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SLEEP AND ATHLETIC PERFORMANCE (M GRANDNER, SECTION EDITOR)

Sleep and Nutrition in Athletes

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Abstract

Purpose of Review Whilst it is known that athletes are particularly vulnerable to sleep difficulties due to high training and competition demands, the relationship between sleep and nutrition in this population is less clear.

Recent Findings Nutrition is becoming an area of increased interest in relation to athlete sleep and recovery. The adaptive response to training is dictated by a number of variables: duration, intensity, frequency and type of exercise in combination with nutrition both pre- and post-exercise. Training adaptations and recovery including sleep can be optimised by appropriate nutrition practises. There are numerous nutrients that show promise in relation to the promotion of sleep and athlete recovery which are discussed in this article.

Summary Whilst the number of studies investigating the effect of nutritional interventions on sleep in athletes is increasing, more research is necessary in elite athletic populations.

Keywords Athletes · Sleep · Nutrition · Recovery

Introduction

The potential role of nutrition and sleep in athlete recovery has recently become a key area of research focus. The concept that nutritional interventions may improve athlete sleep and recovery, via mechanisms such as improving hormonal status, muscle protein synthesis and/or muscle glycogen stores, has stimulated increased research in this area. Whilst evolving the research in this domain is in its infancy and further research is necessary to develop nutrition guidelines, products, protocols and tailored interventions for athletes are designed to enhance sleep and/or recovery. The current review is aimed at summarising the existing body of knowledge and understanding of the interaction of sleep, nutrition and recovery with a specific focus on sleep promotion. Further research is warranted to assess the impact of each of the nutrients discussed in this review, on the sleep and recovery of athletic populations incorporating polysomnography and dietary standardisation.

This article is part of the Topical collection on *Sleep and Athletic Performance*

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Sleep and Athletes

It is clear from the current literature that sleep inadequacy has been reportedly high amongst elite athlete populations due to both sport-specific factors (i.e. training, injury, travel and competition), athlete-specific factors (i.e. individual versus team sport and endurance versus power athletes) and lifestyle/social factors (i.e. habitual caffeine use, technology and social media use in an 'always connected' society) [1••]. Moreover, research has highlighted athlete specific factors for sleep inadequacy such as high training loads, short and long-haul travel, evening competition (after 6:00 pm) and training-related early morning start times (before 8:00am). Inadequate sleep may have a negative impact on athlete sleep and performance; particularly, it is likely that athletes may have greater physical and mental recovery needs than the general population [1••]. When sleep is reduced to < 7 h of cognitive performance, physical performance and injury risk are adversely affected [2••, 3, 4]. Adequate sleep, including afternoon naps [5, 6], can counteract the negative performance [7•], cognitive [8], immunity [9], oxidative stress [10] and pain outcomes [11] that may be a consequences of inadequate sleep. Whilst sleep is a vital part of the athlete lifestyle, it has consistently been reported that athletes' sleep is inadequate [2••, 3, 4, 12, 13•]. The repetitive demanding nature of an annual training and competition cycle can test athletes' physiological and psychological capacity. Training, competition, work, education, nutrition and other lifestyle factors and exposure to technology (i.e. blue light exposure)can have a detrimental impact on athletes' ability to match their circadian phase with the opportunity for sleep. If the circadian phase and sleep schedule are not matched, the duration and quality of sleep can be negatively affected [6], which can negatively impact training adaptations, increase the risk of maladaptation and reduce subsequent performance. Athletes must maintain a balance between stress and recovery and adopt modalities that manage fatigue and enhance recovery [14]. The additional benefits of good sleep for athletes include a reduced risk of overtraining/under recovery and reduced injury risk [14–18]. Unless an athlete recovers efficiently their subsequent training, workload and ultimately performance will suffer [19]. If the athlete does not recover properly, fatigue accumulates resulting in maladaptation and reduced performance; if this is not addressed, the athlete can develop non-functional over-reaching or unexplained underperformance syndrome in the short term and ultimately over-training syndrome in the longer term [20, 21].

