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Symposium Two: Chrono-nutrition for health

Review Article

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Sleep and nutrition for athletes. The Nutrition Society, Scottish Section Conference 2024

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Abstract

Sleep is vital for the maintenance of physical and mental health, recovery and performance in athletes. Sleep also has a restorative effect on the immune system and the endocrine system. Sleep must be of adequate duration, timing and quality to promote recovery following training and competition. Inadequate sleep adversely impacts carbohydrate metabolism, appetite, energy intake and protein synthesis affecting recovery from the energy demands of daily living and training/competition related fatigue. Sleep's role in overall health and well-being has been established. Athletes have high sleep needs and are particularly vulnerable to sleep difficulties due to high training and competition demands, as such the implementation of the potential nutritional interventions to improve sleep duration and quality is commonplace. The use of certain nutrition strategies and supplements has an evidence base i.e. carbohydrate, caffeine, creatine, kiwifruit, magnesium, meal make-up and timing, protein and tart cherry. However, further research involving both foods and supplements is necessary to clarify the interactions between nutrition and the circadian system as there is potential to improve sleep and recovery. Additional research is necessary to clarify guidelines and develop products and protocols for foods and supplements to benefit athlete health, performance and/or recovery. The purpose of this review is to highlight the potential interaction between sleep and nutrition for athletes and how these interactions might benefit sleep and/or recovery.

Sleep is vital to maintain physical and mental health, recovery and performance in athletes. Sleep also has a restorative effect on the immune system and the endocrine system. Sleep requirements differ across the lifespan but for sleep to have a restorative effect on the body, it must be of adequate duration, timing and quality. Good sleep is characterised by satisfaction, appropriate timing, adequate duration, high efficiency and alertness during waking hours. Sleep disturbance and sleep deprivation can have negative health consequences, and both are implicated in inflammatory disease and all-cause mortality(1). In terms of athletes, sleep deprivation adversely impacts carbohydrate metabolism, appetite, energy intake and protein synthesis affecting recovery from the energy demands of daily living and training/competition related fatigue. Sleep's role in overall health and wellbeing has been established. However, the relationship between sleep and nutrition in specific populations (i.e. athletes) warrants further investigation.

Chrononutrition and athletes

Given the adoption of a 'food first' (i.e. consuming whole foods where possible as opposed to supplements) approach by many athletes, there is scope for investigation of 'functional foods' based interventions designed to promote athlete recovery and/or enhance sleep quality, sleep quantity and recovery. The adaptive response to training is dictated by a number of variables: duration, intensity, frequency and type of exercise in combination with timing, quality and quantity of nutrition(2). Nutrition support must be periodised in relation to the demands of the athlete's daily training load and overall nutrition goals(3).

Chrononutrition refers to the relationship between food intake and the circadian clock system(1). The circadian system responds to external and internal signals because the oscillation period is not precisely 24 hours(1). Circadian rhythms are generated by the suprachiasmatic nuclei (SCN) located in the hypothalamus(4). The SCN, a pair of nuclei located above the optic chiasm at the base of the third ventricle(5), are the 'master clock' of the mammalian circadian system(6). The SCN receive environmental cues such as the light-dark cycle and additional information from other areas of the brain (e.g. when we eat or exercise). Nutrients such as glucose, amino acids, sodium, ethanol and caffeine, as well as the timing of meals can affect circadian rhythms(7).

Chrononutrition has been defined as including two aspects:

1. Timing of food intake or contributions of food components to the maintenance of health.
2. Timing of food intake or contributions of food components to alter or reset the human system of internal clocks[1].

Neurotransmitters such as serotonin, gamma-aminobutyric acid (GABA), orexin, melanin-concentrating hormone, cholinergic, galanin, noreadrenaline and histamine are involved in the sleep-wake cycle[8], nutritional interventions that act upon these neurotransmitters may influence sleep and vice versa. Dietary precursors can influence the rate of synthesis and function of neurotransmitters e.g. serotonin synthesis is dependent on the availability of its precursor tryptophan in the brain[9]. Tryptophan is transported across the blood brain barrier by a system that shares transporters with a number of large neutral amino acids (LNAA) e.g. leucine, histidine, methionine and valine. The ratio of tryptophan:LNAA in the blood is vital to the transport of tryptophan into the brain and can be increased by consumption of either tryptophan or tryptophan-rich protein[10]. In terms of general health further research involving both foods and supplements is necessary to clarify the interactions between nutrition and the circadian system as there is potential to reduce the prevalence and burden of chronic diseases, through the promotion of sleep health. In terms of athletes, further research is necessary to clarify what foods and supplements can be used to benefit health, performance and/or recovery. The purpose of this review is to highlight the potential interaction between sleep and nutrition for athletes and how these interactions might benefit sleep and/or recovery.

