

The Effects of Physical Activity on Sleep among Adolescents and Adults: A Narrative Review

Sophie Desjardins^{1,*}, Manuel Tanguay-Labonté¹

¹Department of Psychology, Université du Québec à Trois-Rivières, Canada.

ABSTRACT

Objective: Examining the correlation between physical activity measures and sleep in normal adolescents and adult population.

Methods: A systematic review was conducted on the effects of exercise, its intensity, its frequency and its timing and sleep outcome. Using the databases including *MEDLINE*, *PsycINFO* and *SPORTDiscus*, keywords used were "sleep", "circadian rhythm", "exercise", and "physical activity".

Results: To improve the general quality of sleep amongst adolescents and adults, individuals should engage in physical activity at any time of day. It also appears very advantageous to engage in long-term physical activity to maintain the positive effects on sleep. Nonetheless, it seems that sedentary individuals can also benefit from occasional physical activity to improve the quality of their subsequent sleep period.

Conclusion: A virtuous relationship between physical activity and sleep may exist in normal adolescents and adults. People should seek to benefit from this link to improve both the quality of their sleep and of their daily functioning. However, larger scale studies, controlling for variables might help to better delineated this relationship.

Corresponding author: Sophie Desjardins, Department of Psychology, Université du Québec à Trois-Rivières, Canada

Keywords: sleep, physical activity, exercise, adolescents, adults

Received: Mar 30, 2018

Accepted: May 17, 2018

Published: May 22, 2018

Editor: Karim Sedky, Cooper Hospital-Rowan University

Introduction

The American Academy of Sleep Medicine [1] maintains that physical activity is a highly effective tool of good sleep hygiene. Many authors [2-5] share this view.

The World Health Organization [6] defines physical activity by type, frequency, intensity, duration and total quantity. These variables are often retained during studies of physical activity and sleep. However, most studies do not control for all of these variables simultaneously. The findings are consequently less conclusive because specific covariates need to be examined in addressing the relationship between physical activity and sleep.

Another variable of physical activity that may influence sleep, not used by the World Health Organization, is the time of day when it occurs. Some authors [7,8] argue that physical activity performed before the sleep period does not influence the quality of sleep, whereas other researchers report opposite results [9]. These results will be reviewed in this paper.

Links between physical activity and sleep

No meta-analysis exists about the links between physical activity and sleep in the adolescent population. However, regarding the adult population, three meta-analyses [10-12] were performed before the 21st century. The meta-analysis of Kubitz et al. [11] examined 32 studies of acute exercise and 12 studies of regular exercise, while the meta-analysis of Youngstedt et al. [12] reviewed 38 studies of acute exercise.

The latest meta-analysis [10] included the studies of the two previous meta-analyses and added the most recent ones. Of the 66 studies included in the analysis, 41 were studies of acute exercise and 25 were studies of regular exercise. Results suggested that acute exercise has a beneficial effect on many objective indices of sleep: total sleep time (TST) ($d = 0.22$, $p < .001$), slow-wave sleep (SWS) ($d = 0.19$, $p = .03$), sleep efficiency (SE) ($d = 0.25$, $p < .001$), sleep onset latency (SOL) ($d = -0.17$, $p = 0.03$), wake time after sleep onset ($d = -0.38$, $p < .001$), and stage 1 sleep ($d = -0.35$, $p < .001$). It means that TST, SE, and duration of slow wave sleep were increased, and that SOL, time awake after sleep onset and duration of stage 1 were decreased, on days after acute exercise

compared to control days of no exercise. Acute exercise also had effect on rapid eye movement sleep (REM) ($d = -0.27$, $p = .005$), indicating that REM was shorter on days after acute exercise compared to control days. Results also suggested that regular exercise has effects on TST ($d = 0.25$, $p = .005$), SE ($d = 0.30$, $p = .002$) and SOL ($d = -0.35$, $p < .05$), indicating that individuals who participated in regular exercise training had significantly greater TST and SE and shorter SOL than individuals in control conditions. Effects were moderated by sex, age, baseline physical activity level of participants, as well as exercise type, time of day, duration, and adherence. Significant moderation was not found for exercise intensity, aerobic versus anaerobic classification, or publication date.

The generalization of these findings to adolescents is uncertain as adolescent sleep and circadian rhythms may differ from that of adults. Adolescence is a period of maturation and development in which biological and environmental factors are likely to cause changes in sleep patterns [13]. For example, percentage of stage 2 sleep increases with age from childhood until old age [14]. It is also known that SWS decreases across adolescence by 40% from preteen years and continues a slower decline into old age, even when length of nocturnal sleep remains constant [15]. Moreover, adolescents are recognized to have a biological delay in the timing of sleep onset, which can result in them staying awake later [16].

Given the above, the purpose of this narrative review is to present the studies that link physical activity and sleep in adolescents and adults within the normal population. Unlike previous meta-analyses, the following review: (1) includes adolescents and adults, (2) focus specifically on intensity, frequency, and time of day of the physical activity, as well as on the subject physical fitness; (3) includes studies without the presence of a control group or of a control condition; (4) excludes studies of populations with sleep disorders; (5) is accessible to researchers, clinicians and people who have no background in statistics or research.

Method

The databases used for this compilation of studies are *MEDLINE*, *PsycINFO* and *SPORTDiscus*. The keywords used for the research are: "sleep", "circadian

rhythm", "exercise", and "physical activity".

Regarding the adolescent population, all of the pertinent scientific papers were included regardless of the date, until December 2015 inclusively. For the adult population, all of the pertinent scientific papers from August 1995 to December 2015 inclusively concerning the links between physical activity and sleep were retained. The articles retained were written in English.

The criteria for the inclusion of articles were: (1) publication date of the article, depending on the study population (see above); (2) objective of examining links between physical activity and sleep; (3) presence of at least one sleep variable studied (sleep quality, stages of sleep, SOL, SE, TST or number of nighttime awakenings after sleep onset {NAASO}); (4) measurement of physical activity according to different factors (time of day, intensity, frequency or physical fitness of the sleeper); and (5) participants were adolescents (ages 12 to 17) or adults under 65 years old.

The criteria for the exclusion of articles were: (1) featuring individuals who had a physical or a mental health problem that might interfere with either their sleep or ability to exercise; (2) presence of concomitant clinical disorders (diagnoses); and (3) children younger than 12 or adults older than 65.

Figure 1 presents a synthesis of the research strategy used to compile the articles. Twenty-one articles were excluded after review. Of them, 6 were non-pertinent [5,17-21], 2 had no precise measure of sleep [22,23], 2 had no precise measure of physical activity [24,25], and 11 had a methodology that did not respect the above inclusion and exclusion criteria [26-36].

Objective measures of sleep were based on actigraphy (e.g. SleepWatch or Actiwatch), sleep-electroencephalography (EEG) devices or polysomnography (PSG). Subjective measures were provided by the Pittsburgh Sleep Quality Index [37] or the Insomnia Severity Index [38].

Time of physical activity were examined across studies and divided into: morning (just after the awakening to three hours after awaking), early evening (six to three hours before bedtime) and late evening (three hours to 30 minutes before bedtime). In addition,

physical activity was divided into: easy (usually corresponding to 45% of maximal oxygen uptake [VO_{2max}]), moderate (60% of VO_{2max}), and vigorous (75% of VO_{2max}) [39]. VO_{2max} was defined by Hill and Lupton [40] as the oxygen uptake attained during maximal exercise intensity that could not be increased despite further increases in exercise workload, thereby defining the limits of the cardiorespiratory system. A moderate intensity can also refer to an exercise at 65-70% of maximal heart rate, while high-intensity exercise is at 85-90% of heart rate [41]. Furthermore, moderate-to-vigorous exercise can be defined as a planned and continuous physical activity in which conversation is not possible [42].

