The Importance of Sleep for Athletic Performance

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ABSTRACT

ENSURING THAT ATHLETES FUNCTION OPTIMALLY THROUGHOUT TRAINING IS AN IMPORTANT FOCUS FOR THE STRENGTH AND CONDITIONING COACH. SLEEP IS AN INFLUENTIAL FACTOR THAT AFFECTS THE QUALITY OF TRAINING, GIVEN ITS IMPLICATIONS ON THE RECOVERY PROCESS. INTENSE TRAINING MAY PREDISPOSE ATHLETES TO RISK FACTORS SURROUNDING DISTURBED SLEEP PATTERNS. THESE MAY BE DUE TO INHERENT PHYSICAL EXERTION, COMMITMENT TO EXTENSIVE TRAINING SCHEDULES, THE EFFECTS OF TRAVEL, DOMESTIC OR INTERNATIONAL, AND THE PRESSURES THAT COMPETITION EVOKES. EDUCATING ATHLETES ON THE IMPLICATIONS OF SLEEP SHOULD BE IMPLEMENTED BY STRENGTH AND CONDITIONING COACHES TO OPTIMIZE ATHLETE RECOVERY, PROMOTE CONSISTENT SLEEP ROUTINES, AND SLEEP LENGTH.

INTRODUCTION

A common approach while optimizing athlete performance is to include daily monitoring of fatigue, stress, and recovery (1,29,34). Although there are many strategies to influence each of these, sleep is a strategy that contributes to significant recovery from multiple fatiguing events, including both cognitive and physiological tasks, and is an influential factor in avoiding overtraining (11). Sleep deprivation leads to poor performance, reduced motivation and arousal levels, and reduced cognitive processes leading to poor attention and concentration and heightened levels of perceived exertion and pain perception (13). Limitations to physiological processes include disrupted glucose metabolism and neuroendocrine functioning, a compromised immune system, and reduction in cardiovascular performance (13). Clearly, sleep is important for the athlete by providing opportunity for the body to recover from training and preparing for the subsequent training or competition day (11). General recommendations suggest that 7–9 hours of sleep is adequate for psychological (ability to learn, motivation, and memory) and physiological (metabolism and inflammation) recovery (5). Additionally, it has been suggested that athletes require a greater quantity of sleep (39) to recover sufficiently from injury, intense training periods, and competition. Recovery is promoted through the release of hormones, where growth hormone and androgens are both essential for muscle repair, muscle building, bone growth and promoting the oxidation of fat (3). Melatonin is produced by the neurotransmitter serotonin, which is stimulated by darkness and subsequently released from the pineal gland during the night to prompt sleep (4). Melatonin has a range of antioxidant properties (23), and given its sensitivity to light and the influence this hormone has upon recovery and health, promoting a suitable sleeping environment is paramount.

Sleep deprivation is considered common amongst athletes (8,21,22,42), where sleep duration and quality is often neglected when optimizing recovery and competition performance (41). This alludes to the need of greater athlete education surrounding this subject, because subsequently, sleep deprivation leads to disruption of training intensity and performance at competition (38). In light of this, sleep can be improved with a few recommendations, including strategies to fall asleep and the timing and duration of sleep. Therefore the aim of this review is to provide support for athletes to enhance their sleep quality and subsequently improve their training and performance.

SLEEP STAGES

There are 5 individual stages of sleep involving varied levels of consciousness and brain activity, occurring over consecutive phases (43). These stages are known as 1, 2, 3, 4 and rapid eye movement (REM). Stages 1–4 within this cycle are typically referred to as nonREM (NREM) and are the progressions of sleep before the first episode of REM sleep transpires. The approximate cycle duration between NREM and REM is 90 minutes, with the specific duration of REM increasing independently across the night. Before stage 1 occurs and the onset of sleep begins, the body must be in a relaxed state for 5–20 minutes, outlining the need for athletes to avoid any form of stimulating activity (e.g., watching TV and using tablets) before beginning sleep.

KEY WORDS:
REM; melatonin; nonREM; growth hormone

Stage 1 lasts for between 10 seconds and 10 minutes, where the individual is still consciously aware of any environmental change, meaning there is a high potential for awakening to occur, highlighting the need for an optimal sleeping environment (no sound, lights off, etc.). Stage 2 lasts between 10 and 20 minutes, and is the beginning of actual sleep, followed by stages 3 and 4. Altogether, these are the deepest stages of sleep, occurring for 30–40 minutes and largely the period in which growth hormone is released (13). After the last phase, stages 3 and 2 are repeated before progressing directly to REM, which is the most active state of sleep. This process is repeated up to 6 times, contributing to sleep quality. The total structure of sleep constitutes 75% NREM and 25% REM, with the majority of REM met within the last third of night time sleep (6). A greater frequency and duration of REM experienced during total sleep is suggested to enhance recovery processes and lead to a more optimal wakefulness (43). Therefore, because of the linear relationship between REM duration and frequency, and sleep length, it is vital that athletes maximize the potential for sleep duration.