Chrononutrition (i.e. the relationship between food intake and the circadian clock system) is becoming an area of increased interest in relation athlete performance and recovery [22•, 23•]. The adaptive response to training is dictated by a number of variables: duration, intensity, frequency and type of exercise in combination with nutrition both pre- and post-exercise [24]. Training adaptations can be maximised by optimal nutrition practises or reduced by suboptimal nutrition practises. Contemporary research has demonstrated the pivotal role of both macronutrient and micronutrient availabilities in regulating skeletal muscle adaptations to exercise [24–26]. Nutrition support must be periodised in relation to the demands of the athlete's daily training load and overall nutrition goals [26]. Researchers and practitioners now consider 'Competition Nutrition', which is performance focused, and 'Training Nutrition', which is adaptation focused, as two separate entities [26]. There are numerous other effects of nutrition and interactions between nutrition and exercise that ultimately determine exercise performance and/or recovery that warrant further investigation. Whilst it is known that athletes are particularly vulnerable to sleep difficulties due to high training and competition demands [1••], the relationship between sleep and nutrition in this population is less clear which have been summarised in this article (see Table 1).

Table 1 Practical application of nutrition in relation to sleep in athletes

Food/nutrient	Potential benefit
Tryptophan	↓ SOL
Tart cherries	Sleep: ↑ TST, TIB & SE ↓ daytime sleepiness Recovery: ↓ muscle soreness & ↓ inflammatory response (may be useful during periods of short recovery e.g. multi-heat events
Nitrate	↑ Subjective sleep quality & ↓ global PSQI score
Kiwifruit	↑ Subjective sleep quality
Warrants further investigation	
Antioxidants	The specific antioxidant ingested, dose and timing of ingestion all affect outcomes Food-based interventions warrant investigation in relation to sleep promotion and recovery in athletic populations
Kiwifruit	Kiwifruit consumption to promote sleep and recovery in athletes Kiwifruit products/supplements in relation to athlete sleep/recovery
Protein supplementation	Effect of 40 g dose < 60 min pre-sleep on sleep and recovery Effect of casein ingestion pre sleep on sleep
Magnesium	Potential sleep promotion effects > 12 weeks of follow-up if necessary Research warranted in athletic populations
Tryptophan-rich protein	Consumption of whole food sources and their impact on athlete sleep and recovery (e.g. meals containing combinations of tryptophan rich protein)
Probiotics	The impact of supplementation/different strains on sleep in athletes
Nitrate	The impact of nitrate ingestion on the sleep and recovery of athletes

Antioxidants

Antioxidants significantly delay or prevent oxidative damage of a target molecule [27]. Cells contain an endogenous antioxidant system composed of enzymatic and non-enzymatic antioxidants. It is well established that exercise results in increased free-radical production in skeletal muscle [28]. Research indicates that exercise-induced free-radical production results in oxidative damage to cells and plays a role in muscular fatigue during prolonged exercise [29]. Due to the fact that exercising muscles produces free radicals, many athletes choose to consume antioxidant supplements in an attempt to reduce exercise induced free-radical damage and/or muscle fatigue. The antioxidant capacity of several dietary micronutrients is an emerging area of interest to support the endogenous antioxidant defence system of athletes and attenuate the negative effects of oxidative damage due to free radicals. Supplemental antioxidants such as Vitamin E, Vitamin C, carotenoids, coenzyme Q10 and anthocyanidins are commonly consumed by athletes in an attempt to reduce oxidative stress (OS), following training. Optimal nutrition, hydration and rest are the most effective strategies for recovery in athletes [30].

It must be noted that antioxidants are heterogeneous; they function in a distinct manner and do not solely regulate reactive oxygen species (ROS) [31]. It is important to consider that consumption of an antioxidant does not guarantee that the compound will act as an antioxidant within the body, therefore positive findings from one antioxidant or combination of antioxidants cannot be generalised [32]. It has been suggested that a high intake of antioxidants could potentially reduce training adaptations [26]. Further, it is accepted that repeated exercise bouts (i.e. training) induce disruption in skeletal muscle homeostasis that regulate training adaptations [33, 34]. It has been reported that high doses of antioxidants could reduce training adaptations of muscle mitochondrial biogenesis [33]. However, not all antioxidant studies have demonstrated negative effects, and it has been suggested that the specific antioxidant used, the dose and timing of ingestion all affect outcomes [35].

Further research is necessary to develop practical guidelines for antioxidant supplementation to enhance training adaptation and/or post exercise recovery and to specifically investigate if antioxidants could be used to promote sleep in athletes. It must be noted that the majority of research investigating the effects of antioxidant supplementation to date has employed high doses. Given the adoption of a 'food first' approach by many athletes [26], there is scope for investigation of food based interventions designed to promote athlete recovery and/or enhance sleep health.