Subjects are usually labelled "unfit" if they are described as having low or average fitness, if they did not perform regular aerobic exercise, or if they possessed low peak oxygen uptake (VO_{2peak}) values (<50 or <40 ml \times kg^{-1} \times $minute^{-1}$ for males and females, respectively) in response to an exercise test. Subjects are labelled "moderately fit" if they engaged in regular aerobic exercise (three times per week for ≥ 20 minutes) or if they have VO_{2peak} values above 50 and 40 ml \times kg^{-1} \times $minute^{-1}$ for males and females, respectively. "Very fit" subjects are competitive endurance athletes [21].

Results

The set of results obtained from the articles retained will be discussed in this section. Note that the results are reported by study population, namely adolescents (section I) or adults (section II).

Section I – Influence of Physical Activity on Adolescents' Sleep

Multiple links have been drawn between physical activity and sleep. Consequently, in this section each variable of physical activity (namely time, intensity and frequency of physical activity as well as physical fitness of sleepers) will be reviewed individually relative to the benefits associated with sleep. Note that 8 articles regarding adolescents were retained [41-48]. These articles are listed in Table 1.

Time of Physical Activity

First, a study by Dworak et al. [41] involving 11 healthy males, demonstrates that physical activity early in the evening has significant positive repercussions for adolescents on polysomnographic measures. Three

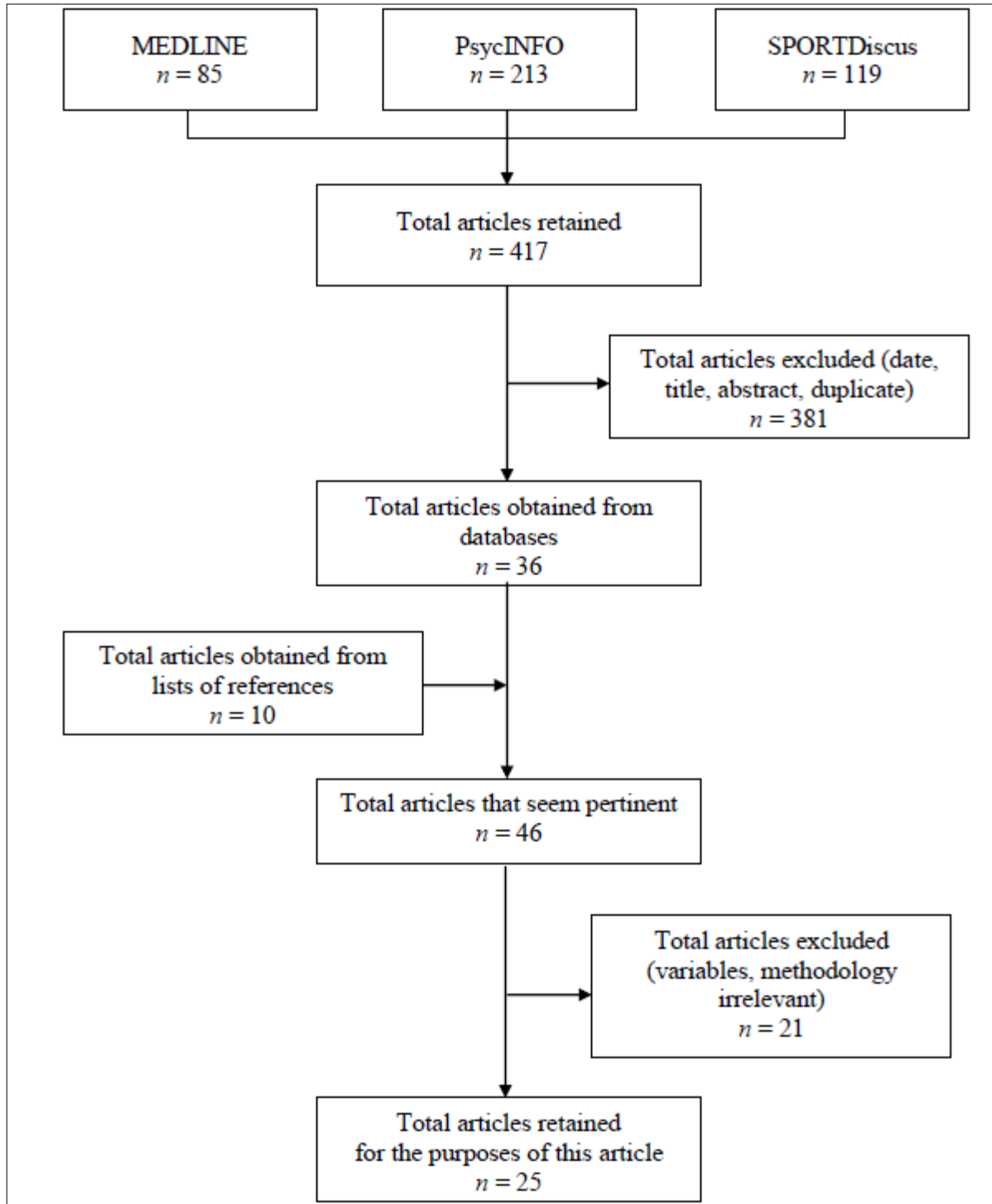


Figure 1. Research strategy for pertinent scientific articles.

Table 1. Articles retained regarding adolescents to achieve the research objectives.

Study	N	% Male	Population
Brand et al., 2009*	36 chronic and intense football players versus 34 controls	100	Adolescents
Brand et al., 2010a	12 football players versus 12 controls	100	Adolescents
Brand et al., 2010b	17 high exercisers versus 21 low exercisers	53	Adolescents
Brand et al., 2010c	258 athletes versus 176 controls	36	Adolescents
Delisle et al., 2010	822 11th- and 12th-grade students	56	Adolescents
Dworak et al., 2008	11 healthy males	100	Adolescents
Foti et al., 2011	14,782 9th-12th-grade students	53	Adolescents
Kalak et al., 2012	51 participants	47	Adolescents

*Note: The sample in Brand et al. (2010a) is a subsample of the sample of Brand et al. (2009). Otherwise, there is no overlap between the studies of Brand et al.

experimental conditions were compared: baseline (no exercise), moderate exercise in early evening, and high intensity exercise in early evening. The results showed decreased SOL, while SE and SWS increased, with rapid cycle going from the first to the fourth stage of sleep, after high-intensity exercise compared to moderate exercise and basal conditions. Note, that all of the adolescents studied were considered normal. (In the present article, the adjective "normal" is used to designate individuals who are neither sedentary nor extremely physically active; they are thus situated between the two poles of this continuum). Therefore, according to the results of this research, intense physical activity in the early evenings may be advantageous.

Kalak et al. [42] conducted a study on 51 adolescents who engaged in physical activity in the morning. Compared with the control group, who were hardly physically active, they found that adolescents who were regularly physically active had better

subjective sleep quality as assessed by the Insomnia Severity Index. This result is also supported by the objective measures obtained, notably a larger proportion of SWS, shorter SOL and prolonged REM latency. Exercise in the morning may thus improve sleep.

Therefore, the positive effects of physical activity on adolescents' sleep are observed when physical activity occurs in either the early evening or morning.

Intensity of Physical Activity

Physical activity varies in intensity. For the same individual, varying intensity of exercise may have different effects on the subsequent sleep period. Examining this variable is therefore important to understand the links between physical activity and sleep.

