Review article

Sleep and Athletic Performance

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ABSTRACT

Sleep deprivation or fragmentation may impact upon psychological, hormonal and glucose metabolism of elite and recreational athletes. The effect of sleep on performance is now part of the conventional wisdom of sport science. The physiology and pathology associated with sleep are important as potential causes of poor performance. The physiology includes the basics of sleep and sleep hygiene. The pathology is what may be present to a minimal or mild degree but will impact on sleep hygiene and performance the following day. The interaction between sleep and athletic performance is evident by published papers but the question is raised as how to apply this information in the athletic setting. An evidence based approach is difficult to be established due to the complex physiology of sleep and the intervariability among athletes. Sleep should be incorporated in the training programme based on the individualised needs of athletes whereas all athletes should be investigated for potent sleep disorders.

INTRODUCTION

Sleep deprivation or fragmentation may impact upon psychological, hormonal and glucose metabolism of elite and recreational athletes.[1,2,3] The effect of sleep on performance is now part of the conventional wisdom of sport science. Many articles have been written in the past 10-20 years on the effect of jet lag on athlete's performance but sleep is more than abnormalities in chronobiology.[4,5]

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The physiology and pathology associated with sleep are important as potential causes of poor performance. The physiology includes the basics of sleep and sleep hygiene. Both of these have been suggested to impact on the athlete's performance. Retiring to bed for sleep at 10 o'clock makes it more likely that the athlete will be in Non-REM stage three sleep at between 1-3 am when Growth Hormone (GH) is secreted. GH acts as a repair hormone for athletes who are training hard during the day. This repair of damaged or injured tissue needs to have GH for optimal repair.[6]

The pathology is what may be present to a minimal or mild degree but will impact on sleep hygiene and performance the following day. Insomnia has many causes and a polysomnograph (sleep study) may be indicated to define the problem. Up to 40% of the general population snore. A mild form of sleep apnea is heavy snoring which also may be a cause of sleep fragmentation. Sleep apnea will deprive an athlete of a fully comprehensive nights sleep.[6]

Sleep is important for memory and learning. An athlete who has a lack of sleep will not perform complicated tasks as well as the athlete with a good nights sleep.[1]

PHYSIOLOGY OF SLEEP

Sleep Stages

Sleep can be objectively studied by using polysomnography, a technique combining the measurement of brain activity with electroencephalography (EEG), eye movements with electro occulography, and muscle tone with electromyography. Using this technique, two types of sleep can be distinguished: non-rapid-eye-movement (NREM) and rapid-eye-movement (REM) sleep, which are organized in a series of sleep cycles during the night.

In polysomnography interpretation, sleep onset is marked when the alpha rhythm (stage W), which corresponds to wakefulness, attenuates and is absent from 50% of the epoch.

The first stage of sleep, stage N1, for almost 90% of people who have well-formed alpha rhythms in relaxed wakefulness is characterized by the attenuation of posterior dominant activity together with overall slowing of the background for more than 50% of the epoch.

N2 sleep is characterized by low-amplitude, mixed-frequency background with two superimposed, morphologically distinct waveforms: sleep spindles and K complexes. The presence of either is necessary for scoring N2.

Formerly known as stage 3 and stage 4, or slow-wave sleep, N3 is a non-rapid eye movement (REM) sleep stage with the highest arousal threshold. It is characterized by high- amplitude and slow-frequency activity dominating ≥20% of the 30-s epoch.

