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REVIEW ARTICLE

Stress, Sleep and Recovery in Elite Soccer: A Critical Review of the Literature

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Abstract In elite soccer, players are frequently exposed to various situations and conditions that can interfere with sleep, potentially leading to sleep deprivation. This article provides a comprehensive and critical review of the current available literature regarding the potential acute and chronic stressors (i.e. psychological, sociological and physiological stressors) placed on elite soccer players that may result in compromised sleep quantity and/or quality. Sleep is an essential part of the recovery process as it provides a number of important psychological and physiological functions. The effects of sleep disturbance on post-soccer match fatigue mechanisms and recovery time course are also described. Physiological and cognitive changes that occur when competing at night are often not conducive to sleep induction. Although the influence of high-intensity exercise performed during the night on subsequent sleep is still debated, environmental conditions (e.g. bright light in the stadium, light emanated from the screens) and behaviours related to evening soccer matches (e.g. napping, caffeine consumption, alcohol consumption) as well as engagement and arousal induced by the match may all potentially affect subsequent sleep. Apart from night soccer matches, soccer players are subjected to inconsistency in match schedules, unique team schedules and travel fatigue that may also contribute to the sleep debt. Sleep deprivation may be detrimental to the outcome of the recovery process after a match, resulting in impaired muscle glycogen repletion, impaired muscle damage repair, alterations in cognitive function and an increase in mental fatigue. The role of sleep in recovery is a complex issue, reinforcing the need for future research to estimate the quantitative and qualitative importance of sleep and to identify influencing factors. Efficient and individualised solutions are likely needed.

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Key Points

Because sleep provides psychological and physiological functions that are considered critical to optimal recovery, the increased frequency of sub-optimal sleeping patterns in elite soccer players means this is a common cause of impaired recovery in these athletes.

Various situations and conditions that can interfere with sleep—including light, napping, caffeine/alcohol consumption, match-induced arousal, travel fatigue, inconsistency in schedules, inter-player variability in sleep preference—may potentially affect sleep.

The detrimental effects of sleep disturbance on post-soccer-match fatigue mechanisms include muscle glycogen resynthesis inhibition, muscle damage increase and/or impairment of muscle damage repair, cognitive function impairment and mental fatigue increase.

1 Introduction

Regular participation in recreational soccer induces many favourable health benefits including positive adaptations of the musculoskeletal, metabolic and cardiovascular systems [1]. Sleep quantity and quality may also be improved by regular exercise [2, 3]. Brand et al. [3] found that male junior (aged 15.4 ± 0.9 years) soccer players (12.7 ± 2.1 h of practice per week) subjectively report better scores for sleep quality, shortened sleep latency, and a lower number of awakenings after sleep onset, combined with a longer total sleep time in comparison with controls. Polysomnography—the gold standard of sleep measurement [4]—analyses reveal that, compared with controls, junior soccer players also show greater sleep efficiency, shortened sleep onset latency, less awakenings after sleep onset, more time in stage 4 sleep, and less rapid-eye-movement (REM) sleep [2]. Such positive results are in agreement with health-based survey research reporting associations between regular physical activity and better sleep [5]. Unfortunately, participation in elite soccer induces side effects. A survey about the sleep complaints of 19 professional soccer players after night matches (start times ranging from 8:00 p.m. to 9:00 p.m.) was performed in February 2015 in a French top-level team participating in the UEFA (Union of European Football Associations) Europa League (unpublished observation). 95 % ($N = 18$) of players indicated worse sleep in the nights after night matches. Schwenk et al. [6] showed that two of the most common retirement concerns reported by players are difficulty with pain (48 %) and trouble sleeping (28 %). Throughout their career, players are frequently exposed to various situations and conditions that can interfere with sleep, potentially leading to acute and chronic sleep disorders.

This article provides a comprehensive and critical review of the current available literature regarding the potential acute and chronic stressors that could influence sleep disturbance and recovery in elite soccer players. The effects of sleep disturbance on post-soccer-match fatigue mechanisms and recovery time course are also described. Underpinning the concept of stress and recovery is the model for overtraining and recovery by Kenttä and Hassmén [7]. This model adopts a holistic perspective and postulates that different types of stress contribute to the total amount of stress. The psycho-socio-physiological stresses placed on elite athletes may actually result in an inability to obtain appropriate sleep [8]. It is postulated that the sleep-related problems experienced by some athletes can only be fully understood in this larger context. This review summarises current research that evaluates the role of sleep in recovery from competition, using soccer (Association Football) as the main sport of interest. A computerised literature search was performed using PubMed with the following keywords used in different combinations: 'sleep', 'sleep loss', 'sleep deprivation', 'sleep extension', 'recovery', 'fatigue', 'glycogen', 'inflammation', 'immunity', 'injury', 'soccer', 'football', 'match', 'training', 'stress', 'travel', 'light', 'nap', 'temperature', 'caffeine', 'alcohol', 'screen'. All titles and abstracts were carefully read and relevant articles were retrieved for review. In addition, the reference lists from both original and review articles retrieved were also reviewed. The negative effects of travel across multiple time zones on sleep [9] are not addressed in the present review due to limited travel of this nature in European domestic leagues or the UEFA Champions League. Only the effects of travel fatigue encountered during domestic flights on sleep are addressed. Additionally, it is not the aim of the present review to assess the effects of terrestrial altitude on sleep [10], Ramadan [11, 12], disturbed sleep and nightmares before competition [13, 14] or sleep apnea [15].