Kalak et al. [42] examined 51 adolescents and found that moderate physical activity has a favourable impact on adolescents' sleep. They note a larger

proportion of SWS, along with short SOL, delayed onset of REM sleep and better subjective sleep quality.

These results diverge from those obtained by Dworak et al. [41], who find no significant objective impact relative to the base measures in their group that engages in moderate physical activity. In contrast, they argue that intensive physical activity has positive and significant repercussions. Particularly, they note that intensive physical activity fosters better SE, shorter SOL, more SWS, and an ability to move from the first to the fourth stage of sleep at a faster rate. Analysis of the methodology of the preceding two studies mentioned shows that the divergence of results between them may result from the frequency of physical activity. Therefore, greater frequency of physical activity may suffice to exert significant positive effects on adolescent sleep who engage in moderate physical activity. In the study of Kalak et al. [42], subjects went running every morning for three consecutive weeks. In the study of Dworak et al. [41], subjects performed exercise sessions on two days only.

However, Foti et al. [48] did not find a significant association between intensity (low, moderate or sustained) of physical activity and the variable of "sufficient sleep" in adolescents who participated in their study. These results diverge from those obtained by Delisle et al. [47], who affirm that only intensive physical activity is associated with sufficient sleep, with the exception of exercise at five times a week. Foti et al. [48] also hypothesised that frequency could be more important than intensity of physical activity. The study by Foti et al. [48] examined nearly 15,000 adolescents, whereas the second study involved only 822 students. Lastly, it is difficult to draw conclusions of cause-and-effect given the correlation in the research outlines of these studies. Thus, several non-controllable variables may have influenced the results obtained. Further, no objective measure of sleep was defined (SWS, REM sleep, SE, etc.).

Furthermore, two studies [44,46] report that sustained physical activity has important and enduring repercussions on sleep. The results show that compared with a control group, intensive physical activity leads to better objective and subjective sleep quality: better subjective sleep quality [46], a larger proportion of SWS

[44], a smaller proportion of REM sleep [44], shorter SOL [44,46], and a decrease in NAASO [44,46]. However, as mentioned previously, the results of these studies indicate that these benefits are possible only for individuals who exercise regularly.

Brand et al. [45] obtained nearly identical results amongst adolescents who engaged in sustained physical activity. More effective sleep, more SWS and less REM sleep were documented. However, the lack of benefits observed regarding subjective sleep quality, SOL and NAASO can be explained by the fact that the methods used differed amongst the three studies that Brand et al. conducted in 2010. Brand et al. (1) compared 12 vigorous football players versus 12 controls with sleep-EEG registration and subjective measures following a day without exercise; (2) compared sleep-EEG patterns and data from subjective measures of 17 higher leisure time exercisers and 21 controls following a day without exercise; and (3) compared 258 athletes and 176 controls with subjective measures 7 consecutive days.

Overall, it seems that physical activity performed at a sustained intensity has enduring positive benefits regarding the sleep period. Moderate physical activity may also be beneficial, but the findings are very heterogeneous, even less supportive to low intensity exercise. It is also important to mention that the frequency of physical activity also seems to explain much of the results obtained.

Frequency of Physical Activity

Kalak et al. [42] found that regular physical activity is a factor that favours better subjective and objective sleep. These authors observed structural changes in adolescents' sleep who exercised five times a week during a three-week short program to include a larger proportion of SWS, shorter SOL and delayed onset of REM sleep. These results converge with those of other studies.

Brand et al. [45] compared two groups of adolescents who engaged in frequent physical activity after one day of inactivity. The two groups were formed based on the frequency of their physical activity. The authors observed that the more regular the physical activity, the more efficient the sleep period. This translated into a smaller proportion of REM sleep in

favour of a larger proportion of SWS, fewer NAASO and longer sleep period. Foti et al. [48] found other positive results and affirm that regular physical activity over a longer period lengthens the sleep period.

To summarise, all of the studies mentioned in this section have favourable results that demonstrate that the frequency of physical activity, be it high or regular, has positive impact on adolescents' sleep.

Physical Fitness of Sleepers

Roveda et al. [49] assert that the effect of physical activity on sleep may differ between individuals under the same protocol. A distinctive inter-individual characteristic that may influence the results obtained in the literature is the individual's physical fitness level.

First, two studies [43,46] demonstrate that physical fitness has a major impact on sleep. Amongst athletes, a better night is reported compared with sedentary peers. Sleep is much more restorative and of better quality in individuals who are physically active. These individuals also have shorter SOL and fewer NAASO. Nearly identical results amongst other athletes were found a year later by Brand et al. [44]. These researchers also found a smaller proportion of REM sleep in favour of a larger proportion of SWS. This architectural pattern indicates more effective sleep that promotes physical recovery.

In normal adolescents, positive effects of physical activity have been demonstrated: a larger proportion of SWS [41,42,45], a faster onset of SWS [41], a shorter SOL [41,42], delayed onset of REM sleep [42], a smaller proportion of REM sleep [45], fewer NAASO [45], a longer sleep period [45], a more efficient sleep period [41] and better quality subjective of the sleep period [42]. In contrast, by analysing all of the results of the studies mentioned in this paragraph, the benefits of physical activity on sleep appear to be strongly influenced by the frequency or intensity of the physical activity.

Overall, a link seems to exist between individuals' physical fitness level and the quality of their sleep. Higher physical fitness was associated with improved sleep quality and its parameters.

Section II – Influence of Physical Activity on Adults' Sleep

After having examined the links between physical activity and sleep in the adolescent population, we report the results regarding the adult population in a similar manner. Time, intensity and frequency of physical activity as well as physical fitness of sleepers are addressed. Seventeen articles were retained to examine the effect of physical activity on sleep parameters in adults [7-9,39,49-61]. These articles are listed in Table 2.

Time of Physical Activity

First, Roveda et al. [49] examined 11 healthy males and found important benefits related to physical activity performed during the day and particularly the morning: individuals fell asleep more quickly, their sleep is more restorative, with longer sleep period. The latter observation contradicts the findings of Tatum [55] that physical activity in the morning is associated with a shorter sleep period. The difference between the two studies can be explained by the fact that the participants in Tatum's study were exclusively university students, who generally go to sleep later than adults in the general population [55], and by the time spent between awakening and physical activity. This latter study also included larger number of participants (1,003 individuals), mostly females, which might also contribute to this difference.

In addition, engaging in physical activity late in the evening has long been considered as impairing individuals' ability to sleep [1]. Because physical activity increases the body temperature, consequences on the subsequent sleep period are generally expected when these two events occur at close intervals [62]. Taylor [62] asserts that physical activity provokes a state of alertness that prevents the body from achieving a state of relaxation in order to prepare for the sleep period. However, O'Connor et al. [9] had demonstrated a few years earlier that the increase in body temperature before the sleep period did not interfere at all with the objective sleep quality. These results are supported by the observation of stability in SOL, NAASO and SE amongst their participants.

Lastly, Taylor [62] advances that an increase in body temperature following physical activity in the early

Table 2. Articles retained regarding adults to achieve the research objectives.