Sleep and athletes

The repetitive and 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 their sleep opportunity (i.e. the time available for sleep). A variety of metabolic and/or neural factors of central (brain) or peripheral (muscle) origin contribute to fatigue. Peripheral alterations in skeletal muscle, cardiovascular function and metabolic strain are linked to acute fatigue[11] and investigation of the CNS contribution to acute fatigue is an emerging field of research[12]. Athletic performance induces physiological disturbance but also causes psychological stress due to the need for sustained periods of concentration, perception, skill and decision making. During field-based team sports, the athletes' environment is in a constant state of flux and players must synthesise information regarding in-game scenarios, teammates and opponents before choosing an appropriate action based upon set objectives (e.g. strategy, tactics) and action constraints (e.g. technique, physical capacity)[13]. Such cognitively demanding tasks often lead to mental fatigue, adversely impacting performance.

If the circadian phase and sleep schedule are not matched, the duration and quality of sleep can be negatively affected[14], which can negatively impact training adaptations, increase the risk of maladaption and reduce subsequent performance. Athletes must maintain a balance between stress and recovery and adopt recovery modalities that manage fatigue and enhance recovery[15]. In terms of general health, optimising sleep prevents and/or reduces the risk of illness and benefits energy levels, mood state and cognition, improves immunity and the recovery from illness[16]. Additional benefits for athletes include a reduced risk of overtraining/under recovery and reduced injury risk[9,15,17–19]. Similar to inadequate nutrition and physical activity, sleep disturbances and long or short sleep durations are behavioural risk factors for inflammation[20]. For sleep to be truly restorative it must be of adequate duration, of sufficient quality and be well timed[17]. This is especially true for elite athletes with typically high training loads and competition demands may have greater physical and mental recovery needs than the general population.

Sleep and recovery

Sleep requirement or sleep need is defined as the optimum amount of sleep required to remain alert and function throughout the day[21]. The National Sleep Foundation has produced guidelines regarding sleep duration recommendations[22]. Sleep needs change over the lifespan from adolescents (recommended 8–10 h), to adults (recommended 7–9 h) and older adults (7–8 h)[22], however due to the nature of training and competition athletes may require more sleep. A recent study in elite athletes (n = 175) included a self-report assessment of sleep need, athletes reported an average sleep need of 8.3 ± 0.9 h[23]. The length of sleep depends on number of factors, not least volitional control (e.g. staying up late, waking by alarm, socialising, etc.), which can make it difficult to characterise a 'normal' sleep pattern due to high individual variation[24]. Sleep length is also dictated by genetic determinants[25]. The relationship between sleep and recovery can be viewed in terms of three key factors that affect the recuperative outcome:

1. Sleep duration (total sleep requirement; hours/night, plus naps)
2. Sleep quality (sleep disorders, environmental disturbance or sleep fragmentation)
3. Sleep phase (circadian timing of sleep)[17]

Muscle fatigue or soreness may adversely affect sleep, with inflammatory cytokines linked to disruption of normal sleep[26,27], while poor sleep increases muscle soreness[28]. Inadequate recovery can reduce autonomic nervous system (ANS) resources, with an associated reduction in heart rate variability (HRV) and increased heart rate[29]. HRV responds to changes in training load and is negatively affected by total sleep deprivation[30], following adequate recovery, HRV values increase due to a slower heart rate and reduced ANS excitability.

Athletes may experience significant problems sleeping due to lack of an appropriate sleep routine relating to changing training schedules, timetables and other sleep-incompatible behaviours, e.g. late night blue light exposure[31]. For athletes, post competition routines and heightened arousal (i.e. medical care, recovery strategies, meals, media commitments and travel) can lead to later bedtimes, which can adversely affect sleep quality and quantity. Reduced sleep is associated with increased catabolic and reduced anabolic hormones which results in impaired muscle protein synthesis[32], blunting training adaptations and recovery. Extensive sleep loss (≥30 h sleep deprivation) has been associated with a reduction in muscle glycogen content[33].

Sleep was reported as the most important recovery modality utilised by South African athletes (n = 890; International n = 183, National n = 474, Club n = 233) [15]. While Erlacher et al.[34], found that 66% (n = 416) of elite German athletes (n = 632) reported pre-competition sleep problems including difficulty

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falling asleep, waking during the night and early final waking times. Similarly, modest sleep loss has been associated with reduced psychomotor performance in adults as demonstrated by increased psychomotor vigilance task lapse totals[35].