2 Sleep and Recovery

Sleep provides a number of important psychological and physiological functions that may be fundamental to the recovery process. Several theories of the function of sleep have been proposed [16, 17]. One neuro-metabolic theory suggests that sleep assists in the recovery of the nervous and metabolic cost imposed by the waking state [17]. During sleep, which includes five distinct stages (stages 1, 2, 3, 4 and REM stage), metabolic activity is at its lowest point (i.e. slow breathing, low heart rate, and low cerebral blood flow) and the endocrine system increases the secretion of growth hormone via the pituitary gland allowing physiological restitution [18, 19]. Learning and motor memory are associated with slow-wave sleep, REM sleep [20–22] and sleep spindles [23] during the night, and result in overnight systems-level plastic reorganization within the brain, including increased activation in the primary motor cortex [24]. Nishida and Walker [23] have found that motor skill improvements are significantly associated with stage-2 non-REM sleep ($r = 0.55$, $p = 0.04$), and also with the density ($r = 0.65$, $p = 0.01$) and power ($r = 0.57$, $p = 0.04$) of locally expressed sleep spindles—a defining electrophysiological signature of non-REM sleep involving short (≈ 1 s) synchronous bursts of activity (12–15 Hz). Walker et al. [24] have reported a systems-level change in the functional magnetic resonance imaging scanning of a learned motor-sequence task after a night of sleep (8.1 ± 0.8 h). Specifically, during a retest session on a previously learned motor sequence and following sleep relative to wake, increased activity observed in the primary motor cortex, medial prefrontal lobe, hippocampus and cerebellum may support faster motor output and more precise mapping of key-press movements; whereas decreased activity in parietal cortices, the insular cortex, temporal pole and fronto-polar region may reflect a reduced need for conscious spatial monitoring and a decreased emotional task burden [24]. Consequently, knowledge of the complex effects of sleep disorders among elite soccer players needs to be supplemented with sufficient understanding of sleep's role in recovery, and possible sleep hygiene strategies to alleviate these issues [25].

We previously reviewed recovery strategies aimed at accelerating the time to achieve complete recovery among professional soccer players; that is, nutrition, cold water immersion, active recovery, stretching, compression garments, massage, electrical stimulation, and sleep [26]. A survey on recovery strategies used in elite soccer revealed that sleep was considered as an effective recovery strategy by 95 % of practitioners in charge of recovery in French professional soccer teams [26]. Venter [27] determined how elite team sport athletes themselves perceive the importance of various recovery modalities. The recovery modality that was rated as important by all players from all sport codes (i.e. field hockey, netball, rugby union and soccer), regardless of sex, type of sport or level of participation, was sleep. However, despite a widespread use of the aforementioned recovery interventions, a common issue for recovery from training or competition relates to sub-optimal sleeping patterns noted in athletic populations [28]. Sleep disturbances after training or competition are common and can negatively impact on the recovery process [26].

The sleep needs of athletes remain largely unknown given that the measurement of sleep in athletes is not common [12]. There are two primary methods utilised to assess sleep. The first is polysomnography, which provides information on sleep staging and is considered the gold standard for assessing sleep quantity and quality [4]. A second method for measuring sleep is by means of actigraphy (wrist activity monitors). As it is non-invasive and allows data collection over significant periods of time at home or while travelling, actigraphy is particularly useful for understanding sleep patterns among athletes [4]. Four main studies have examined the amount and quality of sleep that elite athletes obtain [28–31]. Specifically, there is limited scientific information regarding sleep requirements and characteristics in elite soccer players. However, from the available evidence among elite athletes it would appear that sleep quantity and quality are reduced compared with age-matched controls [28]. Playing elite soccer may involve constraints that can interfere with sleep if occurring too close to bedtime, such as exposure to bright light, engaging in exciting or emotionally stimulating activities, consuming products containing alcohol or caffeine, variable wake-up times and/or bedtimes as a result of variable match schedules [32]. In the following sections, the potential acute and chronic causes of sleep deprivation among elite soccer players are reviewed (Table 1).

Table 1 Potential acute and chronic stressors that could influence sleep quantity and/or quality in elite soccer players

Acute stressors (e.g. during/after night soccer match)
Bright polychromatic light ($\approx$2000 lux) in stadium
Excitement and arousal as a consequence of competition
Match outcome-related mood
Playing away: 'first-night effect' during the first night in a hotel; light in the airport; light in the plane; cumulative travel fatigue over the season
Use of electronic floodlit media devices (e.g. tablets, smart phones)
Caffeine and/or alcohol consumption
Day-time napping
Chronic stressors
Inconsistency in match schedules leading to irregular sleep routine
Day-time napping
Individual chronotype (especially evening chronotype—'night owls') conflicting with the demands of the soccer club
Early morning training session start time

3 Stressors Affecting Sleep Quantity and Quality

3.1 Night Soccer Matches

The central oscillator or body clock, located in the suprachiasmatic nuclei of the hypothalamus, is adjusted mainly by the light–dark cycle with light information passing from retinal ganglion cells via a direct pathway, the retinohypothalamic tract [33]. Melatonin (*N*-acetyl-5-methoxytryptamine) is derived from tryptophan and is mainly produced by the pineal gland [34]. Melatonin, inhibited by light and secreted by the pineal gland during the hours of darkness, is thought to play an important role in transmission of time information from the body clock to the peripheral oscillators located in most human cells [9]. Regular changes in physical activity and arousal are also important to adjust the body clock and may strengthen the day–night contrast in lifestyle (e.g. cold environmental temperatures during the night time, physical activity and bright light exposure during the daytime) [33, 35]. Conversely, a phase shift as experienced by night and rotating shift workers involves desynchronization at the molecular level in the circadian oscillators in the central nervous system tissue and in most peripheral tissues of the body

[36]. In this section, the potential chronodisruptive effects of evening soccer matches on sleep (i.e. performing intense exercise with a high degree of arousal in combination with bright light exposure) are reviewed.