SLEEP AND PERFORMANCE

During sleep, recovery is promoted largely through hormone activity (14). In addition to acting as an antioxidant, melatonin activates other proinflammatory enzymes to neutralize oxidative radicals which harm cells and promote tissue inflammation (30). Immune function is also modulated through melatonin through both nervous and endocrine systems. Finally, melatonin regulates circadian rhythms in response to light and dark cycles with low and high levels of secretion, respectively (24). Released within deep sleep (stages 3 and 4), growth hormone and androgens are both essential for muscle repair, muscle building, bone growth, and promoting the oxidation of fats (3). Sleep promotes the restoration of the immune and endocrine systems, recovery of the nervous system and the metabolic expenditure of the previous training day, and stimulating memory and learning potential for the subsequent training day (16). Hausswirth and Mujika (2013) additionally identify how during deep sleep, the enhanced activity of various neuronal connections prevents the onset of possible deterioration that would be incurred because of reduced activity due to sleep deprivation.

The use of extended sleeping time has been explored in past research within athletes who habitually endure sleep deprivation or experience significant sleep debt. Comparing a 4-week baseline habitual sleep period to a 7-week sleep extension period involving at least 10 hours sleep each night, basketball performance measures were enhanced (23), sprint times were faster (15.5 ± 0.54 seconds versus 16.2 ± 0.61), and shooting accuracy improved by 9% coupled with decreased reaction times, reported "sleepiness" and improved profile of mood states (POMSs). The increased sleep time was achieved by altering the subjects' academic and training schedules around an extended sleeping period rather than sleep being dictated by training and academic scheduling. Accompanied with an encouragement to achieve minimal 10-hour sleep each night with routine sleep and wake times, both sleep journals (470 ± 65.9 to 624 ± 68.4 minutes) and actigraphy (400.7 ± 61.8 to 507.6 ± 78.6) reported significant increases in sleep duration. Therefore, time management is vital, particularly for student athletes. To date however, this seems to be the only study to determine the effect of greater sleep time on athletic performance and a control group was not included.

In addition to extended habitual night time sleep, napping during the day has been suggested as a useful tool to enhance recovery processes, notably for athletes who experience loss of sleep during the night (11). A 30-minute nap between 13.00 and 13.30, after a night of just 4 hours sleep, leads to improvements in alertness and mental and physical performance (44). Reported sleepiness reduced after napping and short-term memory improved, coupled with enhancements in reaction time and greater performance for 20 m sprints. Therefore the importance of sleep is paramount in promoting optimal cognitive functioning to facilitate learning and performing skills within training, and ensuring recovery of physiological mechanisms to avoid significant muscle inflammation and maintenance of the immune system. Although extended sleep periods are ideal for athletic performance, if it is not possible, napping may be a valuable assistant.

SLEEP DEPRIVATION

Previous research has highlighted how common poor sleep quality is among the athletic population. In a group of Olympic athletes, significant reductions in actual sleep (84.3 ± 5.7 versus 89.7 ± 3.3) and efficiency (80.6 ± 6.4 versus 88.7 ± 3.6, repeated stages of the sleep cycle leading to optimal volumes of REM sleep) were identified in comparison to a control group of a nonathletic population (22). In a group of South African athletes, 41 and 60% reported difficulty in falling asleep and difficulty in waking up, respectively (42). In addition, among 632 German athletes 32% reported numerous waking experiences during sleep and 79% reported difficulty in falling asleep on the night before competition, leading to increased tiredness during the following day (8). Research has also explored the differences between habitual sleep patterns of individual and team athletes (21), indicating that individual athletes slept and awakened earlier and gained less sleep than team sport athletes. However, both sets of athletes obtained far less sleep than the recommended 7–9 hours per night. Evidently, athletes commonly struggle with sufficient sleep volume and quality, effecting training and performance.