Sleep patterns have been shown to influence athletic performance while athletic performance has also been shown to impact sleep patterns. Following a single night of sleep restriction (5 h), mean tennis serve accuracy declined significantly from baseline 53% to 37%[36]. Tuomiletho et al.[31], investigated the sleep patterns of professional male ice hockey players (n = 23) using polysomnography (PSG) and found than mean total sleep time (415 mins) was inadequate. Sleep duration (<8 h) has been identified as the strongest predictor of injury in adolescent athletes)[19]. The Karalinska Athlete Screening Injury Prevention (KASIP) study investigated injury occurrence in Swedish adolescent elite athletes (n = 340; 178 males and 162 females) and demonstrated that athletes reaching the National Sleep Foundation[37] sleep guidelines (>8 h) reduced injury risk by 61%) while athletes who consumed the recommended nutrition guidelines reduced injury risk by 64%)[18]. These findings illustrate the interactions between sleep and athlete recovery. Sleep extension (>10 h per night for 2 weeks) demonstrated improved sprint time (16.2 vs 15.5 sec), free throw shooting accuracy (7.9 vs 8.8), 3-point shooting accuracy (10.2 vs 11.6), mean reaction time (psychomotor vigilance task 310.84 ± 77.13 vs 274.51 ± 42.01ms) in collegiate Basketball players (n = 11)[38]. Profile of mood states (POMS) scores indicated physical (7.8 vs 8.8) and mental (6.9 vs 8.8) wellbeing in training and games also improved following the period of sleep extension[38], however, the absence of a control group must be noted as it is a limitation of this study. More research is necessary to investigate the sleep of athletes and potential interventions to improve overall sleep quality and quantity.

Sleep and nutrition

Sleep is essential to recover from the mental and physical demands of training and competition, and athletes have reported sleep as their most important recovery modality[15]. Unless an athlete can recover quickly, their subsequent training, workload and ultimately performance will suffer[39]. If the athlete does not recover, fatigue accumulates resulting in maladaption and reduced performance, which can develop into non-functional over-reaching or unexplained underperformance syndrome in the short term and ultimately over-training syndrome in the longer term[40,41]. Elite athletes have high sleep needs and are particularly vulnerable to sleep difficulties due to high training and competition demands[42]; as such investigation of the potential nutritional interventions to improve sleep duration and quality are warranted[43].

Caffeine

Caffeine increases the state of alertness, antagonising adenosine receptors, which also leads to a reduction in the inclination to sleep[3,44]. Caffeine consumption can lead to poor sleep which, in turn, can lead to increased caffeine consumption[45].

It has been suggested that caffeine use is commonplace in athletic populations; 75–90% of athletes consume caffeine before or during competition[45–47]. In endurance athletes (n = 234) higher levels of consumption of caffeinated beverages has been linked to poorer subjective sleep quality[48]. While, it has been suggested that chronic low dose caffeine ingestion may blunt any potential ergogenic effects[49], moderate doses (~3 mg/kg/d) appear to pose no problems for most athletes[50]. However, in terms of sleep, moderate caffeine doses have been shown to increase sleep onset latency (i.e. the amount of time it takes to get to sleep) and decrease total sleep time and sleep efficiency[51]. Hence, athletes training/competing in the late afternoon (>5 pm) need to consider its potentially detrimental effect on sleep. It has recently been suggested that athletes should adopt a strategic individualised approach to caffeine consumption during competition[52]. An afternoon nap has been suggested as an effective strategy for athletes to attenuate the cognitive and physical deterioration in performance resulting from either sleep loss or fatigue induced by training/competition[53]. Equally, naps have been shown to enhance mood, alertness and cognitive performance in those who typically get the amount of sleep they need on a nightly basis[54], therefore napping may be an effective strategy even for athletes who get adequate sleep. In terms of duration, it has been suggested that when athletes have a nap opportunity, <30 mins is preferrable to avoid sleep inertia (i.e. a feeling of disorientation/ drowsiness upon waking)[42]. A 15–20 min 'coffee-nap' mid-afternoon has also been proposed whereby athletes consume caffeine (150–200 mg) immediately before napping to counter-balance sleepiness following the nap[43,55]. Alternatively, 90 mins is also considered an optimal nap period as this facilitates a complete sleep cycle to occur, reducing the effects of sleep inertia[56].

