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PHYSIOLOGICAL REVIEW

Sleep, circadian rhythms, and athletic performance

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SUMMARY

Sleep deprivation and time of day are both known to influence performance. A growing body of research has focused on how sleep and circadian rhythms impact athletic performance. This review provides a systematic overview of this research. We searched three different databases for articles on these issues and inspected relevant reference lists. In all, 113 articles met our inclusion criteria. The most robust result is that athletic performance seems to be best in the evening around the time when the core body temperature typically is at its peak. Sleep deprivation was negatively associated with performance whereas sleep extension seems to improve performance. The effects of desynchronization of circadian rhythms depend on the local time at which performance occurs. The review includes a discussion of differences regarding types of skills involved as well as methodological issues.

Introduction

The impact of sleep deprivation, disruption of circadian rhythm, and time of day on athletic performance has been extensively investigated, but a systematic overview is still lacking. Circadian rhythms are seen in the sleep–wake cycle as well as in several other aspects of human functioning. These rhythms are generated by the suprachiasmatic nuclei. The period of the endogenous rhythms is somewhat longer than 24 h [1]. However, the circadian rhythms are also influenced by external cues (zeitgebers) which normally entrain the endogenous rhythms to a 24-h rhythm [2], thereby preventing them from "free-running". There are individual differences in the phase of circadian entrainment (i.e., morningness–eveningness dimension). Morning types have an advanced rhythm (early bed and rise times) and evening types display a delayed rhythm (late bed and rise times), compared to intermediate types [3].

According to the two-process model of sleep regulation, humans' tendency to sleep is determined by the time passed since the last sleep episode (homeostatic factor) as well as by time of day (circadian factor) [4]. The homeostatic factor is evident in humans' rising need for sleep after sustained wakefulness, while the circadian factor is evident in the increasing sleep propensity that normally occurs during the dark part of the 24-h d.

Studies have taken different approaches in investigating how sleep deprivation and circadian disruption affect athletic performance. Some studies have focused on physiological measures, while others assess athletic performance. Furthermore, sports differ greatly as to which skills are important for successful performance [2]. The focus of the present review concerns the impact of sleep and circadian rhythms in studies utilizing direct measures of athletic performance, which are arguably more relevant to real sports competitions than are physiological responses to exercise (e.g., heart rate and oxygen uptake) [5].

Methods

We searched the databases ISI Web of Science, PubMed and PsycInfo for articles using each of the following words: *Chrono**, *diurnal*, *morningness*, *eveningness*, *morning type**, *evening type**, and

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*circad**, in combination with each of the words: *Athletic*, *performance,* and *sport**. The inclusion criteria were *peer reviewed journal articles* written *in English* and published between 1980 and 2012, reporting data of *objective measures* of *athletic performance* (e.g., times, scores etc.). Studies were excluded if they exclusively reported: *a)* physiological responses to exercise, *b)* subjective measures of sport performance, *c)* sports involving minimal physical performance (e.g., shooting, darts, driving), *d)* simple tests of reaction time, grip strength, flexibility and balance, *e)* case studies and studies in children, *f)* studies in the effect of medication or stimulants on performance, *g)* studies in eumenorrheic women or on effects of menstrual cycles on performance, and *h)* studies conducted in settings where the effect of sleep deprivation cannot be distinguished from the effect of training or fatigue (e.g., expeditions, extreme competitions lasting several days, military training operations). The search yielded a total of 3726 records, including duplicates. After selecting relevant articles, we examined their reference lists for additional studies that met our inclusion criteria. A total of 113 articles were included.

We hypothesized that the overall findings from these studies would indicate that sleep deprivation and desynchronization of circadian rhythms negatively affect performance and that performances display a diurnal variation, being better in the evening than in the morning.

Results – sleep loss

Total sleep deprivation

Anaerobic performance is often examined using procedures involving subjects' performance on ergometer cycles, such as the Wingate anaerobic power test or force-velocity tests. Intensity is high and duration of performance is short: the Wingate test typically involves 30-s or 60-s effort, while the Force-velocity test includes several 6-s sprints. Research indicates that total sleep deprivation is not detrimental to performance on these tests. No effect on Wingate performance was found after one night of sleep deprivation [6,7], after 48 h [8], or even after 60 h of sleep deprivation [9]. A night of total sleep deprivation, however, was found to decrease evening performance, possibly through attenuation of the normal rise in performance during evening hours due to cumulative fatigue [7]. Another study reported no effect of one night of sleep deprivation on total work done or time to exhaustion in an intensive all-out cycling exercise [10].