3.1.1 High-Intensity Exercise and Sleep

Both the scientific community and lay opinion strongly discourage vigorous exercise in the run up to bedtime based on the contention that exercising near bedtime is associated with disturbed sleep [32]. However, there is little reliable scientific evidence to support this recommendation. We found two studies that have showed a significant delay in sleep onset after exercise performed late in the night [37, 38]. Browman and Tepas [37] have shown a significant delay in sleep onset of 6 min after a 45-min, light-intensity cycling exercise completed by young male subjects with moderate fitness only 5 min before bedtime. However, due to post-match routines (i.e. medical care, recovery strategies, meals and the return trip) such a short period between exercise completion and bedtime is not conceivable in soccer settings. Oda and Shirakawa [38] compared the effects of different intensities (moderate: 60 % and high: 80 % heart rate reserve) of 40 min of pre-sleep treadmill running (9:20–10:00 p.m.) on sleep onset with a control condition. Compared with the non-exercise control condition, the sleep-onset latency was significantly longer (+14.0 min, $p < 0.05$) in the high-intensity exercise condition. In addition, the total sleep time was significantly shorter (−14.6 min, $p < 0.05$), while the sleep efficiency was significantly lower (−3.1 %, $p < 0.05$) following high-intensity exercise, compared with non-exercise. A significant difference was also observed in the subjective scores of the 'ease of going to sleep' between high-intensity exercise and non-exercise conditions ($p < 0.05$).

Conversely, several studies have showed no effect and/or beneficial changes in sleep outcomes after exercise performed in the night. Robey et al. [39] examined the effect of early evening high-intensity training on the sleep of elite male youth soccer players. Main results showed that sleep parameters (sleep duration, sleep-onset latency [time taken to fall asleep], sleep efficiency [indirect measure of sleep quality], wake time after sleep onset, bedtime, sleepiness on waking, self-reported sleep quality) were not affected after performing early evening (4:30–6:30 p.m.) high-intensity repeated sprint training sessions compared with nights where no evening training was performed. Accordingly, no differences are observed for any night sleep measures derived from polysomnography (i.e. total sleep time, sleep efficiency, sleep onset latency, REM sleep onset latency, wake after sleep onset, proportion of the night spent in different sleep stages) when male cyclists undergo either no exercise or cycling for 15 min at 75 % peak power plus a 15-min maximal time trial at 7:00 p.m. [40]. Results from several studies [41–43] have even found that evening exercise may be associated with positive changes in sleep continuity and sleep architecture. Buman et al. [41] found in a large sample of 1000 adults (aged 23–60 years) that evening (i.e. <4 h before bedtime) moderate or vigorous exercisers did not differ in any of the self-reported sleep metrics compared with non-exercisers. More specifically, evening exercisers indicated that their sleep was of equal or of higher sleep quality and duration on days they exercised compared with days they did not exercise [41]. From a meta-analytical review examining 2863 adults (aged 18–89 years) of varying baseline physical activity levels (i.e. 24 % of the 66 studies examined individuals with high baseline physical activity, 23 % of studies examined individuals with low baseline physical activity, and the remainder examined individuals with mixed or unknown baseline physical activity), Kredlow et al. [42] concluded that acute exercise <3 h before bedtime may be beneficial, and exercising 3–8 h before bedtime detrimental for some sleep outcomes (i.e. lower wake time after sleep onset and less time spent in light sleep stage 1 when exercising near bedtime). Brand et al. [43] have reported among young regular evening exercisers that greater self-perceived exertion when completing moderate to vigorous exercise 1.5 h before bedtime was associated with higher sleep efficiency ($r = 0.71$, $p < 0.001$) and shortened sleep onset latency ($r = -0.33$, $p < 0.05$) assessed by electroencephalograms. However, results may differ when investigating elite soccer players performing a 90-min competitive soccer match where exercise intensity and stress level are much higher than those reported in these studies [41–43]. In this respect, future studies may also investigate if sleep requirements differ according to playing position and/or individual activity performed during the match. As it has been proposed that sleep parameters may be affected as a result of a greater need for recovery sleep due to more demanding workloads [44], it may be hypothesised that players in a more 'physically' demanding position (i.e. fullbacks, midfielders and forwards [45, 46]) may exhibit positional differences in sleeping patterns compared with goalkeepers and central defenders.

Collectively, these results indicate that time of day of exercise may be particularly relevant when studying the influence of evening exercise on subsequent sleep. Future studies are required to expand these results with elite soccer players performing a 90-min competitive soccer match in illuminated and noisy ambient conditions. In the survey on the sleep habits after night matches (start times ranging from 8:00 p.m. to 9:00 p.m.), players reported taking a long time to fall asleep after night soccer matches (sleep start: 03:00 ± 01:02 a.m.) [unpublished observation]. Exercise-induced changes in core temperature [47] could potentially affect sleep by disrupting the thermo-physiological cascade leading to sleep initiation [48]. In the previously mentioned study [38], a dose thermal response, relative to the exercise regimens, was observed at bedtime (non-exercise: 36.87 ± 0.07 °C < moderate-intensity exercise: 37.17 ± 0.08 °C < high-intensity exercise: 37.33 ± 0.08 °C, $p < 0.01$). In this respect, the effect of ambient temperature on core temperature [49] and subsequent sleep may be also assessed. Exercise type (e.g. magnitude of impacts during practice [42]) may also influence the relationship between evening exercise and sleep. Another explanation for the potential effect of pre-sleep exercise on sleep onset may be related to the delay in recovery of parasympathetic activity following exercise leading to persistent high heart rate at bedtime and for several hours after bedtime [38]. Cerebral, endocrine, and circadian phase-shift responses should also be examined in future studies as physiological mechanisms potentially explaining the effects of exercising prior to sleep on sleep variables [38]. For example, it appears that acute and regular exercise leads to a broad variety of physiological changes such as an increased secretion of brain-derived neurotrophic factor [50, 51] which may have a positive influence on sleep [52]. However, performing exercise in association with loaded psychosocial stress and decreased sleep quantity/quality may lead to decreases in plasma brain-derived neurotrophic factor [53]. Future studies on the relationship between evening exercise, level of stress, neurotrophic factors and subsequent sleep are warranted.