Study	<i>N</i>	% Male	Population
Bulckaert et al., 2011	9 participants	44	Adults
Flausino et al., 2012	17 good sleepers	100	Adults
Hague et al., 2003	16 healthy individuals	50	Adults
Kobayashi et al., 1999, cited in Myllymäki et al., 2011	Sedentary participants	-	Adults
Leopoldino et al., 2013	22 sedentary participants	-	Adults
Myllymäki et al., 2011*	11 physically fit adults	64	Adults
Myllymäki et al., 2012	14 healthy males	100	Adults
O'Connor et al., 1998	16 male participants	100	Adults
Roveda et al., 2011	15 healthy, trained, males	100	Adults
Souissi et al., 2012	12 trained subjects	-	Adults
Tatum, 2011	1,003 participants	25	Adults
Taylor et al., 1997	7 female swimmers, competitive at a national level	0	Adults
Tsunoda et al., 2015	5,349 participants	51	Adults
Wong et al., 2013	12 sedentary participants	25	Adults
Wu et al., 2015	4,747 college students	42	Adults
Yoshida et al., 1998	5 healthy university students	100	Adults
Youngstedt et al., 1999	16 highly fit male cyclists	100	Adults

*Note: The subjects in the two studies of Myllymäki et al. are different, so there is no overlap between these studies.

evening helps promote sleep. The author notes that the decrease in body temperature when the sleep period approaches is a normal biological process. Given that physical activity increases body temperature, the body seeks to regain its homeostasis and thereby uses the same processes as during the approach of the sleep period to decrease body temperature, namely dilation of blood vessels and increased blood flow to the peripheral regions of the body [62]. This process therefore acts as a catalyst of sleep initiation. Morin et al. [63] corroborate these findings by affirming that physical activity early in the evening improves the general quality of sleep in different members of the population.

By controlling for body temperature, Souissi et al. [54] found important differences concerning the effects of physical activity early in the evening on the sleep period. The authors observed lower SE in 12 adults when physical activity occurs late in the evening compared with more SWS, fewer NAASO and shorter SOL when physical activity occurs earlier. Similarly, Bulckaert et al. [50] observe negative effects on SWS when physical activity occurs in the late evening for 9 participants. In contrast, Yoshida et al. [60] also compared the effect of physical activity on sleep depending on the time it occurred, and found different results. Notably, the study analysed physical activity at three different periods, namely the morning, early evening and late evening. The authors observed better subjective sleep quality and more SWS during the first cycle of sleep when the 5 participants were physically active in the late evening. The difference between the results reported in this paragraph may be explained by important methodological weaknesses, specifically the low number of participants: between 5 and 12 participants for the three studies.

Wong et al. [58] examined 12 participants and found that physical activity does not influence negatively the main parameters of sleep (namely TST, SOL, wake after sleep onset, REM onset, SE, and SWS) when it occurs in the early evening. Indeed, this study demonstrates that the only significant effect is an increase in the time spent in the first two stages of sleep.

Other studies have also investigated the effect of the timing of physical activity on sleep, including that

of Kobayashi et al. [52]. The authors demonstrated that physical activity in late evening significantly reduces the SOL compared with physical activity at another time of day. Another study by Myllymäki et al. [8], involving 11 adults, found a better sleep period after physical activity in the late evening. Specifically, better SE, less time spent in the first stage of sleep, and fewer NAASO were reported. In addition, the authors observed significantly more time spent in the first four stages of sleep amongst participants of the experimental group compared with the control group. All of these results were corroborated a year later by Flausino et al. [7], who used a similar methodology to Myllymäki et al. [8], with the exception of time spent in the first four stages of sleep.

Further, it seems that the increase in body temperature following physical activity does not systematically interfere with sleep quality, notably SOL. However, other variables linked to physical activity before the sleep period may need to be considered. Since exercise may increase heart rate (HR) even after the exercise is completed, this variable has often been considered by authors.

First, Bulckaert et al. [50] reported that physical activity late in the evening may have a negative effect on SWS in adults. Their study measured HR at different stages of sleep. Compared with the base measure, HR was highest during SWS in participants who had gone cycling before sleeping. This increase in HR putatively competes with SWS, in which a state of deep relaxation is optimal. A rapid HR would impede the body from recovering optimally. More than a decade earlier, Youngstedt et al. [61] had maintained that physical activity just before the sleep period had no effect on the HR of physically active individuals. They explained this result by the possibility that these individuals had developed a different metabolism from others, and that their parasympathetic nervous system could recover more easily following physical activation. This would help them decrease their HR rapidly before the sleep period.

In addition, Myllymäki et al. [39] studied the effect of physical activity during the evening in other adults. These authors filled a gap in study by Youngstedt et al. [61] conducted in 1999 by investigating the architecture of sleep. Supported by a highly rigorous

methodology, this study reached the same conclusions as that of Youngstedt et al.: (1) individuals' metabolism seems to play an important role in an individual's capacity to recover following physical activity; and (2) physical activity in the evening does not seem to have a negative effect on objective and subjective sleep quality.

To summarise, HR has no effect on objective and subjective sleep quality when individuals are physically active before the sleep period. The hypotheses formulated by Bulckaert et al. [50] are theoretically probable, but contradict the results obtained by other studies that used a similar methodology [9,52,60] where participants generally had good or satisfactory sleep quality. The methodological weaknesses reported above may explain these divergent results, but several other variables linked to physical activity may also affect the results, including the intensity of physical activity.

In sum, the results suggest that adults should engage in physical activity at any time of day.

Intensity of Physical Activity

Some studies conclude that light, moderate or sustained physical activity has no negative or positive effect on the sleep period [9,39,61]. In contrast, Tatum [55] reports a positive association between SE and intensity of physical activity.

Several studies report benefits related to the intensity of physical activity. Moderate activity was associated with better SE [7], shorter SOL [52], less time spent in the first stage of sleep [7] and fewer NAASO [7]. In addition, an increase in the proportion of SWS in the first cycle of sleep and better subjective sleep quality were observed [60]. The diverging results obtained in the two preceding paragraphs may be explained by the fact that the studies that did not find a favourable result for sleep included solely physically active participants. Indeed, in general, moderate physical activity seems to have an effect only on individuals considered normal or sedentary.

Taylor et al. [56] reported similar findings among 7 female athletes, namely that the variation in intensity of physical activity over a long period affects objective sleep quality in female athletes. Specifically, the authors conclude that the higher the effort of

physical activity, the more the sleep architecture is modified to increase the proportion of SWS during the first cycle of sleep, which corroborates the energy conservation theory of Berger and Phillips [64]. In contrast, the athletes studied did not report any changes in the subjective quality of the sleep period, which contradicts the results obtained by Tsunoda et al. [57], who noted a subjective improvement in the sleep period in their participants who engaged in moderate to sustained physical activity. The divergence between these results can be explained by the fact that the study by Tsunoda included over 5,000 participants, whereas the study by Taylor et al. involved only seven participants. In addition, the research was correlational for the study by Tsunoda et al., and experimental for that of Taylor. It is therefore difficult to draw precise conclusions given the limitations of the methods used for the two studies.

Further, an increase in time spent in the first two stages of sleep was observed in individuals who engage in sustained physical activity [58]. In addition, Roveda et al. [49] report better SE, a longer sleep period and a reduction in SOL amongst individuals who engage in sustained physical activity. Lastly, a larger proportion of time spent in the first four stages of sleep was observed in respondents who engage in sustained physical activity [8].

Souissi et al. [54] report similar results. They also observe the benefits of intensive physical activity on sleep: an increase in SWS, fewer NAASO and shorter SOL. However, these characteristics are present only when physical activity takes place in the afternoon. When intensive physical activity occurs in the evening, the authors report less efficient sleep. Therefore, although the intensity of physical activity may affect sleep quality, it seems that the time it occurs may also have a significant impact on sleep.

To summarise, moderate physical activity can improve sleep in normal or sedentary individuals. In athletes, more intense exercise seems required to achieve the same benefits. In that case, the afternoon seems like a particularly good time to train.