The three essential electrographic phenomena required to score an epoch as stage R (Rapid Eye Movement sleep) are (1) low amplitude and mixed frequency activity in the EEG channels, (2) presence of rapid eye movements, and (3) low muscle tone in the digastric electromyogram (EMG) channel.[7] When scoring sleep the newer guidelines published in The AASM Manual for the Scoring of Sleep and Associated Events should be taken into consideration.[8]

Circadian and wakefulness-sleep physiology

Brain arousal is regulated by systems located in the brainstem, basal forebrain and hypothalamus. These arousal systems promote wakefulness while their inhibition promotes sleep.[9] Ascending arousal systems are important for activating cortical neurons and promoting cognition. The circadian timekeeping system is composed of a self-sustained master circadian clock, located in the suprachiasmatic nuclei of the hypothalamus but there is evidence that close interaction between different central and peripheral clocks is necessary to maintain robust circadian rhythms of

physiology and metabolism.[10] Rhythmic clock gene expression during light-dark cycles has been described in some brain regions involved in cognition, affect, and arousal pathways including prefrontal, parietal and cingulate cortex, amygdala, caudate-putamen, nucleus accumbens, hippocampus, ventral tegmental area, and dorsomedial hypothalamus.[9]

Ripperger and Albrecht based on a molecular biology perspective, indicated that the timing system regulates the synchronization of an organism to its environment. This may optimize energy handling and responses to daily recurring challenges. Energy management is essential for athletes in order to reach peak performance. Athletic performance shows a time –of –day effect attributable to sleep wake cycle and the internal body clock but the role of these two factors has not been separated on previously conducted studies.

Reilly and Waterhouse[11] proposed specific research designs and protocols in order to assess the separate roles of the body clock and sleep wake cycle. On the other hand, desynchronization of an organism due to its lifestyle or problems with its circadian clock not only causes discomfort but also may aggravate conditions such as depression, metabolic syndrome, addiction, or cancer.[12]

Apart from impaired cognition misalignment between internal circadian timekeeping and sleep-wakefulness/environmental schedules results in circadian sleep disorders. The most common circadian sleep disorders are Delayed Sleep Phase Disorder, Advanced Sleep Phase Disorder, Jet Lag, Non-24 H Sleep Wake Disorder, and Shift Work Disorder.[9]

Sleep hygiene

The term sleep hygiene was first introduced by Paolo Mantegazza in 1864. In 1977 Peter Hauri gave more solid scientific roots to the concept of sleep hygiene and established this term in the frame of modern sleep medicine.[13] Sleep hygiene education includes aspects of lifestyle, behaviour and environmental factors. It has been found that it is ineffective as a therapeutic approach unless it is reinforced by additional interventions. Additional interventions comprise cognitive behaviour exercises such as relaxation training, sleep restriction and stimulus control.[14] Sleep hygiene education constitutes a component of cognitive behavior therapy which has been suggested as initial therapy even for pathological conditions such as chronic insomnia.[15] Harsora and Kessmann summarized evidence analyzing meta-analyses results and concluded that cognitive behaviour therapy is an effective treatment modality for primary insomnia.[15] Although instructions about exercise habits are included in the spectrum of sleep hygiene education Reilly and Edwards[16] clearly pointed out that there are still unanswered questions about the potential for exercise in improving the quality of sleep. They, also, highlighted the fact that the sleep needs of athletes have not been defined adequately and challenged the role of restorative naps in athletic performance.

Intervariability among athletes

Human sleep needs can vary by age and among individuals in the general population and the optimal amount of sleep depends on an individual's circadian rhythms. The interaction between the internal biological clock and sleep is evident by studies on the effects of jet lag the main symptom of which includes sleep disorders.[17] Athletes differ from the general population and factors that may alter the requirement for sleep among various sports include: training volume and intensity, training timetable and psychological stress of training.

J. Leeder et al[18] in a cross sectional study found that elite athletes exhibit poorer quality of sleep in comparison with non athletes. Athletes in individual sports have more sleep problems than athletes in team sports and sleep disturbance the night before competition is quite common.[19] T. Reilly and B. Edwards summarized a number of sports and recreational activities that are affected by sleep loss.[20]

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Leeder et al studied a cohort of Olympic athletes and measured sleep quality and duration by the use of wristwatch actigraphy. The results of this study provided a better understanding of elite athlete sleeping patterns. The main finding was that in general, athletes appear to get a comparable quantity of sleep to controls but the quality of athlete sleep was inferior. Additionally, there was a significant difference between markers of sleep efficiency between males and females.[18]

In addition to the nature of exercise (anaerobic or aerobic), the time of day when exercise takes place may influence sleep. E. Bambaeichi et al[21] found that the time of day impacts on muscle strength measures and proposed that the time of day is a variable that should be controlled for when designing a study. In another study[22] it has been shown that electromyographic activity of major thigh muscles was not time-of-day dependent although there was diurnal fluctuation in muscular power and neuromuscular fatigue.