3.1.2 Light and Sleep

Elite soccer players are exposed to bright light in the stadium and also after the match, which may have an impact on sleep. Light possesses alerting effects and melatonin levels have an inverse relationship with alertness. Light may suppress melatonin and may therefore influence sleep [54–56]. Bright light exposure decreases sleepiness, increases alertness, improves performance on behavioural tasks and attenuates the nightly drop in core body temperature [55]. Factors such as the dose (illuminance levels), exposure duration, timing and wavelength of light have an important influence on the alerting response to light in humans, with bright polychromatic light (≥1000 lux) sufficient to elicit maximal alerting effects [54]. In modern stadiums, players are exposed to 250 floodlights and 2000-lux bright light [57] whereas, in the general population, mean light exposure is <10 lux from midnight to wake time [35]. The circadian drive for sleep is maximal during the night between 2:00 and 6:00 a.m., and the homeostatic drive for sleep (sleep pressure) usually increases when exceeding 16 h of prior wakefulness [54]. This optimal drive for sleep occurs at a time when players are likely still exposed to light (e.g. light in the airport, light in the plane, and light of the screens from smart phones or tablets) after the match. During travel, players are prone to consult social networks and/or electronic press, viewing films, using smart phones and/or writing short messages. In a survey on the sleep habits after night matches, players revealed that 79 % ($N = 15$) of them use technology (i.e. television viewing, computer/laptop, smart phones) before going to bed (unpublished observation). Growing evidence suggests that exposure to a myriad of electronic floodlit media devices (e.g. televisions, computers, tablets, smart phones) [58] can have detrimental effects on sleep quality, sleep quantity and timing [59, 60]. For example, Arora et al. [59] investigated the effects of technology use (e.g. television viewing, video games, computer or laptop for studying, Internet for social networking, smart phones for calling or texting) before going to bed on multiple sleep parameters. Overall, there was a negative correlation ($r = 0.15$; $p < 0.001$) between the quantity of bedroom technology and sleep duration. Technology use before going to bed was associated with difficulty falling asleep or difficulty 'switching off their minds' when attempting sleep. Main results showed that frequent users of social networking sites reported almost 1 h less sleep ($p < 0.001$) and frequent bedtime television viewing reduced ($p = 0.008$) sleep duration by approximately 20 min.

3.1.3 Arousal and Sleep

Modern athletes are facing more mental, emotional and social demands than ever before, with, amongst others, pressure on personal relationships, media demands, sponsor needs and public interest [61]. When playing night soccer matches (e.g. 9:00 p.m. kick off), soccer players are required to perform at their peak when psychomotor vigilance and subjective alertness tend to decrease after a typical day of activity [62], which may lead to sleep disturbance. The outcome of the match may also have an influence on players' mood states and subsequent sleep. Players show a range of pleasant emotions following a win, whereas losing results in unpleasant emotional changes (i.e. more tense, depressed, tired, and miserable) [63, 64], which may be detrimental to sleep induction. Inter-individual differences regarding the effects of mood states on sleep are possible. For example, personality aspects (neuroticism) and resources of the individual contribute to perceived stress which may have implications on sleep duration and quality as well as daytime consequences of disturbed sleep [65]. As previously described, electronic media exposure may have alerting effects, possibly due to the suppression of melatonin by the bright light emanating from electronic screens. The engaging and exciting content of electronic media may be another explanation. Arora et al. [59] proposed that visual content exposure or cognitive processes (decision-making, problem-solving, memory) occurring from engaging with electronic devices may increase the difficulty switching off the mind when attempting sleep. Moreover, it is possible that exposure to violent content (visual or verbal) before bedtime may promote adverse sleep outcomes such as nightmares [59].

3.1.4 Caffeine, Alcohol, Medication and Sleep

Caffeine is a popular psychoactive substance used by most individuals, including soccer players. Soccer players anecdotally report ingesting moderate to large quantities of caffeine before the match and/or during half-time in the form of coffee, chewing gum, energy drinks, etc. Conflicting results are present in the literature regarding the effect of caffeine ingestion on subsequent sleep [66, 67]. For example, Drake et al. [66] showed that sleep disturbance may occur when caffeine (400 mg) is taken up to 6 h prior to bedtime with $\approx$1-h objective total sleep time reduction ($p < 0.05$) observed relative to placebo. Conversely, Pontifex et al. [67] showed that a moderate dose of caffeine (6 mg kg^{-1} body mass) ingested in the early evening (5:00–8:00 p.m.) did not significantly affect sleep duration, wake time, number of wake episodes during the night and sleep efficiency during that night. Additionally, caffeine ingestion did not have a negative effect on next-day physical performance assessed between 3:00 and 5:00 p.m., suggesting little effect of caffeine ingestion on the recovery process [67]. However, analysis of pre-bedtime urine samples showed that urinary caffeine concentrations were significantly higher ($p < 0.01$) after the caffeine trial compared with the placebo trial 6 h after caffeine ingestion; and higher urinary caffeine concentrations were associated ($p < 0.01$) with greater sleep disturbances (i.e. wake time and sleep efficiency) [67]. The potential detrimental effects of caffeine on sleep have been reported elsewhere and may be explained by the inhibition of melatonin secretion via caffeine binding to adenosine receptors [68–70]. Future studies are required to assess the potential detrimental effect of caffeine ingested before an evening match on subsequent sleep as caffeine is likely part of a cycle of poor sleep leading to increased caffeine consumption, which in turn promotes impaired sleep [71]. The wide individual variation seen in relation to the effects of caffeine on sleep quality should also be assessed [72].

