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Sleep of athletes – problems and possible solutions

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Human performances are highly dependent on one of the main biological rhythms, namely the sleep–wake rhythm. This rhythm is driven by the living clock and is functional in the adaptation to day–night differences in the environment. The athlete, like all humans, is set up to be awake and in good shape to exercise during the day, and to sleep and recover during the night. Regular vigorous physical activity, such as the light–dark cycle or social cues, can be considered as a *zeitgeber*. It has been shown to reinforce the synchronisation of human circadian rhythms, which means that physically active people have a stronger circadian rhythmicity than those who are sedentary. Sleep and exercise also have strong relationships that are independent of the biological clock. On the one hand, athletic performances have been shown to be dependent upon both the quality and the quantity of sleep that has been taken before the competition. The detrimental effects of sleep deprivation are shown by increased lapsing, cognitive slowing, memory impairment, decreased vigilance and sustained attention, and shift in optimum response capability. Its effects on physical performance are manifested as a decline in the ability to perform maximal exercise. Aerobic and anaerobic pathways are both affected, as are fatigue and recovery processes. Sleep deprivation can also phase shift and decrease the amplitude of many individual rhythms. All these effects are dependent on the timing and the length of the waking state, but many of them are seen after only few hours of sleep deprivation. On the other hand, exercise by itself has been shown to have an impact on subsequent sleep. Sleep latencies and fragmentation are reduced and the deep slow wave sleep is increased. It is beyond doubt that athletes need more sleep than sedentary people, and so athletes, in order to perform optimally, need to respect the "rules" imposed by the circadian pacemaker for establishing consistent sleep periods.

Keywords: sleep; biological rhythm; athlete; exercise; performance

Introduction

Athletic performances are highly dependent on one of the main biological rhythms, namely the sleep–wakefulness circadian cycle. While asleep, the organism is inefficient; this part of human lives is devoted to rest and the recovery from the other parts of the cycle, which are dedicated to alertness and physical and cognitive activities. It is common sense that a "good tiredness" (understood as being physical) leads to a "good sleep" and, that conversely, a state of "being off form" follows "a bad" night. This is because sleep plays

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several key roles in the circadian rest–activity cycle. These complex inter-relationships are shown in Figure 1, which summarises the main argument of this paper.

The left section of the diagram shows the sleep–wakefulness system in the brain. Sleep and alertness depend upon fluctuations in vigilance, which have a main period of approximately 24 hours. These fluctuations are driven by the internal body clock to match the light and dark phase of the environment, with – in humans – sleep during the night and wakefulness during the day. This system is partly regulated by feedback loops (Richardson 2005; Klerman and Hilaire 2007) and by knowledge of the body state in which physical activity has an important role to play.

The right section of the diagram schematically represents the interactions between the brain and the exercising body. The relationships are summarised by the four different arrows. The first arrow indicates that athletic performances have rhythmic variations driven by the body clock. In particular, athletic performances are highly dependent on the level of vigilance and its fluctuations. The second arrow indicates that physical exercise acts directly on circadian rhythmicity by modifying the output of the body clock. Arrow 3 represents the direct influence of good or bad sleep on sports performances and, finally, arrow 4 represents the direct influence of exercise on sleep.

The aim of this review is to consider these different interactions, which show how these major physiological functions – sleep and physical activity – are so closely bound that any modification of one has consequences on another. Athletes have to take all this knowledge into account if they are to achieve their personal best performances.

Circadian rhythmicity of athletic performances (arrow 1)

Most basic components of performance, such as temperature, muscular strength, flexibility, metabolic and psychomotor functions, have rhythmic peaks and troughs that