Sleep deprivation effects on performance indicators include reductions in reaction times, increases in unstable emotional states (43), and significant reductions ($p < 0.001$) in maximal bench-press (−9 kg) and deadlift

(−30 kg) performance after just 3 hours of sleep each day for 4 days (31). Therefore, a lack of sleep can limit the ability to train effectively to enhance strength and power. Because skill training requires optimal cognitive functioning for learning and memory to consolidate a new skill (9), efficiency of skill training each day to enhance competition performance will be limited because of sleep deprivation. Causes of sleep reduction are largely linked with anxiety before competitions and 82% of 283 elite Australian athletes reported sleep disturbances because of this (18). The effects of sleep reduction have also been considered for specific exercises that stress different energy systems. For intermittent sprint efforts, involving anaerobic performance, sleep deprivation over 2 consecutive nights resulted in slower sprint times (37). Similarly for endurance-based performances, 24 hours of reduced sleep resulted in decreased aerobic performance over a 30-minute period (6,224 ± 818 to 6,037 ± 759) (27). Ultimately this outlines the need for athletes, globally, independent of predominant energy system used within their sport, to incorporate a sound sleep strategy to avoid any form of sleep loss. A review of articles assessing sleep, including mood response to sleeping patterns and the results of sleep extension and deprivation on measures of physical and cognitive performance, can be found in Table 1.

MEASURES OF SLEEP QUALITY

A common approach to measure sleep within a performance setting and be cost effective is to complete sleep questionnaires. This method is predominant in previous research that has explored sleep deprivation and sleep extension (33), with various questionnaire types that focus solely on specific sleep components, such as disturbance, sleep duration, time for falling asleep and time for waking up. The Competitive Sport and Sleep questionnaire and the Pittsburgh Sleep Quality Index are examples that have been implemented to understand athletes' sleep qualities around competition (18). In addition, the inclusion of sleep as a general component within a readiness to train questionnaire identifies various aspects of stress, recovery, and lifestyle elements in response to daily training. Although self-reported methods are useful, allowing self-reflection from the athlete and identifying the areas of concern, they are subjective in nature.

It is also possible for objective measures of sleep to be recorded, although added cost for use of specific software and equipment will be involved. Polysomnography is considered as the criterion approach providing information on various aspects of sleep quality and quantity, which includes sleep efficiency, total sleep time, number of awakenings, and time in each sleep stage (12). However, this method requires high levels of expertise and is not practical with regard to monitoring sleep specifically for athletes. Actigraphy is an alternative method involving wristwatch devices that monitor body movement and, accompanied with sleep diaries, can sufficiently determine sleep time, sleep-onset latency, wake after sleep onset, and the efficiency of sleep (23). This method proves as a successful measure of sleep that is noninvasive and can collect data for a period of 2 weeks (12).

The use of smartphone sleep apps may be of some interest due to the ease of integration that this may provide to the athletes' lifestyle. A recent review however on the validity of current apps suggests that strong scientific evidence is lacking (2), with high variability in results influenced by phone type and position of the device when recording data.

RECOMMENDATIONS

The amount of sleep athletes require is commonly regarded as at least 7 hours each night (43); however, this figure will change with each individual athlete. In comparison to nonathletes, athletes require a greater volume of sleep for sufficient recovery to occur as a result of high volumes of training modalities (22). Furthermore, young athletes that participate in this high volume of training load are suggested to sleep for a minimum of 10 hours each night (5), with additional suggestions that this should occur for all elite athletes regardless of age, who participate in long training days (35). In light of this, the athlete should sleep for at least 7 hours and enough to ensure sleepiness is avoided during the following training day. To facilitate these adequate sleeping hours, routines must be reached where sleeping and waking times are consistent, stimulating the quality of sleep. Improving sleep quality reduces sleep latency and enhances transition through the sleep stages, promoting volume of REM sleep and therefore optimizing recovery and wakefulness (43).

AMBIENT CONDITIONS

A further consideration is the temperature of the environment, which influences the onset of sleep and the efficiency of the sleep stages. Heat exposure leads to greater wakefulness when attempting to sleep and reduces time spent experiencing REM (26), supporting an environment maintained at room temperature and suitable bedding/clothing to be used to avoid temperatures that are too hot. Thermoregulation and sleep are strongly linked (40), with the core body temperature following a cycle, consistent to that of the 24-hour sleep-wake cycle and the circadian rhythm (26). Core temperature decreases with the onset of sleep while the peripheral temperature increases with greater blood flow to the skin (20), accelerating the onset of sleep, (19) and associated strongly with melatonin secretion (4). Temperatures above and below the thermal neutral temperature of 29°C may disrupt sleep and prompt awakening (15), identified with partially clothed subjects. However, the influence of bed covers and clothing results in sleep to be affected more often by heat rather than cold exposure (26) and because wakefulness is the only sleep stage that can endure thermal increases (28), awakening occurs to maintain thermoregulation. Therefore bedding, clothing, room temperature, and humidity must be considered to avoid contributing to increasing the core temperature of the