In a survey conducted on a professional team from the Italian Serie A followed over 5 years, 66 % of the players declared themselves to be regular drinkers of alcoholic beverages [73]. The hours after training or competition are particularly prone to alcohol consumption as a means of socialising [74] which may lead to significant loss in sleep hours [75]. Prentice et al. [75] compared the effects of normal post-game behaviour with recommended behaviour on physical performance in the days after a rugby union game played between 6:30 and 8:00 p.m. Compared with baseline values, large volumes of alcohol ($\approx$20 standard drinks containing 10 g of alcohol; $p < 0.01$) and a loss in sleep (between 1 and 4 h of sleep; $p < 0.001$) was reported by the customary behaviour group in the hours after the game. Conversely, no difference in alcohol consumption or hours slept were reported for the recommended behaviour group compared with their baseline. This study demonstrates that players should be educated on appropriate activities and behaviours after a match. This may prevent the potential associated detrimental effects of alcohol consumption on sleep and recovery [76, 77]. Negative effects on sleep occur already with short-term use of alcohol, despite hypnotic-like effects during the first hours of sleep, especially during the latter part of the night (increased light sleep) [76].

Elite soccer players consume a considerable quantity of medication, with non-steroidal anti-inflammatory drugs the most frequently prescribed medications accounting for almost half of all reported medicines used [78]. During recovery from a soccer match, soccer players are prone to delayed onset muscle soreness [79] that may induce difficulties remaining immobile during sleep and thus impairing sleep quantity and quality [80]. Non-steroidal anti-inflammatory drug consumption may consequently influence overall sleep by mediating exercise-induced muscle soreness. However, this strategy should not be recommended considering the fact that several studies have reported no beneficial effect of non-steroidal anti-inflammatory drugs in alleviating muscle soreness after contraction-induced muscle injury [81, 82]. In elite soccer, substances acting on the upper and lower respiratory tract are also frequently prescribed, with antihistamines being the most common of these [78, 83]. As antihistamines present sleep-promoting properties (e.g. diphenhydramine [84, 85]), future studies are required to analyze the long-term effect of antihistamines on sleep among soccer players.

3.1.5 Napping and Night-Time Sleep

Day-time napping behaviour for team sport athletes was documented by Lastella et al. [29]. Nap frequency (i.e. the percentage of days on which a nap is taken) was 11 % among team sport athletes with a mean duration of 00:59 ± 01:02 h:min, suggesting a high inter-individual variability [29]. The effects of sleep extension and napping on performance have also been described [4]. Anecdotally, it is a common routine for soccer players to nap during the afternoon before a night match. This strategy may be justified by the improvement in alertness and aspects of mental and physical performance observed after a 30-min nap [86] which may favour performance during the night match. Additionally, motor memories are dynamically facilitated across midday naps (66.1 $\pm$ 4.5 min), enhancements that are associated with regionally specific sleep spindles [23]. One should consequently ask if napping may disturb subsequent night sleep, especially among players who are not accustomed to napping during the week. Petit et al. [87] examined the effects of a post-prandial 20-min nap on subsequent sleep in athletes. Post-lunch naps were scheduled at 1:00 p.m. with subjects required to lie on a bed in a darkened room for 1 h. Subjects were awakened by intercom when approximately 20 min of sleep had elapsed. Results showed that the subjects slept for 21–22 min in the hour they stayed in bed with sleep efficiency that approximated 70 %, with predominance in percentages of sleep stages 2 and 3. Furthermore, there was a significant effect ($p < 0.01$) of naps compared with no naps for sleep onset latency in a post-trial night. In the normal sleep condition without napping, the sleep onset latency in a post-trial night was 13.3 $\pm$ 5.5 min and increased significantly after post-lunch naps, reaching higher values (24.3 $\pm$ 11.8 min; $p < 0.01$). Consequently, a daytime nap may be encouraged as a strategy to counteract sleep debt and sleepiness [29]; however, it may induce more difficulties in falling asleep in the subsequent night [87]. Additionally, taking a nap may be associated with less efficient sleep the next night [88]. Future studies are required to confirm these results when nap durations similar to those reported by Lastella et al. [29] are performed during the afternoon before a night match.

3.2 Inconsistency in Match Schedules

Societal demands from media across many time zones require soccer players to perform at various times of the day, which may have consequences for both performance and sleep. Soccer matches are scheduled at different times throughout the day, ranging from midday kick-offs (e.g. English Premier League) to night-time matches under floodlights (e.g. 8:45 p.m. for UEFA Champions League; 10:00 p.m. for Spanish Liga de Fútbol Profesional).

Competition time is a critical factor affecting performance, with late afternoon and early evening the time periods when best performances are most often likely to occur; whereas around midday times are particularly disadvantageous for peak performance [33, 89]. Soccer players perform at an optimum between 4:00 and 8:00 p.m., when not only soccer-specific skills but also measures of physical performance are at their peak [90]. The circadian rhythm of soccer performance can be explained by several factors [33]: (i) external changes in the environment, such as ambient conditions in light and temperature, sense of occasion from media attention and crowd behaviour; (ii) changes related to the sleep–wake cycle, such as mental fatigue due to time awake and physical fatigue due to muscle activity—both decreasing performance—times of training and habitual competition [91] and sleep loss; (iii) internal changes due to the body's internal body clock [33, 90, 92].

Circadian rhythms are endogenous rhythms with a periodicity of approximately 24 h [93]. The suprachiasmatic nucleus is synchronised by various photic and non-photic stimuli, primarily with the environment by the light–dark cycle, and to a lesser degree by other environmental conditions such as social routine, physical exercise and food intake [35, 36, 93]. These external influences—called zeitgebers or 'time-givers'—synchronise the internal circadian rhythm [19, 35]. Circadian rhythm sleep disorders result from a misalignment between the timing of the circadian rhythm and the external environment (e.g. jet lag and shift work) or a dysfunction of the circadian clock or its afferent and efferent pathways (e.g. delayed sleep-phase, advanced sleep-phase, non-24-h, and irregular sleep–wake rhythm disorders) [93]. The most common symptoms of these disorders are difficulties with sleep onset and/or sleep maintenance and excessive sleepiness that are associated with impaired social and occupational functioning [93]. For example, shift workers, on average, report more problems sleeping than any other subset of the general population [19]. As previously discussed, the mismatch between internal and external time regarding environmental conditions related to evening soccer matches and especially bright light exposure tends to promote chronodisruption [35]. Inconsistency in match schedules is a topical issue preventing regular sleep routine [8, 94] and leading to desynchronization among professional soccer players.