Frequency of Physical Activity

A study by Leopoldino et al. [53] among 22 individuals demonstrates that doing exercise for one

hour twice a week decreases daytime sleepiness in sedentary individuals. The authors also conclude that their program, which lasted only 12 weeks, suffices to improve sleep quality, concomitantly increasing participants' quality of life. Leopoldino et al. maintain that the benefits of the training program are an increase in SWS and a decrease of SOL. However, Wu et al. [59] did not find an association between physical activity three times a week and better sleep quality. This later study involved 4,747 college students.

Hague et al. [51] examined 16 healthy individuals and found that one day without physical activity had a negative impact on subsequent sleep. Specifically, Hague et al. observed an increase in REM sleep, an increase in SOL, and a decrease in SWS in their participants. Given that the participants were physically active adults, these conclusions point to a structural change in the sleep period amongst individuals who have a stable lifestyle, after only one day that deviates from their usual routine. Similarly, Tatum [55] observed a positive association between frequency of physical activity and SE, which highlights the importance of the frequency variable.

In short, it appears very advantageous to engage in long-term physical activity to maintain the positive effects on sleep. Nonetheless, it seems that sedentary adults can also benefit from occasional physical activity to improve the quality of their subsequent sleep period.

Physical Fitness of Sleepers

Several studies show that physical activity amongst normal people has a positive impact on sleep: better SE, less time spent in the first stage of sleep, fewer NAASO [7,54], more SWS [54], and more time spent in the first four stages of sleep [8].

Amongst individuals considered as sedentary, physical activity promotes SE and reduced daytime sleepiness [53,60]. The latter change is attributed to an increase in SWS [53,60]. Amongst these participants, physical activity has other benefits, including an increase in the subjective quality of the sleep period [60], and a decrease in SOL [53]. Further, the decrease in SOL is also observed in another study of the same type of participants [52]. However, these results are not corroborated by Wong et al. [58], who observe only a

minor improvement in the sleep parameters when sedentary individuals engage in physical activity, namely more time spent in the first two stages of sleep. It is possible that these divergent results arise from methodological weaknesses such as the number of participants, which was low in some studies [58,60].

Regarding physically active individuals, several authors [9,39,61] found no effect of physical activity on sleep.

These results run counter to those of Roveda et al. [49] and of Hague et al. [51]. Roveda et al. found that physically active adults slept better when they engaged in physical activity than when they stopped. Accordingly, the authors observed a longer sleep period characterised by a reduction in SOL, along with higher SE, when participants were physically active. Other results demonstrating the importance of remaining physically active were obtained by Hague et al. Notably, they noticed an increase in REM sleep, an increase in SOL, a reduction in the time required to achieve REM sleep and a reduction in SWS after one day without physical activity. Therefore, for individuals who are physically active, stopping physical activity may have important negative consequences on sleep.

In summary, benefits of physical activity on sleep appear more important in sedentary individuals compared to physically active adults. In return, stopping physical activity in the latter group may interfere with sleep.

Discussion

In general, given the results compiled in this article, physical activity seems to have a positive impact on both objective and subjective sleep quality. Therefore, individuals who want to improve their sleep should adopt a physical activity program that considers the variables reviewed in this article. Specifically, the results of this review generally demonstrate that the proportion of SWS increases during the sleep period following physical activity. This is very beneficial for individuals who are physically active because it is during SWS that the growth hormone is secreted, which is responsible for the body's recovery [65]. However, exercise decreases REM which is where consolidation of memory [66] and emotional memory processing occur [67]. The decreased REM propensity may be due to an

increased need for non-REM or alternatively an indicator of sleep fragmentation [68]. Another plausible mechanism for the alteration of REM episodes is the elevation of catecholamine levels, rather than some direct brain function response [69].

Researchers have observed that the frequency of physical activity amongst adolescents has a significant impact on sleep duration [45,47,48]. However, other variables linked to physical activity in the studies examined were not associated with an increase in sleep duration. Therefore, adolescents who want to increase their sleep period to the prescribed number of hours by engaging in physical activity should attempt to increase the frequency of exercise. For the adult population, only one study [49] observed a significant increase in sleep time following physical activity. Specifically, the sleep period is longer when physically active individuals engage in intense physical activity.

Further, in the literature several results diverge concerning links between exercise and sleep. Given these inconsistencies, it is possible that some non-isolated and non-considered covariates or potential moderators may have influenced the results. As Torsvall [70] argued, many divergences of opinions found in the literature on the effect of physical activity on sleep originate in the methodologies used.

Before exploring the covariates or potential moderators, it is important to point out that the relationship between physical activity and sleep is complex [28] and that is difficult to control all the variables simultaneously. Our inventory of the concomitant variables is therefore not a judgment on the quality of studies consulted for this article, but rather recommendations for the methodological orientation of future research on physical activity and sleep.

First, it is known that light exposure affects sleep via circadian rhythms [26,71,72]. Light exposure affects individuals in all situations, not necessarily during physical activity exclusively. Most studies reviewed for this article did not control exposure to daylight (or artificial light) during the data collection. Future research could control this variable. Given the diversity of lifestyles and ways to engage in physical activity, it would be advisable to consider inter-individual

differences in light exposure, which could bias the results.

Some results may have been influenced by the participants' level of sleep disturbance, which may create a floor or ceiling effect. Even if people with significant sleep difficulties were eliminated from the studies selected to attain our research objectives, some floor or ceiling effects may have been present in the studies. For example, Youngstedt [73] and Driver and Taylor [3] mention that the more an individual's sleep is disturbed, the greater their potential for improvement, and vice-versa. It may therefore be relevant to consider this possibility when results diverge between two studies with similar methodologies. For instance, the sleep of participants in the first study may be more or less disturbed (as indicated by base measures, for example) than that of their peers in the second study. Although it may seem difficult or unrealistic to control each of these individual differences in sleep disturbance, it would be interesting for researchers and readers to keep this possible variance in sleep disruption in mind when they observe studies with similar methodologies but disparate results.

Further, other variables associated with ceiling effects were reported by several authors [3,21,58]: healthy lifestyle that improves sleep, and physically active individuals who may have developed optimal sleep before the data collection. Several studies compiled in this article did not control for these variables. Therefore, future research could have respondents complete questionnaires on lifestyle, and use protocols where sleep is studied in active individuals after withdrawal from physical activity or in comparison with a control group.

In a similar vein, Driver and Taylor [3] emphasise the importance of adding subjective measures to studies of the links between physical activity and sleep, for example: the feeling of waking up in fine form, the feeling that sleep was restorative, etc. Not all studies addressed this dimension. We must bear in mind that collection of subjective data may support objective data, which can reinforce the results obtained. However, as Youngstedt et al. [74] report, the use of self-reported measures has limitations. Specifically, this approach is biased by nonconformity to the norm and the lack of precision when participants report their data.

Overall, given these particularities, studies of this subject should include more subjective measures to support the objective measures, to partly isolate the disadvantages of each type of measure.

Another important point to consider concerns research protocols. As Youngstedt et al. [74] assert, several studies of the links between physical activity and sleep examined sleep after only one or two days of physical activity. Yet given that sleep is influenced by several other variables, it seems difficult to attribute a unique effect of physical activity to sleep when interpreting the results. To fill this gap, Youngstedt et al. propose that the effect of physical activity on sleep be observed for several days, notably by manipulating the daily level of physical activity. They argue that this level may vary on a continuum from a completely sedentary day to a day where participants must engage in physical activity more intensely and longer than usual.