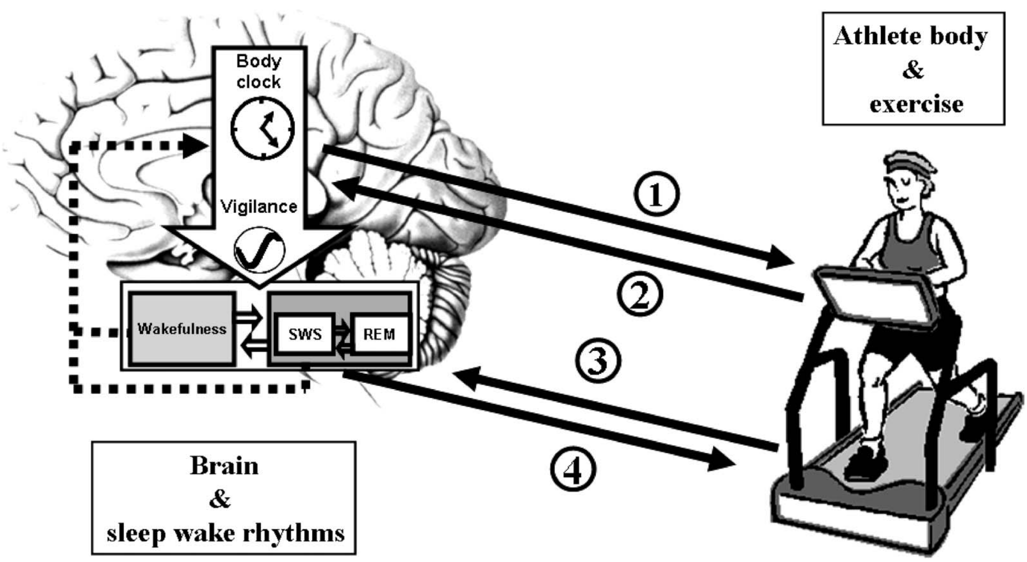

Figure 1. Schematic representation of the relationships between sleep and exercise. On the left-hand side, sleep is a brain activity driven by the living body clock, but which is also dependent on the body activity. On the right-hand side, exercise is a body activity which is closely dependent upon both the body clock and sleep.

follow a circadian pattern. This phenomenon explains why sports performances peak in the afternoon or early evening (for reviews see Reilly et al. 1997; Davenne 1998; Cappaert 1999; Drust et al. 2005). Only the circadian rhythm of vigilance is relevant to this paper. Vigilance describes alertness and the ability to perform mental tasks. Athletes have to be aware of the fact that their psychomotor capacities, particularly when the skill involved depends on reaction time and sustained attention, are considerably reduced during the night and the early morning. An increase in the frequency of injuries has been reported if exercise occurs at these times of day (Winget et al. 1985). The rhythm of vigilance is tightly linked with that of core temperature (Aktinson and Davenne 2007). These two rhythms persist in exercise lasting at least 24 hours (Davenne and Lagarde 1995).

Vigilance also has ultradian (much less than 24 hours) periods. A decrease of vigilance and an increase of sleepiness are observed at the beginning of the afternoon, in association with an increase in accidents and a decrease in performance at this time of day (Horne and Reyner 1999). Different studies have shown that humans are programmed by the body clock to sleep and recover in the middle of the day (Lavie 1985). Numerous benefits of napping, for physical and cognitive performances during the following afternoon, have also been shown (Reilly et al. 1996; Mallis and Deroshia 2005). Naps also prevent sleep restriction due to domestic or occupational schedules that do not permit enough sleep during the night. Therefore, athletes are encouraged to have a short (less than 30 min, to avoid sleep inertia, Klerman and Hilaire 2007; Matchock and Mordkoff 2007) and regular sleep period at the beginning of each afternoon.

Effect of exercise on circadian rhythms (arrow 2)

Environmental light, in particular the alternation of light-darkness due to the rotation of the earth on its axis, is one of the principal time-givers (*zeitgeber*), and synchronises the internal clock (for example, Boivin et al. 1994). However, in the same study, this role was also allocated to other time-givers, such as the social rhythms, the timing of meals, the sleep–wake cycle, and regular physical activity. Both the animal and human literature show that an increase in physical daily activity could be associated with changes of the period, phase and amplitude of the circadian rhythms (Harma et al. 1982; Aktinson et al. 1993; Redlin and Mrosvosky 1997; Koteja et al. 2003; Mistlberger et al. 2003). Opposite effects can be obtained by imposing a sedentary way of life. Physical activity is also efficient in counteracting the desynchronization due to shift work or jet lag (Waterhouse et al. 2000a, 2000b; Mauvieux et al. 2003; Nakao et al. 2004; Waterhouse et al. 2007), to mental retardation (Tomporowski and Ellis 1985) or to ageing (Van Someren et al. 1997; Gruau et al. 2001).