Kick-off time is often out of synchrony with the typical time for training during the week leading to the match. This lack of synchrony might affect both performance in competition and internal circadian rhythm synchronization. It has been shown that reduced physical performance due to expression of circadian variation can be partially ameliorated by training at that particular time of day [95]. Consequently, professional soccer players may potentially benefit from training in the night under floodlights in anticipation of playing night soccer matches. Hébert et al. [96] found that following a week of increased daytime bright-light exposure, subjects became less sensitive to nocturnal light (500 lux). There was significantly more melatonin suppression (10–15 %; $p < 0.05$) after the dimlight exposure week compared with after the week of bright-light exposure, resulting in less of an alerting response caused by nocturnal light. Future studies should assess if regularly training in the night under floodlights is an efficient strategy to find sleep more easily after a competitive night soccer match. However, this strategy should not be recommended for the moment due to the likely detrimental impact of bright light on sleep resulting in fatigue during the week prior to the match.

Teams competing in UEFA Champions League are asked to arrive at the place of competition the day before the match [97], resulting in a night spent in a hotel before a game for the away team. The first-night effect is a well-known phenomenon that is thought to result from an individual's lack of adaptation to the unfamiliar environment (usually a sleep laboratory) [98]. The main characteristics of this effect are decreased total sleep time, decreased REM sleep and a lower sleep efficiency index [98]. Future studies are required to assess if a first-night effect may be similarly present during the first night in a hotel. Unusual surroundings and noises in and/or outside a room [99] may be identified as reasons for poor sleep before important competitions or matches among individual and team sport athletes [13, 100]. Finally, Fowler et al. [101] demonstrated, via monitoring players' sleeping patterns while away, that sleep may be affected due to altered schedules compared with home, where players are left to their own practices. Players tend to be in bed earlier on both the day before and the day after a match; and also sleep for longer the day after away compared with home matches [101].

3.3 Inter-Individual Variability of Sleep

Inter-individual variability regarding sleep may have an important influence on the elite athlete population. Leeder et al. [28] reported that elite athletes have considerably larger measures of variability for every sleep variable they investigated (i.e. time in bed, sleep latency, time asleep, time awake, sleep efficiency) compared with controls. Sleep has been shown to be influenced by genetic traits [102, 103]. Pellegrino et al. [103] have showed that mutations of *BHLHE41* (basic helix-loophelix family member e41) gene reduce total sleep time while maintaining non-REM sleep and provide resistance to the effects of sleep loss. But inter-individual variability of sleep may also be culturally determined. Professional soccer players are regularly transferred between countries leading to multicultural squads [104]. It has been shown that a number of socio-demographic and socio-economic variables (e.g. age, educational level, household income) influence sleep [71]. Additionally, each player has a preferred sleep schedule that suits his circadian phase, i.e. a particular chronotype which is the individual's propensity to prefer activity during certain times of day. Differences between individuals regarding chronotype are partly innate, but are also shaped by environmental factors such as habitual training start time [105, 106]. In opposition to the inter-individual variation regarding sleep, the schedule of the squad is unique. As a consequence, players' personal sleeping habits may restrict their sleep duration or quality by conflicting with the demands of the soccer clubs [106]. For example, 'night owls' who prefer to go to bed later and sleep in (e.g. 1:00–9:00 a.m.) and who then have to wake up at 7:00 a.m. to train at 9:00 a.m. will curtail their sleep by several hours per night, missing critical periods of sleep [106]. Sleep curtailment encountered during training days may lead to extended sleep on off days when there are fewer morning requirements. Sleep time difference of more than 1 h between training days and days off—particularly evident among evening chronotypes—is considered a sign of 'social jet lag' [107].

Players may encounter sleep disruption after a match played at night but are still required to attend recovery sessions the following morning. It has been shown that athletes go to bed later and wake later ($p \leq 0.01$) after high-intensity exercise at night than after lower intensity/non-training nights when the next day is a rest day [39]. Some evidence also suggests that sleep volume and quality are restricted by early training start times [31]. One practical application is to avoid scheduling early morning training sessions after an evening soccer match to ensure enough sleep opportunity is provided to the players. Such recommendations may also be useful during increased training loads. The avoidance of scheduling early morning training sessions may prevent disruption in restorative slow wave sleep which is believed to be important during a high training load programme [4, 80, 108]. During training camps and/or away matches, it may also be advised to group together players exhibiting similar chronotype in shared rooms in order to prevent inopportune sleep disturbance. It may also be advised to isolate players with sleep disturbance (e.g. sleep-disordered breathing) to a single room [109]. Finally, future studies may assess if a player's chronotype influences the recovery kinetics following a night soccer match. It may be hypothesised that 'night owls' may exhibit faster recovery kinetics than morning chronotypes in such circumstances.

3.4 Travel

The repetitive nature of the competitive season, often combined with the stress of travel, may push athletes beyond their physiological and psychological limits. The negative effects of long international travel on sleep (i.e. reduced sleep duration and efficiency and greater awakenings duration) have been documented [110]. Players who join their national team for international competition or travelling to pre-season training camps may be exposed to the negative effects of travel across multiple time zones on sleep [9]. However, competing in European domestic leagues or the UEFA Champions League is rarely associated with travelling over different time zones, which might be the case in other countries such as the United States [13]. Consequently, the present section focuses on the effects of travel fatigue encountered during domestic flight on sleep. Travel fatigue is a complex summation of physiologic, psychologic, and environmental factors that accrue during an individual trip, such as prolonged exposure to mild hypoxia and cramped conditions with restricted activity [110, 111]. Several studies have assessed the acute effects of short-haul air travel without crossing time zones (total travel time between 3–5 h) on performance and perceptual measures among team sport players [101, 110, 112]. Globally, results showed that travel has no effect on indicators of performance (i.e. technical and tactical performance during competition; countermovement jump performance; Yo-Yo intermittent recovery test performance) but negatively influences perceptual measures (e.g. reduced alertness, greater stress). It must be noted that travel fatigue could be cumulative and may accrue over the course of a season depending on the distances travelled, frequency of trips, and length of the season [111]. As such, research into the longitudinal effects of short haul air travel is warranted. Research into the effects of travel on performance recovery when more than one game is played per week is also justified.

