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Physiology & Behavior 90 (2007) 229–235

PHYSIOLOGY & BEHAVIOR

Relationships between sleep, physical activity and human health

Greg Atkinson [a,*], Damien Davenne [b]

[a] Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Henry Cotton Campus, Webster Street, Liverpool L3 2ET, UK
[b] Centre de Recherches en Activités Physiques et Sportives, University of Caen, France

Received 19 August 2006; accepted 4 September 2006

Abstract

Although sleep and exercise may seem to be mediated by completely different physiological mechanisms, there is growing evidence for clinically important relationships between these two behaviors. It is known that passive body heating facilitates the nocturnal sleep of healthy elderly people with insomnia. This finding supports the hypothesis that changes in body temperature trigger somnogenic brain areas to initiate sleep. Nevertheless, little is known about how the core and distal thermoregulatory responses to exercise fit into this hypothesis. Such knowledge could also help in reducing sleep problems associated with nocturnal shiftwork. It is difficult to incorporate physical activity into a shiftworker's lifestyle, since it is already disrupted in terms of family commitments and eating habits. A multi-research strategy is needed to identify what the optimal amounts and timing of physical activity are for reducing shiftwork-related sleep problems. The relationships between sleep, exercise and diet are also important, given the recently reported associations between short sleep length and obesity. The cardiovascular safety of exercise timing should also be considered, since recent data suggest that the reactivity of blood pressure to a change in general physical activity is highest during the morning. This time is associated with an increased risk in general of a sudden cardiac event, but more research work is needed to separate the influences of light, posture and exercise per se on the haemodynamic responses to sleep and physical activity following sleep taken at night and during the day as a nap.

Keywords: Blood pressure; Circadian rhythm; Diet; Exercise; Shiftwork; Thermoregulation

1. Introduction

Intuitively, one might consider that sleep and physical activity are separate and distinct behaviors. It would seem sensible to suggest that the physiologic mechanisms at work to ensure a relatively inactive and restful sleep are completely different from those that maintain homeostasis during intense exercise. Nevertheless, there are some important relationships between sleep and exercise that have, in fact, been appreciated throughout antiquity.

It was thought in biblical times that the physical work of a labourer promotes good sleep, and that this favorable effect is present irrespective of whether the stomach is full or not; '*The sleep of a labouring man is sweet, whether he eats little or much*'. Nevertheless, there was also a warning for the well-fed, yet idle, rich; '*…but the fullness of the rich will not suffer him to sleep.*' (Ecclesiastes 5:12). Shakespeare suggested that the above relationship between exercise and good sleep was not just unidirectional. In his play *Macbeth*, Shakespeare stressed the importance of obtaining a good nights sleep in order to recuperate properly from prior physical work; '*Sleep that knits up the ravell'd sleave of care, The death of each day's life, sore labour's bath*' (Macbeth 2.2.46–51).

As more scientific knowledge has been gained about sleep, more links between sleep and physical activity have been postulated over and above the general and much-discussed notions that exercise is good for sleep [1], and *vice versa* [2]. For example, it is interesting that narcoleptic individuals have an increased propensity for sudden bouts of daytime sleep, sometimes in response to strong emotions or even exercise [3]. Sleep apnea is apparently present in a large proportion of American professional footballers [4]. One risk factor for sleep apnea is a neck that is large in circumference relative to its length [5]; this anthropometric characteristic is prevalent amongst many American footballers. There is also a growing body of evidence that the links between sleep, physical activity and the prevalence of obesity are more complicated than were previously

* Corresponding author. Tel.: +44 151 231 4249; fax: +44 151 231 4353.
E-mail address: G.Atkinson@ljmu.ac.uk (G. Atkinson).

0031-9384/$ - see front matter © 2006 Elsevier Inc. All rights reserved.
doi:10.1016/j.physbeh.2006.09.015

believed. For example, a short, not a long, sleep length has been found to be associated with an increased risk of obesity [6]. Given the negative impact of a general sedentary daily lifestyle on obesity levels, such findings are surprising and are, therefore, discussed in more detail later in this review.

The aims of the present review are to summarise the various relationships that have recently been highlighted between the human behaviors of sleep and physical activity. The basic physiologic responses to these behaviors are first outlined, with particular emphasis on the thermoregulatory responses to exercise. The particular problems of disrupted sleep and physical activity patterns of the shiftworker are then discussed, which is followed by a summary of the recent research on short sleep length and obesity. Lastly, some new findings about the impact of an increase in physical activity after waking from sleep on haemodynamic responses and cardiac safety are analysed.