Tryptophan-Rich Protein

Tryptophan is an essential amino acid that is a precursor to serotonin and melatonin and has the ability to cross the blood–brain barrier by competing for transport with other large neutral amino acids (LNAA) [18]. The milk protein, α-lactalbumin, has been reported as having the highest natural levels of tryptophan amongst all protein food sources [36]. Ingestion of α-lactalbumin has been shown to increase tryptophan:LNAA in healthy populations by 48% [37] and 130% [38]. Dietary sources of tryptophan include milk, turkey, chicken, fish, eggs, pumpkin seeds, beans, peanuts, cheese and leafy green vegetables [23•]. A significant positive effect of tryptophan (doses $\leq$ 1 g) on sleep, particularly sleep onset latency (SOL), has been observed, but it has been noted that doses $\leq$ 5 g do not appear to affect sleep stages [39]. Further, tryptophan may have minimal effects on sleep in healthy adults who fall asleep easily. Dietary tryptophan has been shown to improve sleep, in a comparison of tryptophan-enriched muesli bars (de-oiled gourd seed: 22 mg/1 g protein) plus glucose with bars containing 250 mg pharmaceutical tryptophan plus glucose and glucose alone [40]. The muesli bars and the pharmaceutical dose produced similar results (5.5% and 6.5% respectively) in terms of reductions in time awake during the night (40), indicating that relatively small doses (250 mg) of dietary tryptophan can positively impact sleep. However, high levels of pharmaceutical tryptophan have been associated with eosinophilia myalgia syndrome (EMS), a serious medical condition which can be fatal [40]. Tryptophan depletion studies have demonstrated decreased tryptophan plasma concentrations affected sleep fragmentation (arousal index [events/h]), REM sleep latency (the interval between first epoch of N2 and the first epoch of REM sleep) and REM density (the cumulated duration of each REM burst divided by the duration of each REM sleep period) compared to baseline and placebo [41, 42]; it must be noted that these studies did not utilise athletic populations.

Athletes routinely consume protein as part of their recovery after training and competition, either in supplement form or as part of a meal. There have been promising findings in terms of protein ingestion, incorporating tryptophan, which warrant replication in elite athlete population [43]. Whilst research is emerging supporting pre-sleep protein ingestion (20–40 g doses) for muscle recovery [44, 45], a dose response has been suggested whereby 40 g doses are necessary to increase muscle protein synthesis [44]. The impact of pre-sleep ingestion of 40 g doses of whey and/or casein warrants further investigation with regards to both muscle recovery and sleep improvement in athletic populations.

Tart Cherry

Tart cherries contain high concentrations of melatonin [46]. Significantly reduced insomnia severity index scores (13.2 ± 2.8 versus control 14.9 ± 3.6; $p < 0.05$) and wake after sleep onset (WASO) time (62.1 ± 37.4 min versus control 79.1 ± 38.6; $p < 0.01$) have been observed in older adults following consumption of a tart cherry Juice blend, compared to a placebo [46]. Further, research has investigated whether melatonin is the mechanism of action with respect to tart cherry juice (2 × servings of 30mls concentrate) on sleep enhancement and improved sleep time and quality [47]. Total melatonin content was significantly elevated and significant increases in time in bed (+ 24 min), total sleep time (+ 34 min) and sleep efficiency total (82.3%) and a significant reduction in daytime napping (− 22%) ($p < 0.05$) were associated with cherry juice supplementation [47]. Although no difference was observed in timing of the Circadian Rhythm, there was a trend to a higher mesor and amplitude. The range of phenolic compounds in cherries which have anti-inflammatory and antioxidant properties may enhance post exercise recovery as well as sleep [48].