3.5 Summary

Therefore, soccer players performing at night may be compared to night shift workers that are required to perform at their peak at a time that is incongruent to their circadian rhythm. Although the influence of high-intensity exercise performed during the night on subsequent sleep is still debated, environmental conditions (e.g. bright light in the stadium, light emanated from screens) and behaviours before and after an evening soccer match (e.g. napping, caffeine consumption, alcohol consumption) as well as engagement and arousal induced by the match may potentially affect subsequent sleep. Travel fatigue and inter-player variability in sleep preference are other potential causes of sleep disturbance among professional soccer players. The role of sleep in psychological and physiological restitution is thought to be particularly important and thus the effects of sleep disturbance on post-soccer match fatigue mechanisms and their recovery time course should be elucidated.

4 Sleep Deprivation and Post-Match Fatigue

Much about the function of sleep has been examined via assessing the impact of sleep deprivation [12]. Sleep deprivation has mainly been studied in military or occupational settings rather than ecologically valid sporting environment settings [113]. The effects of sleep loss (sleep restriction and sleep deprivation) on exercise performance, and physiological and cognitive responses to exercise have been extensively reviewed [25]. Some studies have showed that extensive and total sleep deprivation negatively affects physical recovery among team sport athletes [114, 115], which suggests the significance of sleep debt to athletic performance. Such results should be interpreted with caution as sleep deprivation is rarely total after a soccer match. Another issue related to sleep deprivation studies is the inability to blind subjects to the sleep condition (deprivation versus control), which may result in a negative placebo (nocebo) effect on exercise performance and cognitive function [115]. Soccer involves many physically demanding activities including sprinting, changes in running speed, changes of direction, jumps and tackles, as well as technical actions such as dribbling, shooting and passing. These activities lead to a post-match fatigue that is mainly linked to a combination of glycogen depletion, muscle damage and mental fatigue [116]. In the following sections, the effects of sleep deprivation on post-soccer match fatigue mechanisms and their recovery time course are reviewed.

4.1 Glycogen Repletion

The time course of muscle glycogen repletion after a high-level soccer match is between 2 and 3 days [117, 118]. When the schedule is particularly congested (i.e. two matches per week over several weeks), the recovery time allowed between two successive matches is 3–4 days. Consequently, it is relevant to examine the potential detrimental effects of sleep deprivation on muscle glycogen repletion among players. Skein et al. [114] determined the effects of extensive sleep loss (i.e. 30 h of sleep deprivation) on consecutive-day intermittent-sprint performance and muscle glycogen content among team-sport athletes. Muscle glycogen concentration was significantly reduced in all participants after exercise (122 ± 64 mmol kg^{-1} dry weight) compared with before exercise (310 ± 67 mmol kg^{-1} dry weight) during the baseline session ($p = 0.001$). However, results showed that muscle glycogen concentration was slightly lower before exercise on day 2 in the sleep deprived condition (209 ± 60 mmol kg^{-1} dry weight) compared with day 2 in the normal night's sleep (≈ 8 h) condition (274 ± 54 mmol kg^{-1} dry weight, $p = 0.05$). Similar to active recovery, which significantly impairs glycogen synthesis if performed immediately after high-intensity exercise [119], the increased energy expended during extended hours awake may affect the rate of resynthesis of the depleted muscle glycogen after exercise [114]. Again, it is debatable whether the findings are applicable to elite soccer players given it would be rare for a player to endure one or more night(s) of complete sleep deprivation. Future studies are consequently required to confirm these results with exercise eliciting muscle glycogen contents similar to those encountered after a soccer match ($\approx$200 to 250 mmol kg^{-1} dry weight) [118, 120]. To counteract the potential decreased rate of muscle glycogen resynthesis among soccer players exposed to sleep deprivation, a preventative strategy may be to ensure additional carbohydrate is consumed in these circumstances [121].

4.2 Muscle Damage

Muscle damage is likely a major factor to consider in an attempt to explain post-soccer match fatigue [116]. The repetitive changes of direction, accelerations and decelerations throughout a soccer match induce muscle damage leading to a marked inflammatory response and associated upregulated oxidative stress during recovery [116]. Sleep deprivation affects biochemical markers used to detect muscle damage, inflammatory response and oxidative stress [115, 122, 123]. In a sleep-deprived night ($\approx$0 h) condition, Skein et al. [115] reported elevated creatine kinase and C-reactive protein concentrations throughout recovery after a competitive rugby league match compared with control (normal night's sleep, $\approx$8 h). In the morning after a night of sleep deprivation common to those encountered by soccer players (being awake from 11:00 p.m. to 3:00 a.m.), inflammatory responses were enhanced compared with morning levels following uninterrupted sleep [122]. Positive associations ($p < 0.05$) were also found between sleep disturbances and inflammatory cytokines (interleukin [IL]-6, IL-1b, tumour necrosis factor-α) produced during a period of intense training in elite male rowers [123]. The two potential arguments for delayed recovery in a sleep-deprived condition are that sleep deprivation leads to a greater amount of exercise-induced damage and/or there is an impaired rate of repair after an exercise bout. Dattilo et al. [124] proposed that sleep deprivation could lead to reductions in insulin-like growth factor-1 and testosterone concentrations, and increases in glucocorticoid levels (cortisol), thereby promoting protein degradation. This may explain why sleep deprivation induces significant increases in generalised body pain [125]. Sleep deprivation has an effect on the nocturnal secretion of growth hormone, an anabolic hormone produced during slow-wave sleep and essential to muscle repair [18]. As a link exists between the recuperative processes of sleep and the immune system [80, 126], it may be hypothesised that disturbed sleep impairs the rate of repair after night soccer matches. The severity of the muscle damage varies from microinjury of a small number of fibres to disruption of a whole muscle group suggesting a continuum between muscle damage and injury. The consequences of sleep deprivation on injury risk among soccer players should be consequently considered.