Carbohydrate

The majority of the research has focused on high glycaemic index (GI) carbohydrate consumption pre-sleep. Carbohydrate consumption has been demonstrated to increase plasma tryptophan concentrations[57], increasing the tryptophan:LNAA ratio in the blood and may compliment the sleep promoting effect of tryptophan rich protein[58], this increases tryptophan availability for synthesis to serotonin and ultimately melatonin[59]. A high GI evening meal (4 hours before bed) reduced sleep onset latency (9.0 ± 6.2 mins) compared to a low GI meal (17.5 ± 6.2 min) and the same meal consumed 1 hour before bed (14.6 ± 9.9 min)[44]. Lower carbohydrate intake has been associated with insomnia symptoms (difficulty maintaining sleep)[57]. Higher consumption of whole-grains has been associated with lower risk of sleep problem in endurance athletes[60]. Consumption of a high-carbohydrate meal (130 g) when compared to a low-carbohydrate meal (47 g), or a meal containing no carbohydrate, 45 min before bedtime increased REM and decreased light sleep and wakefulness[61]. The impact of carbohydrate content and timing of evening meals on sleep and athlete recovery requires further investigation.

Creatine

Creatine supplementation has been emerging as a potential option for athletes to ameliorate the decline in cognitive performance associated with sleep loss. Previous research has demonstrated that 50 mg and 100 mg/kg doses of creatine alleviate the decline in simple skill performance accuracy associated with sleep loss (3–5 h sleep)[62]. Following 24 h of sleep deprivation, creatine supplementation was shown to reduce performance deficits in reaction time, mood and balance[63]. Creatine supplementation has also been demonstrated to attenuate the loss of complex central executive function associated with sleep deprivation[64]. Recent research has suggested than a single high dose of creatine (0.35 g/kg) can partially reverse metabolic alterations and fatigue related cognitive deterioration following sleep deprivation[65].

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Protein

Dietary sources of tryptophan (e.g. milk, turkey, chicken, fish, eggs, pumpkin seeds, beans, peanuts, cheese and leafy green vegetables) has been shown to improve sleep. In a comparison of the effect on sleep of tryptophan-enriched muesli bars plus glucose with bars containing 250 mg pharmaceutical tryptophan plus glucose and glucose alone[66]. The muesli bars and the pharmaceutical dose produced similar results (5.5% and 6.5% respectively) for reduction of time awake during the night[66], indicating that relatively small doses (250 mg) of dietary tryptophan can positively impact sleep. Tryptophan depletion studies have demonstrated that decreased tryptophan plasma concentrations result in increased sleep fragmentation[67,68].

Athletes routinely consume protein to facilitate recovery and support immune function[69]. While research is emerging supporting pre-sleep protein ingestion for muscle recovery[70,71], the impact of pre-sleep ingestion of doses of whey and/or casein warrants further investigation with regards both muscle recovery and sleep improvement.

Melatonin

In humans melatonin it is the final product in the metabolism of the amino acid tryptophan and is secreted by the pineal gland at the onset of darkness, triggering sleep due it its hypothermic effect[72]. Ingestion of melatonin affects sleep propensity and has hypnotic effects enhancing sleep quality and duration[73], pharmacological melatonin is commonly used in athletes to manipulate sleep patterns. A positive effect of dosages of either 0.3mg or 1mg of exogenous melatonin on sleep latency have been observed, when administered between 6:00pm and 8:00pm[74]. However, the impact was time dependent as the 0.3mg dose increased sleep onset latency and there was no effect when the 1mg dose was administered at 9:00pm[74]. A dose response relationship was not evident as the 0.3 mg dose, which is similar to endogenous melatonin concentrations, was as effective as the 1mg dose when administered between 6:00pm and 8:00pm.

Tart cherries contain high concentrations of melatonin. Significantly reduced insomnia severity index scores (13.2 ± 2.8 versus control 14.9 ± 3.6) and wake after sleep onset (WASO i.e. time awake) (62.1 ± 37.4 min versus control 79.1 ± 38.6), was observed in older adults following consumption of a tart cherry juice blend, compared to a placebo[75]. Research was conducted to investigate if melatonin is the mechanism of tart cherry juice (2 × servings of 30mls concentrate) sleep enhancement and improved sleep time and quality[76]. Total Melatonin content was significantly elevated and significant increases in time in bed (+24 minutes), total sleep time (+34 minutes) and sleep efficiency total (82.3%) and a significant reduction in daytime napping (−22%) were associated with cherry juice supplementation[76]. 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[77].

Magnesium

Magnesium is believed to enhance melatonin secretion and act as a GABA agonist, the main inhibitory neurotransmitter that acts on the central nervous system[58]. It has been noted that deficiencies in B vitamins and magnesium may also disrupt sleep[58]. Magnesium supplementation has been associated with reductions in daytime sleepiness, sleep onset latency and insomnia symptoms and increased total sleep time and sleep efficiency in older adults[78–80].