Table 1
Previous research investigating the results of sleep extension and reduction on athlete performance

Reference	Intervention	Results	Conclusion
Juliff et al. (18)	283 elite Australian athletes (129 men, 157 women; 24 ± 5 y). Two questionnaires were completed on the nights before competition; Competitive Sport and Sleep questionnaire and the Pittsburgh Sleep Quality Index.	64% reported worse sleep than normal before important competition. 82.1% identified falling asleep as the main problem, largely because of nervous thoughts regarding competition. 59.1% of team sport athletes reported no strategy to combat this and just 32.7% of individual athletes used methods to reduce these effects.	Identification of poor sleep patterns being common among athletes during the nights leading up to the competition. Highlights importance of greater education necessary to enhance the sleep quality in preparation for important competitions.
Mah et al. (23)	11 Stanford University basketball players undertook habitual baseline sleep for 2–4 wk followed by 5–7 wk of extended sleep of at least 10 h each night. Athletic performance measured through a timed sprint and shooting accuracy at each training session. Reaction time monitored with the Psychomotor Vigilance Task (PVT), daytime sleepiness with the Epworth Sleepiness Scale (ESS) and mood through Profile of Mood States (POMS).	Night time sleep increased during sleep extension period by 110.9 ± 79.7 min. Sprint times greater following sleep extension (16.2 ± 0.61 versus 15.5 ± 0.54) and shooting accuracy increasing by 9%. Mean PVT decreased and POMS improved with sleep extension ($p < 0.001$). ESS decreased with sleep extension ($p < 0.01$).	Sleep extension identified to directly enhance sport specific performance.
Skein et al. (37)	10 male team sport athletes completed a baseline session and 2 consecutive days of trials separated by a normal night's sleep or no sleep. Each trial consisted of a 30-min graded exercise run and a 50-min intermittent sprint protocol. Muscle glycogen, voluntary force, POMS, HR and RPE pre and post each trial exercise.	Mean sprint times significantly reduced between the normal sleep and no sleep trials ($p < 0.05$). Muscle glycogen concentration was significantly lower after no sleep (209 ± 60 mmol/kg dry weight) in comparison to sleep (274 ± 54 mmol/kg dry weight) before the start of trials ($p < 0.05$). Sleep loss negatively impacted upon POMS ($p < 0.05$).	Sleep reduction leads to muscle glycogen depletion before exercise, contributing towards reduced performance and perception of mood state, or stress.
Oliver et al. (27)	11 men completed 2 trials separated by 7 d, one trial post normal sleep and one trial post 30 h without sleep. The trial consisted of 30-min treadmill running at 60% $\dot{V}O_2max$ followed by 30 min of self-paced running. Speed, RPE, core and mean skin temperature and heart rate were measured during the trials.	Less distance was covered after the sleep deprivation trial (6,037 versus 6,547 m; $p = 0.016$) during the 30-min self-selected pace treadmill run.	Sleep deprivation induces negative performance outcomes for endurance-based exercise.
Waterhouse et al. (44)	10 men either napped or sat quietly as the control group between 13:00 and 13:30 h after a night of just 4 h of sleep. 30 min after nap, measures of alertness, short term memory, heart rate, reaction time, grip strength and 20 m sprint time were taken.	Napping improved alertness, short term memory and reaction time ($p < 0.05$); however, grip strength was not affected ($p > 0.05$). 20-m sprint times improved (3.971 s versus 3.878; $p = 0.013$).	Implementing the use of napping has the potential to increase alertness and physical performance after restricted sleep duration in athletes.

Table 1 (continued)

Reilly and Percy (31)	8 male subjects (18–24) slept just 3 h for 3 consecutive nights after 4 d of normal sleep where baseline measures were taken. Weightlifting exercises were performed which included biceps curl, bench press, leg press and deadlift. Both for submaximal (20RM) and maximal (1RM). POMS were completed before each test.	Sleep loss significantly reduced maximal bench press, leg press and deadlift ($p < 0.001$). All submaximal lifts reduced because of sleep deprivation, with significance met after the second night of sleep loss ($p < 0.01$). No significant reduction in the maximal biceps curl performance was observed ($p > 0.05$).	Sleep loss will have a significant negative impact on the efficiency of strength specific training following sleep loss, particularly across several days.

body and subsequent disruptions of sleep. In summary, avoiding a sleeping environment that is too hot is more beneficial for maintaining sleep.