Several studies have found that muscle strength is unaffected by sleep deprivation. A 24-h sleep deprivation had no effect on performance on the snatch, clean and jerk, or front squat [11]; 36 h of sleep deprivation had no effect on elbow flexion or extension strength [12], and 60 h of sleep deprivation did not decrease maximal strength and endurance of either upper or lower body muscle groups [9,13]. One night of sleep deprivation had no significant effect on back or leg strength the following day, but back strength was reduced after a night of recovery sleep [14]. Knee flexion torque was unaffected after 30 h of sleep deprivation [15] and after 64 h [16]. Knee extension torque, however, decreased after 30 h of sleep deprivation [15], and after 64 h of sleep deprivation, although only at a low speed of rotation [16]. Endurance of knee extensors and flexors was unaffected after 64 h of sleep deprivation, as were running times for the 40-m dash, while there was a decrease in vertical jump height [16]. The two latter studies did not include appropriate control groups.

In sum, these results suggest that tasks requiring short-term high-power output are largely unaffected by one or several nights of sleep deprivation. One of the mechanisms by which sleep deprivation may affect performance is reduced motivation [7,9,11]. Although these tasks all require motivation [9], they demand that motivation is sustained only for a short time, thus making performance viable even with an accumulated sleep debt.

Regarding performance of a longer duration, one study found that mean sprint performance and performance on repeated deep-squats during a 50-min exercise protocol was reduced after 30 h of sleep deprivation, as was knee extensor strength measured after the 50-min protocol. Total distance covered during the submaximal exercise part of the protocol was not significantly altered, but distance during the first and last 10 min of the submaximal exercise was reduced [17]. Other studies reported that one night of sleep deprivation reduced the total distance covered during treadmill walking [18], while 42 h of sleep deprivation reduced time to exhaustion in ergometer cycling [19], and sleep deprivation for 36 h [20] and 50 h [21] reduced time to exhaustion on treadmill walking. The tests were conducted in the morning or afternoon in at least three of these studies [17,18,21]. Thus, sleep deprivation appears to affect endurance performance. The participants may be less motivated to endure discomfort after sleep deprivation [22]. In addition, sleep deprivation may lead to changes in perception of effort. Ratings of perceived exertion either remained unchanged or increased after sleep deprivation, although actual performance decreased [17–20]. Physiological effects (e.g., changes in cardiovascular, respiratory, and metabolic variables) were negligible in these studies [17–22]. On the other hand, 60 h of sleep deprivation did not significantly affect time to exhaustion in ergometer cycling [23]. The subjects in this study were all women and the task was ergometer cycling rather than treadmill walking, thus, less muscle mass was activated; the subjects were also kept awake by various cognitive tests throughout the sleepless period [23]. Another possible explanation of the divergent results may be the relatively short performance session in this study as compared with the majority of the other studies [17,18,20,21] (19 min vs. 30 min or more).

Partial sleep deprivation

Depriving subjects of sleep in the beginning of the night by delaying bedtime until 03:00 h has been found not to affect performance on the 30-s Wingate test [6,24,25]. However, depriving subjects of sleep at the end of the night had a negative impact, although only on performance in the evening, possibly due to a decrease in the circadian rhythm amplitude and/or due to increased fatigue caused by staying awake for a longer period of time [25].

Restricting subjects' sleep to 2.5–3 h per night (allowed at the end of the night) for three successive days affected neither standing broad jump performance or time to exhaustion on a treadmill [26], nor maximal biceps curl [27]. However, performance on maximal bench press, leg press, and dead lift decreased [27]. The authors noted that these tasks require activation of larger muscle groups than the biceps curl, that the latter tasks were more affected than the first ones, and that a decline in motivation was most likely involved [27]. The performance tests in the latter studies [25–27] were conducted in the evening, while the studies that found no effect of total sleep deprivation on similar measures conducted the tests in the morning or afternoon [9,11,13,15]. All in all these results may indicate an interaction between sleep deprivation and time of day on performance, which is a topic that should receive more attention in future studies. In a study on shift workers recovering from a week of night shifts, endurance time on ergometer cycling decreased, although only the times of the older workers [22]. It is likely that the participants both had experienced a week of partial sleep deprivation and had a delayed circadian phase at the time of testing as a consequence of the night work. The cycling session