Kiwifruit

The chemical composition of kiwifruit is of considerable interest in terms of nutritional value and health benefits. The composition of kiwifruit varies depending on multiple factors such as horticulture, region, soil type, storage, ripening condition and maturity of the fruit[81]. Interest in the antioxidant capacity, enzyme, polyphenolic and phytochemical content of kiwifruit has increased steadily over the last decade. It has been suggested that the various bioactive components in kiwifruit may act synergistically affecting various physiological and metabolic[82]. Contemporary research has focused on the health benefits of kiwifruit particularly in relation to antioxidant capacity, digestion, iron nutrition, metabolic health and immune function[82]. Kiwifruit contain significant amounts of vitamin C but also contain a range of other health promoting nutrients such as vitamin E, vitamin K, folate, beta-carotene, lutein, potassium, copper and fibre[83].

Kiwifruit are nutritionally dense containing a range of nutrients that can benefit sleep and recovery including serotonin, vitamin C, vitamin E, folate, anthocyanidins and carotenoids[84]. A study involving healthy adult volunteers (n = 25) who self-reported sleep disturbance demonstrated consumption of 2 kiwifruit, 1 hour before bedtime for 4 weeks significantly improved actigraphy measured total sleep time (16.9%) and sleep efficiency (2.4%)[84]. Self-report measures also improved significantly, wake time after sleep onset reduced (−28.9%), sleep latency reduced (−35.4%) while sleep efficiency increased (5.4%)[84]. It is clear that sleep quality was significantly improved following the 4-week kiwifruit intervention. In a similar study, students (n = 74) with diagnosed insomnia consumed either 130 g of kiwifruit or a placebo (130 g pear), 1 hour before bed for 4 weeks. While there were no statistically significant differences in objective measures of sleep, there were statistically significant group x time effects for subjective sleep quality and daytime function[85]. Kiwifruit consumption (2 × kiwifruit 1 hour before bed) has also been shown to improve subjective sleep and recovery in elite athletes, from baseline to post-intervention (4 weeks) there were clinically significant improvements in sleep quality (i.e. improved Pittsburgh Sleep Quality Index (PSQI) global scores and sleep quality component scores) and improvements in recovery stress balance (i.e. reduced general stress and sports stress scales)[86]. During the intervention significant increases in total sleep time and sleep efficiency % and significant reductions in number of awakenings and WASO were observed[86].

The Serotonin content in kiwifruit may contribute to improved sleep while the rich antioxidant content may supress free radical expression and inflammatory cytokines. Folate deficiency has been linked to insomnia and restless leg syndrome, the folate in kiwifruit may improve folate status and consequently improve sleep[84]. Although folates are widely consumed in the diet, they are destroyed by cooking or processing. Further research is necessary to investigate the potential benefits and practical application of kiwifruit supplementation to promote post-exercise recovery and promote or improve sleep in athletes.

Practical applications

Based on the available evidence some practical recommendation can be made to promote athletes' sleep and recovery which are summarised in Table 1.

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Table 1. Summary of potential nutrition strategies for athletes to improve/promote sleep or mitigate sleep loss

Nutrient/ food	Strategy
Carbohydrate	High glycaemic index carbohydrate (>1 h before bed) can improve sleep latency, duration and quality.
Coffee nap	15–20 mins 'coffee nap' (150–200 mg caffeine pre-nap)
Creatine	Supplement with creatine to mitigate the cognitive decline associated with sleep loss.
Kiwifruit	2 × kiwifruit (1 hr before bed) may improve sleep duration and quality and reduce fatigue.
Magnesium	Magnesium supplementation may improve sleep quality and duration especially in those who are deficient.
Meals	Combinations of carbohydrate and protein in meals (>1 hr before bed) may improve sleep duration and quality.
Protein	• Tryptophan rich protein can improve sleep. • Protein supplementation (>1 hr before bed) may improve sleep duration and quality.
Tart cherry	Tart cherry juice supplementation (30 ml morning and evening) may improve sleep duration and quality.

Adapted from Ref.[59].

Conclusion

The role of nutrition in sleep quality, quantity and athlete recovery has recently become a key area of research focus. The concept that nutritional interventions may improve athletes' sleep and recovery times via mechanisms such as improving hormonal status, muscle protein synthesis and/or muscle glycogen stores has stimulated increased research in this area. However, while various nutrition strategies are used by athletes to promote sleep and recovery further research is necessary to develop nutrition guidelines, products, protocols and tailored interventions designed to enhance athlete sleep, recovery and performance.

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