NAPPING

The use of napping can be implemented to recover sleep debt, when athletes have had poor night time sleep duration and quality. Among previous research, 30 minutes of nap time is consistent to promote cognitive processes and motor control (44); however, further time must be considered when being implemented into a training day, in order for athletes to fully waken after this period. Various strategies can be implemented to enhance the waking process after short nap times, including caffeine use, awakening under bright lights, and washing the face immediately after wakening (13). Reportedly, the most effective strategy is the ingestion of caffeine before napping, to enhance cognitive processes, measured through memory and reaction time performance tasks (17). Once ingested, caffeine is rapidly absorbed, with plasma concentrations peaking after 30–75 minutes and the half-life of a single dose suggested to last 3–7 hours (32).

Important considerations therefore are necessary regarding length of the nap and time of its occurrence when implemented in conjunction with caffeine use. This method could be considered by athletes, through consuming coffee, for example, before napping during the day to promote rapid and effective recovery post nap, allowing for successful integration within a structured training day. Another consideration should be the time of day in which napping occurs; recommendations suggest to avoid naps in the late afternoon and evening because this will induce negative repercussions on night time sleep routine (44).

PRE-SLEEP ROUTINES

To promote general sleep quality and quantity, it is important to first adhere to optimal strategies that will enhance the processes of falling asleep. Commonly, as discussed above, simple measures are most effective applied in combination and routinely. When preparing for sleep, a dark room is vital, within a cool environment and absent of noise (26). Melatonin release is subject to light and dark sensitivity, so its transmission is promoted within a dark environment which is important because of its sleep promoting effects (13) and enhancing the speed at which sleep begins. This reduces the potential of disturbed sleep, most notably for the initial stage which is the lightest of the sleep stages, and therefore is at the greatest risk of disrupting the onset of sleep. An additional factor that causes disruption in sleep routine, specifically the time in which it takes to fall asleep, is anxiety before a competition (36) and, of course, training. The importance of managing this anxiety has been identified, with various protocols suggested to combat the effects that anxiety has on sleep quality, from goal setting and self-talk (10) to mental rehearsal and implementing visualization therapy techniques (25).

While traveling or at any location away from the routine sleeping environment, the use of eye masks and ear plugs may prove beneficial to further enhance the ability to fall asleep. Combining this with a routine time to go to bed each night will prove more effective. This will also allow opportunity for the athlete to plan his activity leading up to sleep, to avoid using a computer and watching television for example. This activity should also concern the avoidance of caffeine ingestion which may result in sleep disturbance during the night (7). Lastly, the time of day in which napping is used should be limited to no later than midafternoon to avoid interference with the routine sleep time (44). An additional practical consideration is the use of light upon wakening to enhance this process where light has an inverse relationship with melatonin release (4), leading to the suppression of this and a more efficient transition from wakening. Table 2 identifies a checklist athletes should meet to optimize their sleep.

CONCLUSION

Sleep deprivation can contribute to poor performance through reduced motivation and efficiency of cognitive processes, increasing perceived effort, and limiting physiological recovery responses. Monitoring the quality and quantity of sleep can aid in detecting poor sleep patterns and behavior, allowing for intervention to avoid significant reductions in health. The use of diaries outlining hours of sleep and

Table 2 **Checklist for athletes to consider to enhance sleep**
Strategies to promote sleep quantity and quality
Normal sleep
Ensure dark room with no light source present
Quiet environment
Maintain room temperature (~18°C)
Ensure that bedding/clothing does not cause an environment that is too hot
Sleep routine: consistent time each night for falling asleep to begin and waking up
At least 7 h sleep a night
Napping not later than midafternoon
Avoid caffeine and food/fluid ingestion leading up to sleep (no nap, however)
Avoid the use of computer, tablet, TV before sleeping
Napping
Should be used to recover sleep debt
30 min are adequate
Enhance the waking process during a training day through:
Ingestion of caffeine before napping
Awakening under bright lights
Immediate face washing upon awakening

sleep efficiency can be a useful measure for athletes to reflect on their sleeping patterns. In addition, various devices are available to monitor sleep over short periods of time that provide more objective data outlining the time of sleep, waking time, time taken to fall asleep, number of waking occurrences, and estimations of sleep quality, all of which provide information on sleep routines. Recommendations for sleep patterns should be specific to each individual; however, at least 7 hours of sleep is a general recommendation, implemented within a routine of consistent sleeping and waking time. Knowledge surrounding sleep and its importance with regard to recovery, monitoring, and assessment is becoming consistently more predominant within an elite performance setting.

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