Age and gender are factors that may influence an athlete's sleep and that exert a residual effect on subsequent athletic performance. Even athletes of the same team are not completely homogenous with regard to many variables and this should be kept in mind when designing and interpreting results of a study.

Recent findings suggest that the wide inter-individual variability in sleep, in terms of both normal sleep characteristics such as sleep stage organisation, sleep timing and sleep quality; and sleep disorders such as insomnia and circadian rhythm sleep disorders can be attributed to both an underlying genetic component and enviromental factors.[23]

PATHOLOGY OF SLEEP

Insomnia

Insomnia has traditionally been conceptualised as a symptom of another disorder, most notably psychiatric disorders such as depression, anxiety, and substance misuse disorders. Insomnia is characterised by subjective complaints about dissatisfaction with sleep quality or duration, difficulty falling asleep at bedtime, waking up in the middle of the night or too early in the morning, or non-restorative or poor quality sleep.[24] Insomnia is classified in 11 subtypes according to The International Classification of Sleep Disorders (ICSD)[25] and only in three types, primary insomnia (PI), insomnia related to a medical or mental disease and insomnia related to the intake or abuse/dependency from substances according to The Diagnostic and Statistical Manual of the American Psychiatric Association (DSM).[26,27] Insomnia is a common side effect of amphetamine abuse which is used as a doping substance in association with analgesics.[28]

Insomnia presents on a situational, recurrent, or persistent basis. Acute insomnia is often associated with life events or sleep schedule changes such as jet lag or shift work and usually remits once the precipitating event has subsided although for some individuals, sleep disturbance can persist even after the initial cause has disappeared. Insomnia can follow an intermittent course, with recurrent episodes of sleep difficulties associated with stressful events.[24]

Sleep apnea may be a cause of sleep fragmentation but there is still little known about the prevalence and presentation of apnea in athletes and its potential effect on athletic performance.[29]

Jet lag

Jet lag is a syndrome of symptoms manifested by physiologic adaptations that occur when the body is shifted into a new time zone. It should be differentiated from travel fatigue which is a more complex summation of physiologic, psychologic, and environmental factors that accrue during an individual trip, accumulating over the course of a season and reducing the athlete's capacity to recover and perform.[30] Symptoms of jet-lag include periodic fatigue during the day and yet inability to sleep at night, reduced performance, difficulty in concentrating, mental confusion and

disorientation, increased irritability, loss of vigour, gastrointestinal problems, and generalised malaise.[31] Travel fatigue tends to be characterized by persistent fatigue, recurrent illness, changes in behavior and mood, and loss of motivation.[30]

Waterhouse et al based on a field study of jet lag and its symptoms highligted the importance of factors such as the organisation of the journey and the attitude of athletes and sports persons journeying to another continent for training or for an important competition or game.[32] More recently two reviews have been conducted on the management of jet lag. Herxheimer[33] performed a systematic review to provide evidence on the effects of interventions that are implemented to prevent or minimise jet lag. The study showed that evidence ranges from very low to moderate quality and an evidence based approach to jet lag management awaits to be established.

On the other hand, Samuels[30] conducted a narrative review based on the fact that current interventions are based on a modest degree of generalizable evidence and since an evidenced-based approach is difficult to establish he proposed a practical management approach specific to athletes. The structured athlete travel program, according to Samuels, embodies the preflight, in-flight, and postflight model with the travel fatigue monitoring system.

EFFECTS OF SLEEP DEPRIVATION

Peter Walters[34] identifies three areas that can be affected by a lack of sleep.