Our findings are consistent with the meta-analysis performed by Kredlow et al. [10] in demonstrating that exercise has a beneficial effect on sleep. In a similar vein, the results of this meta-analysis indicated that physical fitness of sleepers as well as time of day and frequency of exercise moderate the relationship between exercise and sleep. In contrast, Kredlow et al. found no significant differences in effect size across light, moderate, and vigorous intensity for acute exercise. Due to power constraints, they were unable to examine intensity as a moderator of the effects of regular exercise on sleep. They found, however, that exercise type moderates sleep outcomes. When comparing different types of acute exercise, cycling appeared to be more beneficial than running. The authors stated that this might be because cycling is low impact and tends to result in fewer injuries than running. We can hypothesize that the patients with insomnia or other disorders included in the meta-analysis were particularly sensitive to this, which can explain the discrepancies between our review and the meta-analysis.

Many mechanisms to explain the relationship between exercise and sleep have been proposed. Studies have reported effects of exercise on (1) temperature during sleep, (2) cardiac and autonomic function during sleep, (3) endocrine function during sleep, (4) metabolic function during sleep, (5) the

immune-inflammation response during sleep, (6) mood during the night. These mechanisms will not be explained here. For a review, interested readers can see Buman & King [18], Chennaoui et al. [75] and Uchida et al. [76].

It is important to state the limitations of this article. First, the type of physical activity was not considered in the data analysis. However, contrary to what Kredlow et al. [10] argued but as Tatum [55] contends, it seems difficult to determine the effect of the type of physical activity on sleep because it may be confounded with the effect of the intensity of the physical activity. Therefore, Tatum affirms that the intensity of the activity is more important to consider than the type of physical activity. In addition, only one person compiled the literature review. It is therefore impossible to calculate inter-rater agreement regarding the application of the inclusion and exclusion criteria for the articles compiled. Furthermore, few studies of adolescents could be analysed in this paper, which limited the quantity of data regarding the time of physical activity and the physical fitness of the sleepers in this population. Lastly, effect sizes of results obtained in the scientific papers were not considered during the analysis of the results of this research.

Conclusion

To improve the general quality of sleep amongst adolescents and adults in the normal population, the results of this article suggest that individuals should engage in physical activity at any time of day. Further, it seems that moderate to sustained physical activity must be practised at least twice a week for significant changes in sleep to be observed. It also appears very advantageous to engage in long-term physical activity to maintain the positive effects on sleep. Nonetheless, sedentary and normal individuals can also benefit from occasional physical activity to improve the quality of their subsequent sleep period. However, the benefits will endure only if the physical activity is regular.

Physical activity offers several health-related advantages [6,77-80]. This is why its promotion is particularly important. In a similar vein, it is now established that prolonged sedentary behaviour, characterized by a sitting or reclining posture and low-energy expenditure, tends to be associated with an

elevated risk of insomnia and sleep disturbance [81]. Poor sleep, in turn, has several effects on the health of individuals and on society as a whole. It is associated with lower performance and productivity, higher rates of physical and mental disorders, increased accidents, substance use and abuse, mortality and morbidity, and elevated costs of prescriptions, therapies, diagnostic testing, and doctor visits [82].

Sleep and exercise influence each other through complex, reciprocal interactions including multiple physiological and psychological pathways [75]. People should seek to benefit from this link to improve both the quality of their sleep and of their daily functioning.

Regarding the orientation of future studies on the effects of physical activity on sleep, researchers should include a sufficiently high number of participants to improve the generalisability of the results. During the data collection, many of these studies were found to involve a low number of participants. In addition, it is important to rigorously control the concomitant variables and to seek ecological validity. Future studies with experimental design and longer follow-up periods are warranted. A review on the effects of physical activity on sleep among the elderly would also be pertinent.

References

- American Academy of Sleep Medicine. (2001). *International Classification of Sleep Disorders, Revised: Diagnostic and Coding Manual*. Westchester, IL: AASM.
- Atkinson, G., & Davenne, D. (2007). Relationships between sleep, physical activity and human health. *Physiol Behav*, *90*(2-3), 229-235. doi: 10.1016/j.physbeh.2006.09.015
- Driver, H. S., & Taylor, S. R. (2000). Exercise and sleep. *Sleep Med Rev*, *4*(4), 387-402.
- Youngstedt, S. D. (2005). Effects of exercise on sleep. *Clin Sports Med*, *24*(2), 355-365. doi: 10.1016/j.csm.2004.12.003
- Youngstedt, S. D., & Kline, C. E. (2006). Epidemiology of exercise and sleep. *Sleep Biol Rhythms*, *4*(3), 215-221. doi: 10.1111/j.1479-8425.2006.00235.x
- World Health Organization. (WHO; 2012). *Global strategy on diet, physical activity and health*. Retrieved from <http://who.int/dietphysicalactivity/en/>
- Flausino, N., Da Silva Prado, J., de Queiroz, S., Tufik, S., & de Mello, M. (2012). Physical exercise performed before bedtime improves the sleep pattern of healthy young good sleepers. *Psychophysiol*, *49*(2), 186-192. doi: 10.1111/j.1469-8986.2011.01300.x
- Myllymäki, T., Kyröläinen, H., Savolainen, K., Hokka, L., Jakonen, R., et al. (2011). Effects of vigorous late-night exercise on sleep quality and cardiac autonomic activity. *J Sleep Res*, *20*(1 Pt 2), 146-153. doi: 10.1111/j.1365-2869.2010.00874.x
- O'Connor, P. J., Breus, M. J., & Youngstedt, S. D. (1998). Exercise-induced increase in core temperature does not disrupt a behavioral measure of sleep. *Physiol Behav*, *64*(3), 213-217. doi: 10.1016/S0031-9384(98)00049-3
- Kredlow, M. A., Capozzoli, M. C., Hearon B. A., Calkins, A. W., & Otto, M. W. (2015). The effects of physical activity on sleep: A meta-analytic review. *J Behav Med*, *38*, 427-449.
- Kubitz, K., Han, M., Landers, D., & Petruzzello, S. (1996). The effects of acute and chronic exercise on sleep: A meta-analytic review. *Sports Med*, *21*(4), 277-291.
- Youngstedt, S. D., O'Connor, P. J., & Dishman, R. K. (1997). The effects of acute exercise on sleep: A quantitative synthesis. *Sleep*, *20*(3), 203-214.
- Shochat, T., Cohen-Zion, M., & Tzischinsky, O. (2014). Functional consequences of inadequate sleep in adolescents: A systematic review. *Sleep Med Rev*, *18*(1), 75-87. doi: 10.1016/j.smrv.2013.03.005
- Ohayon, M. M., Carskadon, M. A., Guilleminault, C. & Vitiello, M. V. (2004). Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. *Sleep*, *27*(7), 1255-1273.
- Carskadon, M. A., & Dement, W. C. (2011). Monitoring and staging human sleep. In M. H. Kryger, T. Roth, & W. C. Dement (Eds.), *Principles and Practice of Sleep Medicine*, 5th edition (pp.16-26). St. Louis: Elsevier Saunders.