4.3 Injury Risk

During periods where the schedule is particularly congested (i.e. two matches per week over several weeks), the recovery time allowed between two successive matches lasts 3–4 days, which may be insufficient to restore homeostasis. Alternating between domestic, continental and international matches during these periods may lead to exhausting travel stress and sleep deprivation. As a result, players may experience acute and chronic fatigue potentially leading to injury. Injury risk is 6.2-fold higher in players who play two matches per week compared with those who played only one match per week [45]. There is an absence of scientific data to date examining the role of sleep deprivation on the risk of acute injury. Luke et al. [127] found that sleeping 6 or fewer hours the night before the injury was associated ($p = 0.028$) with fatigue-related injuries among young athletes participating in basketball, football, soccer and running. Milewski et al. [128] found that hours of sleep per night were a significant independent risk factor for injury. Adolescent athletes (15.2 $\pm$ 1.5 years) who slept on average <8 h per night were 1.7 times ($p = 0.04$) more likely to have had an injury compared with athletes who slept for more than 8 h. However, questionnaires were used to assess sleep duration rather than objective sleep measurements [127, 128]. Additionally, sleep deprivation may result in an increased predisposition to injury due to decreased concentration, alertness and attention, reduced reaction time and response speed, and poor sports-specific skill execution [4, 19, 25]. Temesi et al. [129] reported that mean reaction time is 8 % slower ($p = 0.011$) and cognitive response omission rate is higher ($p < 0.05$) after one night of complete sleep deprivation than in the control condition ($\approx$8 h). The percentage decline in incongruent word–colour reaction times during a cognitive-function test is also increased ($p = 0.007$) after a post-match sleep-deprived night ($\approx$0 h) among rugby league players [115]. The duration and severity of sleep inertia and associated decreased cognitive performance depend on the preceding sleep duration, the presence of prior sleep deprivation and individual chronotype [56]. As submaximal exercise restores information processing efficiency to baseline levels following sleep deprivation [129], soccer players experiencing sleep deprivation may particularly benefit from a sufficient warm-up in these circumstances. The availability of evidence suggests that post-match sleep deprivation may result in altered cognitive functioning the following morning, which may affect attention and decision-making skills during ensuing training sessions, potentially resulting in an increase in injury risk.

4.4 Mental Fatigue

Participating in a soccer match leads to acute mental fatigue due to the need for sustained concentration, perceptual skills and decision making combined with opponent pressure during the match [116]. Sleep is important for the brain [17], and it may be particularly critical to recover from mental fatigue induced by a soccer match. An increase in psychological fatigue following sleep restriction would appear to create a neurocognitive state not conducive to either engaging in physical activity requiring a high motivational component or employing optimal decision making [25]. Theories on the reasons for this restricted exercise tolerance following sleep restriction may be attributed to perceptual changes (i.e. increased perceived exertion) [25]. Accordingly, the majority of adverse effects induced by sleep deprivation are identified in the motivational variables relating to performance, which may explain why submaximal prolonged physical performance is more affected than singular, maximal performance by sleep deprivation [4, 25, 129, 130]. Very little is known about the recovery kinetics of soccer match-induced mental fatigue, and future studies are required to determine if acute mental fatigue induced by a soccer match may lead to chronic fatigue as a result of a congested schedule, travel and sleep deprivation. Overtraining syndrome, which is caused by high levels of physiological, psychological and/or social stress in combination with too little regeneration [7], shows marked similarities with chronic fatigue and major depression [131]. Symptoms that these syndromes have in common are mainly neuropsychological symptoms such as inability to concentrate, depression, disturbed mood states, irritability, difficulty thinking, impaired mental and physical performance but also sleep disturbances [131]. Future studies on the relationship between these syndromes are required to identify the initiating factors as well as the factors that influence the symptoms.

4.5 Summary

Sleep disturbance among professional soccer players may be detrimental to the post-match recovery time course. Sleep deprivation may potentially inhibit muscle glycogen resynthesis, increase soccer match-induced muscle damage and/or impair the rate of muscle damage repair, alter adequate cognitive function potentially resulting in injury risk increase, and increase acute mental fatigue potentially leading to persistent fatigue.

5 Conclusion

From the limited scientific information regarding sleep requirements and characteristics in elite athletes, it appears that sleep quantity and quality may be poorer than in controls [28] and may be worsened in the nights after night matches. For professional soccer players, sleep deprivation may be the result of the constraints of elite soccer which are prone to chronodisruption. Regularly playing soccer matches after 8:00 p.m. and the associated exposure to bright light, the consumption of caffeine and/or alcohol, and travel fatigue may present interactive and cumulative detrimental effects on sleep throughout the season. Additionally, the inconsistency currently observed in match schedules as well as inter-player variability in sleep requirements may lead to irregular sleep routines and desynchronization. Sleep deprivation may be detrimental to the recovery processes after a match, that is, impaired muscle glycogen repletion, impaired muscle damage repair, altered cognitive function and an increase in mental fatigue. Consequently, prolonged sleep deprivation may act as an additional stress to the stress imposed by exercise itself, similar to that of altitude or heat [132] or training in conditions of reduced carbohydrate availability [133]. Efficient and individualised sleep hygiene strategies that are tailored to the constraints of elite soccer are needed to limit stressors and enhance the psychological and physiological sleep functions that are considered critical to optimal recovery.

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