1. Cardiovascular performance

A consistent lack of sleep has been shown to reduce cardiovascular performance by 11%.[34] The cardiovascular effects of partial sleep deprivation are evident even in healthy volunteers where it has been shown that sympathetic activity and venous endothelial dysfunction increase after a short term sleep deprivation period.[35] The strong interaction between sleep and cardiovascular performance has been demonstrated in epidemiological studies according to which chronic sleep restriction is a risk factor for developing hypertension and in association with other risk factors can lead to metabolic syndrome and subsequent increased cardiovascular mortality and morbidity.[36]

Azboy and Kaygisiz[37] studied the cardiorespiratory effects of sleep deprivation on runners and volleyball players during rest and exercise. Based on the results of their study they concluded that maximal exercise capability is reduced because sleep loss decreases time to exhaustion and exercise minute ventilation. This study, also, highlighted the fact that sleep deprivation may have variant impact on athletes based on the type of sport. Volleyball players were found to be more prone to poor performance than runners.[36] The deprived of sleep athlete will accumulate enough sleep debt in 15 days to significantly reduce the cardiovascular performance.[34]

Overall physical performance

Mah[38] investigated the effects of sleep extension over multiple weeks on specific measures of athletic performance as well as reaction time, mood, and daytime sleepiness.

Total objective nightly sleep time increased during sleep extension compared to baseline by 110.9 ± 79.7 min ($P < 0.001$). Subjects demonstrated a faster timed sprint following sleep extension (16.2±0.61 sec at baseline vs. 15.5±0.54 sec at end of sleep extension, $P < 0.001$). Shooting accuracy improved, with free throw percentage increasing by 9% and 3-point field goal percentage increasing by 9.2% ($P < 0.001$).

Mean PVT reaction time and Epworth Sleepiness Scale scores decreased following sleep extension ($P < 0.01$). Profile of Mood States (POMS) scores improved with increased vigour and decreased fatigue subscales ($P < 0.001$). Subjects also reported improved overall ratings of physical and mental well-being during practices and games.

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Improvements in specific measures of basketball performance after sleep extension indicate that optimal sleep is likely beneficial in reaching peak athletic performance

2. The psychological effects

Cognitive performance

Cognition can be conscious or unconscious and includes attention, memory and decision making among other processes. Sleep deprivation has a variant effect on cognitive performance based on the type of task or the modality it occupies. Interindividual, age and sex related differences have been found with regard to the impact of sleep deprivation.[39] It can, therefore, be inferred that the effects of sleep deprivation depend not only on the type of sport but on the athletes themselves, as well.

Alhola and Polo-Kantola[39], however, highlighted a controversial finding with regard to sleep deprivation and cognitive performance. They cited studies where motivation and reward has been provided to sleep deprived subjects during task performance. Although, methodological issues decrease the strength of the aforementioned studies it is suggested that motivation affects performance positively despite sleep restriction.

Emotional stability

A lot of studies have demonstrated the association between the emotions experienced during the day and changes in sleep physiology, in particular modified, enhanced or decreased REM-sleep.[40] There is actually a reciprocal relationship between sleep and emotion since not only do daytime events affect sleep, the quality and amount of sleep also influence the way someone reacts to these events.[40] Zohar et al[41] studied the relationship between sleep loss and emotional reactivity in medical residents and found that sleep loss intensified negative emotions and even diminished positive emotions following a goal thwarting or goal enhancing event. Negative emotions for the athlete include an increased perception of effort and fatigue, and in general bad mood which define a type of mental state discouraging for a top performance.

3. Metabolic or Hormonal

Sleep is essential for the cellular, organic and systemic functions of an organism and its absence is potentially harmful to glucose regulation and some hormonal axes. Glucose is the primary source of energy for many tissues and, specifically, muscles are able to store glucose in the form of glycogen.[42] Glucose regulation is markedly influenced by circadian rhythmicity and sleep, therefore, sleep disorders may be associated with slower glycogen storage and a negative impact on athletic performance.

Hormonal changes include an increase in cortisol secretion and a reduction in Insulin-like Growth Factor 1, favoring the establishment of a highly proteolytic environment.