2. Physical activity, thermoregulation and sleep quality

The sleep–wake cycle is one of the more obvious circadian rhythms in the human. What is not apparent, until physiological measurements are obtained, is that sleep is usually initiated when body temperature is falling and individuals tend to wake up after body temperature has begun to rise [7]. These observations, taken together with other findings–that thermoregulation differs between sleep stages and that sleep is disrupted in non-thermoneutral environments [8]–suggest that there is an important link between sleep and thermoregulation.

Sleep can be divided into two main types of stages, rapid eye movement (REM) and non-REM sleep. There are approximately 4–5 non-REM/REM cycles during a typical night's sleep. Core body temperature is decreased, whilst peripheral temperature is increased, during the non-REM stages [9,10]. The REM/non-REM difference in body temperature is most apparent during the first hour of sleep [11]. Several researchers have investigated the effects of passively changing body temperature on these sleep characteristics. If a person is immersed in warm water so that there is an increase in body temperature of 1.5–2.5 °C, then the time between retiring to bed and initiation of sleep (latency) is shortened and the non-REM stages that are associated with a deep recuperative sleep (known as 'slow-wave' sleep stages) are enhanced [12,13]. Such changes are likely to be clinically important for individuals who generally sleep poorly, such as elderly people [14].

Given the relationships between sleep and thermoregulation, one could hypothesise that the circadian rhythm in body temperature is vital to human sleep and, *vice versa*, that good nocturnal sleep is an important factor governing efficient thermoregulation. Nevertheless, it has proved difficult to separate these two hypotheses [15]; i.e. does sleep mediate changes in thermoregulation or is it thermoregulation that induces sleep? Researchers have attempted to manipulate body temperature pharmacologically (using melatonin, for example) in investigations of sleep. Whilst the hypothermic effects of melatonin have been found to affect sleep propensity [16], this secretory product of the pineal gland may also have quite separate hypnotic effects [17] making it a "noisy" pharmacological intervention in sleep research. Krauchi et al. [16] used a multiple regression model to examine the relative strength of various melatonin-induced effects on sleep characteristics. In support of the notion that the hypothermic effects of melatonin are more important than the hypnotic effects, the best predictor of sleep propensity was the gradient between distal and proximal skin temperatures. These data also support the view that warming of the feet induces a rapid onset of sleep [18].

Endogenous concentrations of melatonin are affected by exercise, although there are conflicting findings regarding the direction of this effect [19]. These conflicting results could be due to differences in lighting conditions and time of day of exercise. It is also possible that the intensity of exercise, gender and age are intervening factors [20–22]. Despite the conflicting results, it is clear that exercise has effects on pineal function and that these effects are relatively short-lived. Atkinson et al. [19] concluded that more research work is needed to identify what the chronic effects of exercise training are on melatonin levels, as well as whether any such chronic effects are associated with the sleep problems that are often reported by overtrained athletes. In one study, Lucia et al. [23] examined world-class cyclists during the Tour of Spain stage race lasting 3 weeks. They found that, although urinary levels of 6-sulphatoxymelatonin (a melatonin metabolite) increased in the evening compared to the pre-stage values, generally there was a decline in 6-sulpatoxymelatonin as the race progressed.

An interesting question is whether there are any interactive effects of melatonin and exercise on thermoregulation and sleep quality. Several researchers have administered melatonin prior to a bout of exercise. In two separate studies, McLellen et al. [24,25] administered 1 mg and 5 mg of melatonin to participants 2 h before, and immediately prior to, walking in an environment of 40°C and 30% relative humidity. The participants wore nuclear biological military suits during this exercise leading to uncompensatable heat stress. Melatonin had no influence on the rectal or skin temperature responses at rest or during walking in these conditions. Recently, Atkinson et al. [26] found that prior ingestion of 2.5 mg of melatonin did lower rectal temperature during a subsequent 1-h bout of intermittent running (Fig. 1). The exercise was performed in the morning in this study. No researcher has examined the presence of any such interactive effects of melatonin and exercise in the evening prior to nocturnal sleep.

The results of neuroanatomical research also support the hypothesis that thermoregulatory changes regulate sleep. The most important processing of thermoregulatory information occurs in the pre-optic area/anterior hypothalamus [27]. Sleep can be initiated if this specific pre-optic area of the brain is warmed, causing neurons to increase their firing rate [28]. Moreover, similar effects can be measured if the skin is warmed, suggestive of a direct neural pathway between the periphery and somnogenic areas of the brain [29]. Although a neuroanatomical model of sleep regulation remains to be fully elucidated, the fact that warming the periphery induces sleep may lead to practical methods for sleep facilitation, such as footbaths [15]. Given that the prevalence of insomnia could be as high as 34% in some populations [14], such non-pharmacologic methods have appeal.