R, Kohler M, Bloch KE. Are nocturnal breathing, sleep, and cognitive performance impaired at moderate altitude (1,630–2,590 m)? *Sleep* 2013; 36: 1969.
- Leeder J, Glaister M, Pizzoferrero K, Dawson J, Pedlar C. Sleep duration and quality in elite athletes measured using wristwatch actigraphy. *J Sports Sci* 2012; 30: 541–545.
- Lundby C, Millet GP, Calbet JA, Bärtsch P, Subudhi AW. Does 'altitude training' increase exercise performance in elite athletes? *Br J Sports Med* 2012; 47: i4–i5.
- Lyznicki JM, Doege TC, Davis RM, Williams MA. Sleepiness, driving, and motor vehicle crashes. *JAMA* 1998; 279: 1908–1913.
- Mackinnon LT. Overtraining effects on immunity and performance in athletes. *Immunol Cell Biol* 2000; 78: 502–509.
- Mah CD, Mah KE, Kezirian EJ, Dement WC. The effects of sleep extension on the athletic performance of collegiate basketball players. *Sleep* 2011; 34: 943–950.
- Manber R, Carney CE. Treatment plans and interventions for insomnia: a case formulation approach. 1st edn. New York, NY: Guilford Press, 2015.
- Milewski MD, Skaggs DL, Bishop GA, Pace JL, Ibrahim DA, Wren TA, Barzdukas A. Chronic lack of sleep is associated with increased sports injuries in adolescent athletes. *J Pediatr Orthop* 2014; 34: 129–133.
- Milner CE, Cote KA. Benefits of napping in healthy adults: impact of nap length, time of day, age, and experience with napping. *J Sleep Res* 2009; 18: 272–281.
- Mougin F, Simon-Rigaud ML, Davenne D, Renaud A, Garnier A, Magnin P. Influence of partial sleep deprivation on athletic performance. *Sci Sports* 1990; 5: 83–90.
- Nedelcheva AV, Kilkus JM, Imperial J, Kasza K, Schoeller DA, Penev PD. Sleep curtailment is accompanied by increased intake of calories from snacks. *Am J Clin Nutr* 2009; 89: 126–133.
- Oliver SJ, Costa RJS, Laing SJ, Bilzon JLJ, Walsh NP. One night of sleep deprivation decreases treadmill endurance performance. *Eur J Appl Physiol* 2009; 107: 155–161.
- Onen SH, Alloui A, Gross A, Eschallier A, Dubray C. The effects of total sleep deprivation, selective sleep interruption and sleep recovery on pain tolerance thresholds in healthy subjects. *J Sleep Res* 2001; 10: 35–42.
- Orzech KM, Acebo C, Seifer R, Barker D, Carskadon MA. Sleep patterns are associated with common illness in adolescents. *J Sleep Res* 2014; 23: 133–142.
- Petit E, Mougin F, Bourdin H, Tio G, Haffen E. A 20-min nap in athletes changes subsequent sleep architecture but does not alter physical performances after normal sleep or 5-h phase-advance conditions. *Eur J Appl Physiol* 2014; 114: 305–315.
- Prather AA, Hall MH, Fury JM, Ross DC, Muldoon MF, Cohen S, Marsland AL. Sleep and antibody response to hepatitis B vaccination. *Sleep* 2012; 35: 1063–1069.
- Prather AA, Janicki-Deverts D, Hall MH, Cohen S. Behaviorally assessed sleep and susceptibility to the common cold. *Sleep* 2015; 38: 1353–1359.
- Reilly T, Piercy M. The effect of partial sleep deprivation on weight-lifting performance. *Ergonomics* 1994; 37: 107–115.
- Reyner LA, Horne JA. Sleep restriction and serving accuracy in performance tennis players, and effects of caffeine. *Physiol Behav* 2013; 120: 93–96.
- Roehrs T, Roth T. Sleep, sleepiness, and alcohol use. *Alcohol Res Health* 2001; 25: 101–109.
- Roehrs T, Timms V, Zwyghuizen-Doorenbos A, Roth T. Sleep extension in sleepy and alert normals. *Sleep* 1989; 12: 449–457.
- 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: 287–292.
- Sack RL. Jet lag. *N Engl J Med* 2010; 362: 440–447.
- Samuels C. Sleep, recovery, and performance: the new frontier in high-performance athletics. *Phys Med Rehabil Clin N Am* 2009; 20: 149–159.
- Samuels CH. Jet lag and travel fatigue: a comprehensive management plan for sports medicine physicians and high-performance support teams. *Clin J Sports Med* 2012; 22: 268–273.
- 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: 160–168.
- Schmid SM, Hallschmid M, Jauch-Chara K, Wilms B, Lenhert H, Born J, Schultes B. Disturbed glucoregulatory response to food intake after moderate sleep restriction. *Sleep* 2011; 34: 371–377.