It has been proposed that melatonin may be synthesised in mitochondria [49], making melatonin and its metabolites available to protect the muscle against OS. Melatonin also increases the protective effects of Glutathione, Vitamin C and Trolox, through regeneration by electron transfer processes [50]. A placebo controlled double blind study on older adults demonstrated a food-based supplement containing 5 mg Melatonin, 225 mg Magnesium and 11.25 mg zinc significantly ($p < 0.05$) improved subjective measures of sleep and total sleep time, as assessed via actigraphy [51]. The effects were attributed to the crucial roles both magnesium and Zinc have in endogenous melatonin production [51]. Indeed, there is evidence that tart cherry juice supplementation post-exercise reduces muscle soreness [52]; however, it is unclear if this as a result of a direct scavenging effect [34]. Recent research has demonstrated tart cherry juice supplementation (30mls, twice per day for 7 days) reduced the post-exercise decline in functional performance following intermittent sprint activity (maximal voluntary isometric contractions, 20 m sprint, counter movement jump and 505 agility test), delayed onset muscle soreness (DOMS) and reduced inflammatory response (Il-6) [53]. As regards the reduction in post-exercise inflammatory response, in practise, the researchers suggested that this might be beneficial during periods of high volume training e.g. (pre-season) or where athletes are required to produce multiple performances in a short space of time (e.g. double training sessions), when recovery periods are short [53]. It has recently been demonstrated that 14% of athletes who reported either currently or previously using tart cherry juice self-reported improved subjective sleep quality [54].

Nitrate

The effect of nitrate (100 mL of beetroot juice ≈ 300 mg nitrate) consumption on sleep has recently been observed in male athletes ($n = 30$), with subjective sleep quality improving significantly following nitrate consumption and mean PSQI global scores reducing from 14.5 to 5.8 [55]. However, it must be noted that this study lacked clarity regarding athlete type, training load, timing of nitrate ingestion and any dietary restrictions placed on participants.

Micronutrients and Probiotics

Whilst vegetables and wholegrains are often suggested to improve sleep due to their B3-B6-B12 vitamin and magnesium content [56], this has not been investigated in athletes. Vitamin B12 is involved in melatonin secretion, Vitamin B6 contributes to the synthesis of serotonin from tryptophan and niacin (Vitamin B3) may produce a tryptophan sparing effect [57]. Mixed effects have been observed, with different doses of Vitamin B12 on sleep–wake rhythm and delayed sleep phase syndrome in healthy adults, whilst no effect was observed for sleep duration [57]. Niacin has been shown to increase REM sleep in healthy adults and improved sleep efficiency in participants with moderate to severe insomnia [57]. Niacin is synthesised from dietary tryptophan via the kynurenine pathway [57]. It has been suggested that administration of niacin causes an increase in nicotinamide adenine dinucleotide, which may reduce tryptophan conversion to niacin, increasing tryptophan availability for the synthesis of serotonin and melatonin [57].

The impact of magnesium on the sleep of athletes warrants investigation as it is believed to enhance melatonin secretion and act as a GABA agonist, the main inhibitory neurotransmitter that acts on the CNS [57]. It has been noted that deficiencies in B Vitamins and magnesium may also disrupt sleep [57]. It has recently been suggested that in order to investigate the true relationship between magnesium and sleep, well-designed randomised control trials with follow-up (> 12 weeks) are required [58]; such research should be replicated in athlete populations.

Probiotics have recently received attention in relation to sleep in athletes; two randomised control trials (RCTs) have investigated the impact of probiotics on sleep outcomes in soccer ($n = 27$) over 30 days [59] and rugby union ($n = 19$) over 119 days [60]. In soccer players, probiotic consumption was shown to improve actigraphy derived sleep efficiency (87.46 ± 6.09 to 90.8 ± 3.17) and sleep onset latency (1.38 ± 0.97 to 0.88 ± 0.74) [59]. Whilst probiotic supplementation has been shown to improve subjective sleep quality in rugby players due to increased sleep duration and reduced muscle soreness [60]. These findings warrant further investigation of the potential role of probiotics in athlete sleep promotion and recovery.

Phenolic Compounds

Whilst phenolic compounds (e.g. flavonoids, phenolic acids, stilbenes and phytoestrogens) have been widely investigated in relation to antioxidant capacity and their ability to protect against OS and impact on athlete recovery [50, 61]; future research is warranted in relation to sleep promotion (e.g. anthocyanins and resveratrol). Phenolic compounds scavenge free radicals by hydrogen atom transfer [62], proton coupled electron transfer [63] and sequential proton loss electron transfer [64]. Phenolic compounds are frequently consumed in the human diet as they are abundant in a wide variety of foods and beverages e.g. fruit, vegetables, wine, coffee and tea [65]. However, research has highlighted poor bioavailability, in an investigation involving an average intake of 10–100 mg of phenolic compounds, plasma concentrations rarely exceeded 1 mM [66].