It follows from these considerations that it is likely that the synchronization and amplitude of the biological rhythms of athletes would be higher than in sedentary people. As consequences, athletes are highly sensitive to jet lag (Waterhouse et al. 2000a, 2000b) and/or to any kind of disruptive factors that can desynchronise the circadian rhythms, such as sleep loss, shiftwork or irregular schedules due to training or competitions.

Sleep for the athlete (arrow 3)

Sleep can be divided into two main electrical states which serve different basic functions. Slow wave sleep is a state during which the brain reduces its activities and neuronal activity becomes synchronised. During the deepest states, it produces high-amplitude, low-frequency electroencephalographic waves. This type of sleep is important for athletes because, without its presence at the beginning of the night, growth hormone cannot be released from the pituitary gland (Weitzman 1976; Johns 1981). This hormone, which stimulates the protein synthesis necessary for body restoration, has an important effect on muscle growth and repair, bone building and fat burning (Weitzman 1976), most of which are required in order to recover from strenuous workouts during training and competitions. Studies have shown that if energetic expenditure increases during the day, the blood levels of growth hormone rise during the following night (Kanaley et al. 1997) while, when an athlete loses slow wave sleep, these levels fall considerably (Kato et al. 2002).

During rapid eye movement sleep, the brain is very active. It produces low-amplitude high-frequency EEG waves, very similar to those obtained during wakefulness. It has been proposed that the process which occurs at this time is memory consolidation. The huge neuronal activity observed in the encephalon is postulated to strengthen the neural circuits that underlie learning. Some studies have shown that, after REM sleep loss, procedural memory and motor skills can be affected (Stickgold and Walker 2007). During REM sleep, the brain is partly disconnected from the body due to a blocking of cortico-spinal pathways at the brain stem, motor activity is suppressed, and all muscles are in a state of total relaxation which allows effective myofibril restoration.

An alternation between REM sleep and slow-wave sleep occurs regularly during a normal night's sleep, allowing the various sleep functions to take place. At this time, the body can recover from the deleterious effects of waking and prepare to start as refreshed and alert as possible the following day.

Numerous studies have shown that sleep loss produces a general decline in performance (Pilcher and Huffcutt 1996; Reilly et al. 1997; Meney et al. 1998; Bougard et al. 2006; Reilly and Edwards 2007). The trend is not the same in everyone or for all the components of performance. Mood, psychomotor and cognitive function decline more quickly than physical capabilites. The complexity, duration and boredom produced by the task can also accelerate this decline. Furthermore, when studying the combined effects of time of day and sleep deprivation, it has been shown that sleep deprivation is responsible for a reduction in the amplitude of the diurnal fluctuation in performance (Souissi et al. 2003; Souissi and Davenne 2004; Bougard et al. 2008); this is due to a deterioration at the time when the maximum values of the variable are normally recorded. Thus, sleep deprivation modifies the rhythm of performance, reducing both the average level of performance (mesor) and the peak-to-peak amplitude (Figure 2). However, for a different type of performance (car driving), it seems that the amplitude of diurnal fluctuation persists after a night of sleep deprivation in spite of a modification in the mesor (Lenné et al. 1998).

Even if, for athletes, total sleep deprivation almost never occurred, their sleep before a competition could be reduced or fragmented by many factors including anxiety, the new environment (bedroom), the travel schedule, jet lag and so on. Studies have shown that partial sleep deprivation in these cases has a more profound effect on functioning than either long- or short-term sleep deprivation (Pilcher and Huffcutt 1996). Furthermore, many recent studies report that repetitive partial sleep deprivation drastically impairs hormonal and immune systems. It has been shown that sleep deprivation can slow glucose metabolism by as much as 30–40% (Spiegel et al. 1999), which has consequences for storage of the main source of energy for athletes and can hinder subsequent performances.

The fact that sleep may be the single most important factor when it comes to improving performance to reach a peak level (Rosekind 2005) has been recently reinforced by a study of performances of athletes who were asked to sleep as much as they could. The results