16. Colrain, I. M., & Baker, F. C. (2011). Changes in sleep as a function of adolescent development. *Neuropsychol Rev*, *21*, 5-21. doi:10.1007/s11065-010-9155-5
17. Baehr, E. K., Eastman, C. I., Revelle, W., Olson, S. L., Wolfe, L. F., et al. (2003). Circadian phase-shifting effects of nocturnal exercise in older compared with young adults. *Am J Physiol Regul Integr Comp Physiol*, *284*(6), R1542-R1550.
18. Buman, M. P., & King, A. C. (2010). Exercise as treatment to enhance sleep. *Am J Lifestyle Med*, *4*, 500-514.
19. Buman, M. P., & Youngstedt, S. D. (2015). Physical activity, sleep, and biobehavioral synergies for health. In K. A. Babson, M. T. Feldner, K. A. Babson, M. T. Feldner (Eds.), *Sleep and Affect: Assessment, Theory, and Clinical Implications* (pp. 321-337). San Diego, CA, US: Elsevier Academic Press. doi:10.1016/B978-0-12-417188-6.00015-3
20. Underwood, J. (2010) Sleep now clearly a predictor of performance. *Coaches Plan*, *17*, 31-34.
21. Youngstedt, S. D. (1997). Does exercise truly enhance sleep? *Physician Sports Med*, *25*(10), 72-82.
22. Aerenhouts, D., Zinzen, E., & Clarys, P. (2011). Energy expenditure and habitual physical activities in adolescent sprint athletes. *J Sports Sci Med*, *10*(2), 362-368.
23. Jones, H., George, K., Edwards, B., & Atkinson, G. (2008). Effects of time of day on post-exercise blood pressure: Circadian or sleep-related influences? *Chronobiol Int*, *25*(6), 987-998.
24. Bailey, S. L., & Heitkemper, M. M. (2001). Circadian rhythmicity of cortisol and body temperature: morningness-eveningness effects. *Chronobiol Int*, *18* (2), 249-261.
25. Girardin, J.-L., Mendlowicz, M. V., von Gizycki, H., Zizi, F., & Nunes, J. (1999). Assessment of physical activity and sleep by actigraphy: Examination of gender differences. *J Womens Health Gend Based Med*, *8*(8), 1113.
26. Bonnet, M., & Arand, D. (2005). Sleep latency testing as a time course measure of state arousal. *J Sleep Res*, *14*(4), 387-392.
27. Garcia-Soidan, J. L., Arufe Giraldez, V., Cachon Zagalaz, J., & Lara-Sanchez, A. J. (2014). Does Pilates exercise increase physical activity, quality of life, latency, and sleep quantity in middle-aged people? *Percept Motor Skills*, *119*(3), 838-850.
28. Gerber, M., Brand, S., Holsboer-Trachsler, E., & Pühse, U. (2010). Fitness and exercise as correlates of sleep complaints: Is it all in our minds? *Med Sci Sports Exercise*, *42*(5), 893-901.
29. Harris, K. M., King, R. B., & Gordon-Larsen, P. (2005). Healthy habits among adolescents: Sleep, exercise, diet, and body image. In K. A. Moore, L. H. Lippman, K. A. Moore, L. H. Lippman (Eds.), *What Do Children Need to Flourish: Conceptualizing and Measuring Indicators of Positive Development* (pp. 111-132). New York, NY, US: Springer Science + Business Media. doi:10.1007/0-387-23823-9_8
30. Kobayashi, T., Ishikawa, T., & Arakawa, K. (1998). Effects of daytime activity upon the timing of REM sleep periods during a night. *Psychiatr Clin Neurosci*, *52*(2), 130-131.
31. Lang, C., Brand, S., Feldmeth, A. K., Holsboer-Trachsler, E., Pühse, U., et al. (2013). Increased self-reported and objectively assessed physical activity predict sleep quality among adolescents. *Physiol Behav*, *120*, 46-53. doi:10.1016/j.physbeh.2013.07.001
32. Littman, A. J., Vitiello, M. V., Foster-Schubert, K., Ulrich, C. M., Tworoger, S. S., et al. (2007). Sleep, ghrelin, leptin and changes in body weight during a 1-year moderate-intensity physical activity intervention. *Int J Obes*, *31*(3), 466-475.
33. McClain, J. J., Lewin, D. S., Laposky, A. D., Kahle, L., & Berrigan, D. (2014). Associations between physical activity, sedentary time, sleep duration and daytime sleepiness in US adults. *Prev Med*, *66*, 68-73. doi:10.1016/j.ypmed.2014.06.003
34. Ortega, F. B., Chillón, P., Ruiz, J. R., Delgado, M., Albers, U., et al. (2010). Sleep patterns in Spanish adolescents: associations with TV watching and leisure-time physical activity. *Eur J Appl Physiol*, *110* (3), 563-573.
35. Weydahl, A. (1991). Sex differences in the effect of exercise upon sleep. *Percept Motor Skills*,

- 72, 455-465. doi: 10.2466/PMS.72.2.455-465
36. Weydahl, A. (1991). Sleep-quality among girls with different involvement in competitive sports during fall in the Arctic circle. *Percept Motor Skills*, 73, 883-892. doi:10.2466/PMS.73.7.883-892
37. Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: A new instrument for psychiatric practice and research. *Psychiatr Res*, 28, 193-213.
38. Bastien, C. H., Vallières, A., & Morin, C. M. (2001). Validation of the Insomnia Severity Index (ISI) as an outcome measure for insomnia research. *Sleep Med*, 2, 297-307.
39. Myllymäki, T., Rusko, H., Syväoja, H., Juuti, T., Kinnunen, M., et al. (2012). Effects of exercise intensity and duration on nocturnal heart rate variability and sleep quality. *Eur J Appl Physiol*, 112 (3), 801-809.
40. Hill, A. V., & Lupton, H. (1923). Muscular exercise, lactic acid, and the supply and utilization of oxygen. *Quarterly J Med*, 24(1), 43-51.
41. Dworak, M., Wiater, A., Alfer, D., Stephan, E., Hollmann, W., et al. (2008). Increased slow wave sleep and reduced stage 2 sleep in children depending on exercise intensity. *Sleep Med*, 9(3), 266-272.
42. Kalak, N., Gerber, M., Kirov, R., Mikoteit, T., Yordanova, J., et al. (2012). Daily morning running for 3 weeks improved sleep and psychological functioning in healthy adolescents compared with controls. *J Adolesc Health*, 51(6), 615-622. doi: 10.1016/j.jadohealth.2012.02.020
43. Brand, S., Beck, J., Gerber, M., Hatzinger, M., & Holsboer-Trachsler, E. (2009). Football is good for your sleep: Favorable sleep patterns and psychological functioning of adolescent male intense football players compared to controls. *J Health Psychol*, 14(8), 1144-1155. doi: 10.1177/1359105309342602
44. Brand, S., Beck, J., Gerber, M., Hatzinger, M., & Holsboer-Trachsler, E. (2010). Evidence of favorable sleep-EEG patterns in adolescent male vigorous football players compared to controls. *World J Biol Psychiatr*, 11(2), 465-475. doi: 10.1080/15622970903079820
45. Brand, S., Gerber, M., Beck, J., Hatzinger, M., Pühse, U., et al. (2010). Exercising, sleep-EEG patterns, and psychological functioning are related among adolescents. *World J Biol Psychiatr*, 11(1-2), 129-140. doi: 10.3109/15622970903522501
46. Brand, S., Gerber, M., Beck, J., Hatzinger, M., Pühse, U., et al. (2010). High exercise levels are related to favorable sleep patterns and psychological functioning in adolescents: A comparison of athletes and controls. *J Adolesc Health*, 46(2), 133-141. doi: 10.1016/j.jadohealth.2009.06.018
47. Delisle, T. T., Werch, C. E., Wong, A. H., Bian, H., & Weiler, R. (2010). Relationship between frequency and intensity of physical activity and health behaviors of adolescents. *J Sch Health*, 80(3), 134-140.
48. Foti, K. E., Eaton, D. K., Lowry, R., & McKnight-Ely, L. R. (2011). Sufficient sleep, physical activity, and sedentary behaviors. *Am J Prev Med*, 41(6), 596-602. doi: 10.1016/j.amepre.2011.08.009
49. Roveda, E., Sciolla, C., Montaruli, A., Calogiuri, G., Angeli, A., et al. (2011). Effects of endurance and strength acute exercise on night sleep quality. *Int Sportmed J*, 12(3), 113-124.
50. Bulckaert, A., Exadaktylos, V., Haex, B., De Valck, E., Verbraecken, J., et al. (2011). Elevated variance in heart rate during slow-wave sleep after late-night physical activity. *Chronobiol Int*, 28(3), 282-284. doi: 10.3109/07420528.2011.552820
51. Hague, J. E., Gilbert, S. G., Burgess, H. J., Ferguson, S. A., & Dawson, D. D. (2003). A sedentary day: Effects on subsequent sleep and body temperatures in trained athletes. *Physiol Behav*, 78(2), 261-267.
52. Kobayashi, T., Yoshida, H., Ishikawa, T., & Arakawa, K. (1999). Effects of the late evening exercise on sleep onset process. *Sleep Res Online*, 2(suppl. 1), 233.
53. Leopoldino, A., Avelar, N., Passos, G., Santana, N., Teixeira, V., et al. (2013). Effect of Pilates on sleep quality and quality of life of sedentary population. *J Bodywork Mov Ther*, 17(1), 5-10. doi: 10.1016/j.jbmt.2012.10.001