Kiwifruit

Contemporary research has focused on the health benefits of Kiwifruit particularly in relation to antioxidant capacity, digestion, iron nutrition, metabolic health and immune function [67]. Kiwifruit not only contain significant amounts of Vitamin C but also contain a range of other health-promoting nutrients such as Vitamin E, vitamin K, vitamin C, folate, beta-carotene, lutein, potassium, copper and fibre [68–70]. Kiwifruit contain a range of nutrients that may benefit an athletes sleep and recovery including serotonin, vitamin C, vitamin E, folate, anthocyanidins and carotenoids [71]. Folates are destroyed by cooking or processing; however, kiwifruit are consumed raw and contain 0.23 ± 0.04 μg/g of total folate, 80% higher than carrot juice and 15% higher than orange juice [72], and it has been estimated that a Kiwifruit contains 10% of the average daily requirement [73]. Kiwifruit also contain lutein, zeaxanthin and a range of phytochemicals with antioxidant properties [74]. The serotonin content in Kiwifruit may also contribute to improved sleep whilst the rich antioxidant content may supress free radical expression and inflammatory cytokines. Folate deficiency has been linked to insomnia and restless leg syndrome. As such, the folate in Kiwifruit may improve overall folate status and consequently improve sleep [71].

A study involving healthy adult volunteers ($n = 25$) who self-reported a sleep disturbance demonstrated consumption of 2 Kiwifruit, 1 h before bedtime over 4 weeks significantly improved actigraphy measured total sleep time (361.8 ± 14.9 to 416.6 ± 16.2) and sleep efficiency (93.9 ± 1.03 to 95.9 ± 0.67) ($p = 0.005$) [71]. Self-report measures also improved significantly, with wake time after sleep onset reduced (18.9 ± 4.31 to 12.8 ± 3.49; $p = 0.002$), sleep latency reduced (34.3 ± 3.86 to 20.4 ± 3.53; $p < 0.001$) and increases in sleep efficiency (86.9 ± 1.94 to 91.2 ± 1.53; $p = 0.001$) ($p < 0.002$) (71). In a similar study, students ($n = 74$) with insomnia (defined using the Bergen Insomnia scale) consumed either 130 g of Kiwifruit or a placebo (130 g pear), 1 h before bed for 4 weeks, and sleep was assessed by both actigraphy and sleep diaries. Whilst there were no statistically significant differences in objective measures of sleep, there were statistically significant group × time effects for subjective sleep quality (2.9 ± 0.4 to 3.4 ± 0.4, $F_{1,51} = 5.88$) and daytime function (2.4 ± 0.5 to 3.0 ± 0.6, $F_{1,51} = 4.79$) [75]. Whilst no research has been conducted in athletic populations, these promising findings warrant further investigation in relation to Kiwifruit consumption and potential interactions with the sleep and recovery of athletes.

Conclusion

Antioxidants are commonly consumed by athletes in an attempt to reduce OS, following training. Further research is necessary to develop practical guidelines for antioxidant supplementation to enhance training adaptation, sleep and recovery. It must be noted that the majority of research investigating the effects of antioxidant supplementation to date has employed high doses, which may have drawbacks. Given the adoption of a 'food first' approach by many athletes, there is a scope for the investigation of 'functional food' (e.g. kiwifruit, beetroot, whey and casein)-based interventions designed to promote athlete recovery and/or enhance sleep quality and quantity. Research is necessary to investigate the potential role of Kiwifruit in reducing OS, improving recovery and promoting sleep. Further research is also necessary to investigate if the quality, quantity and timing of sleep can be manipulated to promote the uptake of supplementations designed to reduce OS, following training. Ideally, this research will lead to the development of nutritional interventions for optimising sleep quality, sleep quantity and enhancing post-exercise recovery. Whilst the number of studies investigating the effect of nutritional interventions on sleep in athletes is increasing [6, 9, 15; 18, 57], more research is necessary in elite athletic populations.

Declarations

Ethics Approval All reported studies/experiments with human or animal subjects performed by the authors have been previously published and complied with all applicable ethical standards (including the Helsinki declaration and its amendments, institutional/national research committee standards, and international/national/institutional guidelines).

Competing Interests The authors declare no competing interests.

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•• Of major importance

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