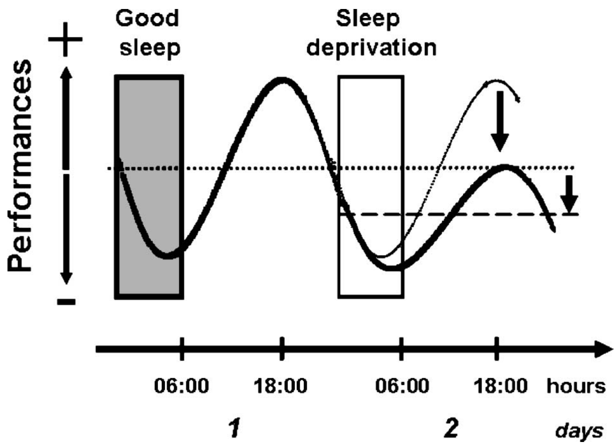

Figure 2. Schematic representation of the circadian curve of athletic performances, before and after a total sleep deprivation. Classically, after a normal sleep, a peak is shown at about 18:00 hours and a trough at 06:00 hours. The day following a night without sleep, the mean (mesor) and the amplitude (difference between the mean and the highest value) are decreased.

showed significant improvements in performances and mood and a decrease in fatigue by comparison with days after a night of sleep of habitual length (Dement 2005).

Effects of exercise on sleep and on the waking state (arrow 4)

Do athletes need more sleep than sedentary people? During the last 30 years, there have been many studies showing that people who regularly practise one or more physical or sporting activities sleep better. Meta-analyses, which reduce the differences in the methodological approaches, strengthen this conclusion (Koslowsky and Babkoff 1992; Kubitz et al. 1996; Youngstedt et al. 1997). To summarise, the quality of the sleep is improved considerably by certain physical activities (Youngstedt 2005). The subjects fall asleep more quickly, wake less often, have less changes of sleep stages and more regular transitions between REM–non-REM sleep cycles. An increase in total sleep time is also noted. In a more subjective way, these people report being in better form when they wake up and during the whole day, even on the days when they do not practise (Penedo and Dahn 2005). Conversely, when daily physical activity is reduced (due to a sedentary occupation, obesity, or prolonged confinement, for example), sleep worsens (Horne 1988), becoming fractionated and shorter. Diurnal vigilance also decreases, with naps being taken in the daytime, which indicates that sleep has an effect on the circadian rhythm of vigilance.

A common assumption is that exercise in the evening disrupts sleep by stimulating alertness. Although studied for more a century, the direct action of physical exercise on the waking state and cognitive performance is still very much under discussion (Tomporowski and Ellis 1986; Brisswalter et al. 2002). Evidently, it is the modifications in the plasma levels of the hormones involved in stress and waking (catecholamines, cortisol, and so on) that are observed during physical activity that stimulate alertness and vigilance (Hogervorst et al. 1996). Exercise would also change the equilibrium between waking and sleeping, by modifying the feedback loops acting upon the central clock. That is, waking would be stimulated for several hours after having exercised, by an effect on serotonin and/or the serotonin/dopamine ratio. In addition, a desire for sleeping (central tiredness) appears to force the body to rest, as is observed after exercise of very long duration (Meeusen et al. 2006). Other evidence (Youngstedt et al. 1999) challenges the assumption that late exercise disturbs sleep; these authors did not find that vigorous exercise performed late at night had any impact on sleep in highly fit male cyclists. What is observed, however, is a phase delay in sleep–wake cycles that might be as potent as the effects of bright light (Van Cauter et al. 1993).

Conclusion

This review has emphasised the fact that sleep and exercise are important physiological variables, which normally alternate with each other. They are mutually interdependent, and also influenced by the body clock that drives the sleep–wake cycle. The main consequence for athletes is that any modification of one inevitably affects the other. Athletic performances have been shown to be dependent on both the quality and the quantity of sleep that has been taken before the competition. The effects are dependent on the timing and the length of waking state, but many of them are seen after only a few hours of sleep deprivation. On the other hand, exercise by itself has been shown to have an impact on subsequent sleep and it is because of this that athletes are long sleepers. Body growth and repair need this extra sleep time. Athletes often have difficulties preserving the total sleep time in the face of competing demands from training schedules, work and family commitments.

What can be done for the athlete? During the training periods, it is important to respect the greater amount of sleep required, allowing spontaneous awakening to occur) and sleep to be taken in an optimal environment (quiet, dark, not too hot, comfortable). It is also important to keep a regular sleep schedule, in particular to try to get up at the same time every day. It would also be valuable if a nap could regularly be taken in the daytime. At competition time, the athlete needs to continue to implement these recommendations but also needs to prevent anxiety, to take additional naps as often as possible, and to be aware of the techniques for coping with jet lag (Waterhouse et al. 2007).

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