- Schultz J. These famous athletes rely on sleep for peak performance, Huffington Post, 2014. Available at: [http://www.huffingtonpost.com/2014/08/13/these-famous-athletes-rely-on-sleep\\_n\\_5659345.html](http://www.huffingtonpost.com/2014/08/13/these-famous-athletes-rely-on-sleep_n_5659345.html) (accessed February 6, 2016).
- Schwartz J, Simon RD. Sleep extension improves serving accuracy: a study with college varsity tennis players. *Physiol Behav* 2015; 151: 541–544.
- Silva A, Queiroz SS, Winckler C, Vital R, Sousa RA, Fagundes V, Tufik S, de Mello MT. Sleep quality



- evaluation, chronotype, sleepiness and anxiety of Paralympic Brazilian athletes: Beijing 2008 Paralympic Games. *Br J Sports Med* 2012; 46: 150–154.
- Simpson NS, Banks S, Dinges DF. Sleep restriction is associated with increased morning plasma leptin concentrations, especially in women. *Biol Res Nurs* 2010; 12: 47–53.
- Skein M, Duffield R, Edge J, Short MJ, Mundel T. Intermittent-sprint performance and muscle glycogen after 30 h of sleep deprivation. *Med Sci Sports Exerc* 2011; 43: 1301–1311.
- 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.
- Sökmen B, Armstrong LE, Kraemer WJ, Casa DJ, Dias JC, Judelson DA, Maresh CM. Caffeine use in sports: considerations for the athlete. *J Strength Cond Res* 2008; 22: 978–986.
- Spiegel K, Tasali E, Penev P, Van Cauter E. Brief communication: sleep curtailment in healthy young men is associated with decreased leptin levels, elevated ghrelin levels, and increased hunger and appetite. *Ann Intern Med* 2004; 141: 885–886.
- Stamatakis KA, Punjabi NM. Effects of sleep fragmentation on glucose metabolism in normal subjects. *Chest* 2010; 137: 95–101.
- Stickgold R, Hobson JA, Fosse R, Fosse M. Sleep, learning, and dreams: off-line memory reprocessing. *Science* 2001; 294: 1052–1057.
- Stickgold R, James L, Hobson JA. Visual discrimination learning requires sleep after training. *Nat Neurosci* 2000; 3: 1237–1238.
- 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.
- Taheri S, Lin L, Austin D, Young T, Mignot E. Short sleep duration is associated with reduced leptin, elevated, ghrelin, and increased body mass index. *PLoS Med* 2004; 1: e62.
- Van Dongen HPA, Baynard MD, Maislin G, Dinges DF. Systematic interindividual differences in neurobehavioral impairment from sleep loss: evidence of trait-like differential vulnerability. *Sleep* 2004; 27: 423–433.
- 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: 117–126.
- Van Dongen HPA, Price NJ, Mullington JM, Szuba MP, Kapoor SC, Dinges DF. Caffeine eliminates psychomotor vigilance deficits from sleep inertia. *Sleep* 2001; 24: 813–819.
- Vgontzas AN, Zoumakis E, Bixler EO, Lin HM, Follett H, Kales A, Chrousos GP. Adverse effects of modest sleep restriction on sleepiness, performance, and inflammatory cytokines. *J Clin Endocrinol Metab* 2004; 89: 2119–2126.
- Walker MP, Brakefield T, Morgan A, Hobson JA, Stickgold R. Practice with sleep makes perfect: sleep-dependent motor skill learning. *Neuron* 2002; 35: 205–211.
- Walker MP, Stickgold R. Sleep-dependent learning and memory consolidation. *Neuron* 2004; 44: 121–133.
- Waterhouse J, Atkinson G, Edwards B, Reilly T. The role of a short post-lunch nap in improving cognitive, motor, and sprint performance in participants with partial sleep deprivation. *J Sports Sci* 2007; 25: 1557–1566.
- Watson NF, Badr MS, Belenky G, Bliwise DL, Buxton OM, Buysse D, Dinges DF, Gangwisch J, Grandner MA, Kushida C, Malhotra RK, Martin JL, Patel SR, Quan SF, Tasali E. Recommended amount of sleep for a healthy adult: a joint consensus statement of the American Academy of Sleep Medicine and Sleep Research Society. *J Clin Sleep Med* 2015; 11: 591–592.
- Williamson AM, Feyer AM. Moderate sleep deprivation produces impairments in cognitive and motor performance equivalent to legally prescribed levels of alcohol intoxication. *Occup Environ Med* 2000; 57: 649–655.
- Wood B, Rea MS, Plitnick B, Figueiro MG. Light level and duration of exposure determine the impact of self-luminous tablets on melatonin suppression. *Appl Ergon* 2013; 44: 237–240.
- Youngstedt SD, O'Connor PJ. The influence of air travel on athletic performance. *Sports Med* 1999; 28: 197–207.
- Yurcheshen M, Seehuus M, Pigeon W. Updates on nutraceutical sleep therapeutics and investigational research. *Evid Based Complement Alternat Med* 2015; 2015: 105256.