Dattilo et al found in their study that sleep debt decreases the activity of protein synthesis pathways and increases the activity of degradation pathways, favoring the loss of muscle mass and thus hindering muscle recovery after damage induced by exercise.[43]

Sleep manipulation as a potential treatment

Based on the effects of sleep restriction the question is raised as to how athletic performance can be improved with sleep manipulation. When sleep deprivation has affected an athlete, the remedy is not as simple as one or two good nights sleep, although such a development is a start. Waterhouse et al[44] have demonstrated that even a short nap has a beneficial effect on sprint performance after partial sleep deprivation. The duration and frequency of a nap as well as its

efficacy in a wide range of sporting activities could not be established based on this study. There is a need for properly designed studies which will incorporate sleep in properly defined measures into the training program to show its effect on performance. Methodological issues of poorly conducted studies have been discussed in the literature[45] with appropriate recommendations for future research protocols.

Overtraining

Overtraining is a well-known athletic condition where an athlete overreaches in the training objectives for a period of time, either through excessive training volume, intensity, or both. Overtraining may lead to overtraining syndrome, a neuroendocrine disorder, which is characterised by increased perception of effort during exercise, frequent upper respiratory tract infections, muscle soreness, sleep disturbances, loss of appetite, mood disturbances, shortness of temper, decreased interest in training and competition, decreased self-confidence, inability to concentrate.[46] Reduced performance is an initial sign of overtrining syndrome but it can be accompanied by, or even preceded, by mood, behavioral, and cognitive changes.[47] Sleep disturbances are a common symptom of overtraining syndrome but it seems that sleep disorders may cause the overtraining syndrome on a much smaller work volume or intensity.

Approaches to insomnia

Several pharmacologic and non-pharmacologic approaches are employed in the management of insomnia that has been proven effective for short-term treatment. The pharmacologic approaches include the use of over the-counter agents (antihistamines, melatonin, and herbal preparations), prescription hypnotic drugs for insomnia (benzodiazepine-receptor agonists, chronobiotic agents, and low-dose doxepin hydrochloride), and other prescription agents not specifically indicated for insomnia (antidepressants, antipsychotics, and anticonvulsants).[24] Some of these agents (especially benzodiazepines) cause muscle relaxation and may affect performance the day after night sedation.

The nonpharmacologic approach includes cognitive behavioural therapy which is a brief, sleep-focused, multimodal intervention that includes psychological and behavioural procedures such as stimulus control, sleep restriction, relaxation strategies, and cognitive behavioral therapy.[15]

Although these therapies can be used as single therapy there is insufficient evidence for some of them that are truly effective as monotherapy and a combined approach is usually preferred.[15]

In a recent systematic review Passos GS et al[48] tried to summarize evidence on the effect of exercise on chronic insomnia and its use as an alternative treatment. They concluded that exercise is effective to decrease sleep complaints and to treat chronic insomnia since aerobic exercise and its effects are similar to those observed after hypnotic medication use. Nonetheless, prospective studies comparing the effects of exercise with medical and nonmedical treatments are warranted before including exercise as a first-line treatment for chronic insomnia are necessary.[48]

CONCLUSION

Understanding the underlying physiology of sleep and its association with the circadian cycle might help in the screening and diagnosis of sleep disorders in athletes. Sleep deprivation with regard to athletes should not only be considered as a result of one or two more or less sleepness nights before competition or due to circadian rhythm disturbance (jet lag). There are important physiological aspects of sleep and there are sleep related disorders that may need assessment with polysomnograms. The interaction between sleep and athletic performance is evident by published papers but the question is raised as how to apply this information in the athletic setting. An evidence based approach is difficult to be established due to the complex physiology of sleep

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and the intervariability among athletes. However, the authors believe that optimal or peak performance can only occur when an athlete's sleep and sleep habits are most favourable. Sleep should be incorporated in the training programme based on the individualised needs of athletes whereas all athletes should be investigated for potent sleep disorders.

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