54. Souissi, M., Chtourou, H., Zrane, A., Ben Cheikh, R., Dogui, M., et al. (2012). Effect of time-of-day of aerobic maximal exercise on the sleep quality of trained subjects. *Biol Rhythm Res*, 43(3), 323-330. doi: 10.1080/09291016.2011.589159
55. Tatum, J. (2011). *The Relationship Between Physical Activity and Sleep* (Unpublished doctoral thesis). University of North Texas, Denton, TX.
56. Taylor, S. R., Rogers, G. G., & Driver, H. S. (1997). Effects of training volume on sleep, psychological, and selected physiological profiles of elite female swimmers. *Med Sci Sports Exercise*, 29(5), 688-693.
57. Tsunoda, K., Kitano, N., Kai, Y., Uchida, K., Kuchiki, T., et al. (2015). Prospective study of physical activity and sleep in middle-aged and older adults. *Am J Prev Med*, 48(6), 662-673. doi: 10.1016/j.amepre.2014.12.006
58. Wong, S., Halaki, M., & Chow, C. (2013). The effects of moderate to vigorous aerobic exercise on the sleep need of sedentary young adults. *J Sports Sci*, 31(4), 381-386. doi: 10.1080/02640414.2012.733823
59. Wu, X., Tao, S., Zhang, Y., Zhang, S., & Tao, F. (2015). Low physical activity and high screen time can increase the risks of mental health problems and poor sleep quality among Chinese college students. *Plos One*, 10(3), e0119607. doi: 10.1371/journal.pone.0119607
60. Yoshida, H., Ishikawa, T., Shiraishi, F., & Kobayashi, T. (1998). Effects of the timing of exercise on the night sleep. *Psychiatr Clin Neurosci*, 52(2), 139-140.
61. Youngstedt, S. D., Kripke, D. F., & Elliott, J. A. (1999). Is sleep disturbed by vigorous late-night exercise? *Med Sci Sports Exercise*, 31(6), 864-869.
62. Taylor, S. R. (2001). The influence of exercise on sleep quality. *Int Sportmed J*, 2(3), 105-134.
63. Morin, C., Hauri, P., Espie, C., Spielman, A., Buysse, D., et al. (1999). Nonpharmacologic treatment of chronic insomnia: An American academy of sleep medicine review. *Sleep*, 22(8), 1134-1156.
64. Berger, R. J., & Phillips, N. H. (1995). Energy conservation and sleep. *Behav Brain Res*, 69(1-2), 65-73. doi: 10.1016/0166-4328(95)00002-B
65. Davenne, D. (2009). Sleep of athletes: Problems and possible solutions. *Biol Rhythm Res*, 40(1), 45-52. doi: 10.1080/09291010802067023
66. Diekelmann, S., & Born, J. (2010). The memory function of sleep. *Nat Rev Neurosci*, 11(2), 114-126. doi:10.1038/nrn2762
67. Walker, M. P., & van der Helm, E. (2009). Overnight therapy? The role of sleep in emotional brain processing. *Psychol Bull*, 135, 731-748. doi: 10.1037/a0016570
68. Driver, H., Rogers, G., Mitchell, D., Borrow, S., Allen, M., et al. (1994). Prolonged endurance exercise and sleep disruption. *Med Sci Sports Exercise*, 26(7), 903-907.
69. Netzer, N. C., Kristo, D., Steinle, H., Lehmann, M., & Strohl, K. P. (2001). REM sleep and catecholamine excretion: a study in elite athletes. *Eur J Appl Physiol*, 84(6), 521-526.
70. Torsvall, L. L. (1981). Sleep after exercise: A literature review. *J Sports Med Phys Fit*, 21(3), 218-225.
71. Campbell, S. S., Dawson, D., & Anderson, M. W. (1993). Alleviation of sleep maintenance insomnia with timed exposure to bright light. *J Am Geriatr Soc*, 41(8), 829-836.
72. Guilleminault, C., Clerk, A., Black, J., Labanowski, M., Pelayo, R., et al. (1995). Nondrug treatment trials in psychologic insomnia. *Arch Intern Med*, 155(8), 838-844.
73. Youngstedt, S. D. (2003). Ceiling and floor effects in sleep research. *Sleep Med Rev*, 7(4), 351-365.
74. Youngstedt, S. D., Perlis, M., O'Brien, P., Palmer, C., Smith, M., et al. (2003). No association of sleep with total daily physical activity in normal sleepers. *Physiol Behav*, 78(3), 395-401.
75. Chennaoui, M., Arnal, P. J., Sauvet, F., & Léger, D. (2015). Sleep and exercise: A reciprocal issue? *Sleep Med Rev*, 20, 59-72.
76. Uchida, S., Shioda, K., Morita, Y., Kubota, C., Ganeko, M., et al. (2012). Exercise effects on sleep physiology. *Front Neurol*, 3, 48. doi: 10.3389/fneur.2012.00048
77. Blair, S. N., Cheng, Y., & Holder, J. S. (2011). Is

- physical activity or physical fitness more important in defining health benefits? *Med Sci Sports Exercise*, 33 (6), 379-399.
78. Laska, M., Pasch, K. E., Lust, K., Story, M., & Ehlinger, E. (2009). Latent class analysis of lifestyle characteristics and health risk behaviors among college youth. *Prev Sci*, 10(4), 376-386. doi: 10.1007/s11121-009-0140-2
79. Health Canada. (2011). *Physical activity*. Retrived from <http://www.hc-sc.gc.ca/hl-vs/physactiv/index-eng.php>
80. Tremblay, M. S., Esliger, D. W., Tremblay, A., & Colley, R. (2007). Incidental movement, lifestyle-embedded activity and sleep: New frontiers in physical activity assessment. *Appl Physiol Nutr Metab*, 9(2), 208-217.
81. Yang, Y., Shin, J., Li, D., & An, R. (2017). Sedentary behaviour and sleep problems: a systematic review and meta-analysis. *Int J Behav Med*, 24(4), 481-492.
82. Wells, M. E., & Vaughn, B. V. (2012). Poor sleep challenging the health of a nation. *Neurodiagn J*, 52 (3), 233-249.