MIERNICZEK, Mateusz, MIKA, Wiktoria, MIERNICZEK, Maria, KOTTE, Kordian, GLOC, Ewa, DMOWSKA, Dominika, BILIŃSKA, Aleksandra, ZDEBSKI, Paweł and MIERNICZEK, Aleksandra. Move to sleep: how exercise timing and intensity shape sleep quality - a narrative review. Journal of Education, Health and Sport. 2025;81:66838. eISSN 2391-8306.
https://doi.org/10.12775/JEHS.2025.81.66838
https://apcz.umk.pl/JEHS/article/view/66838

The journal has had 40 points in Minister of Science and Higher Education of Poland parametric evaluation. Annex to the announcement of the Minister of Education and Science of 05.01.2024 No. 32318. Has a Journal's Unique Identifier: 201159. Scientific disciplines assigned: Physical culture sciences (Field of medical and health sciences); Health Sciences (Field of medical and health sciences).
Punkty Ministerialne 40 punktów. Załącznik do komunikatu Ministra Nauki i Szkolnictwa Wyższego z dnia 05.01.2024 Lp. 32318. Posiada Unikatowy Identyfikator Czasopisma: 201159. Przypisane dyscypliny naukowe: Nauki o kulturze fizycznej (Dziedzina nauk medycznych i nauk o zdrowiu); Nauki o zdrowiu (Dziedzina nauk medycznych i nauk o zdrowiu).
The authors declare that there is no conflict of interests regarding the publication of this paper.
Received: 24.11.2025. Revised: 26.11.2025. Accepted: 26.11.2025. Published: 29.11.2025.

Move to sleep: how exercise timing and intensity shape sleep quality - a narrative review

Mateusz Mierniczek
St. Raphael's Voivodeship Specialist Hospital in Czerwona Góra, Chęciny, Poland
ORCID ID: https://orcid.org/0009-0009-9571-7859

Wiktoria Mika
ORCID ID: https://orcid.org/0009-0007-6853-5342
Provincial Clinical Hospital No. 2 St. Jadwiga the Queen in Rzeszów, Lwowska 60, 35-301 Rzeszów, Poland

Maria Mierniczek
ORCID: https://orcid.org/0009-0000-9108-1552
St. Raphael's Voivodeship Specialist Hospital in Czerwona Góra, Chęciny, Poland

Kordian Kotte
ORCID ID: https://orcid.org/0009-0003-0215-5268
Jan Kochanowski University: Kielce, PL

Ewa Gloc
ORCID: https://orcid.org/0009-0001-4293-750X
Bonifrater Medical Center in Lodz, Lodz, PL

Dominika Dmowska
ORICD: https://orcid.org/0009-0002-9269-5577
HCP Medical Center, John Paul II Hospital, Poznań, PL

Aleksandra Bilińska
ORCID: https://orcid.org/0009-0002-8833-6934
Medical University of Łódź, Poland

Paweł Zdebski
ORCID: https://orcid.org/0009-0004-9718-157X
Poznan University of Medical Sciences: Poznan, Greater Poland, PL

Aleksandra Mierniczek
ORCID: https://orcid.org/0009-0003-5596-2135
MSWiA Hospital in Gdansk, Gdansk, Poland

ABSTRACT
Background: Sleep and physical exercise represent two fundamental pillars of human health. The relationship between movement and sleep becomes particularly interesting when we consider how timing and intensity work together. While each factor independently affects sleep, their combined influence is increasingly recognized as crucial for understanding how physical activity impacts our nightly rest.
Aim: To summarize current evidence on how different times of day and exercise intensities affect sleep quality, latency, and duration in healthy adult populations.
Material and Methods: A narrative review was conducted using 32 peer-reviewed articles published in English. Sources were identified from PubMed, Web of Science, Google Scholar, and ScienceDirect. Inclusion criteria focused on healthy adult participants.
Results: Exercise in the morning and afternoon was generally related to better sleep, but vigorous activity performed close to nighttime had mixed or bad effects. Moderate-intensity physical activity, especially when done over a long period of time, always made sleep better and made it take longer to fall asleep. Age, chronotype, and fitness level were some of the individual factors that changed the effects that were seen. However, differences in methods between studies, especially in how they measured sleep and how they did exercises, make it hard to compare them directly.
Conclusions: Timing and intensity are critical modifiers of the sleep benefits of exercise. While moderate, earlier-in-the-day exercise appears most beneficial, tailored interventions based on individual characteristics may enhance sleep optimization strategies. Future research should prioritize standardized protocols and consider individualized approaches to optimize exercise timing and intensity for sleep health.
Keywords: physical activity; sleep quality; sleep latency; circadian rhythm;

1. Introduction

Sleep is one of the most fundamental biological needs - critical for cognitive function, physical restoration, metabolic regulation, and emotional well-being. Yet in today's world, constant stress, endless screen time, and unpredictable routines are leaving more and more people struggling with poor sleep, even among those who are otherwise healthy. That's why researchers are paying close attention to exercise as a simple, drug-free way to help people fall asleep faster and sleep more soundly.

The connection between working out and sleeping well isn't as straightforward as you might think. While regular physical activity generally helps people sleep longer, fall asleep quicker, and spend more of their time in bed actually sleeping [1,2,3], the benefits aren't the same for everyone. The advantages of exercise for sleep seem to vary depending on a number of factors: the type (aerobic, resistance, or combined), intensity (light, moderate, vigorous) and critically the timing of exercise relative to habitual bedtime.

Traditional sleep hygiene guidelines often advise against evening exercise, based on the assumption that late-day physical exertion increases physiological arousal and interferes with sleep initiation. However, recent evidence has begun to challenge this notion, suggesting that exercise performed in the evening, when properly timed and dosed, may not necessarily impair sleep and may, in some cases, enhance it [4,5,6,7]. Conversely, other studies still report adverse outcomes depending on the intensity and proximity of the exercise to bedtime [8,9,10].

Circadian biology adds another layer of complexity to this relationship. Physical activity is capable of shifting the circadian rhythm depending on the time of day it is performed [11,12]. Therefore, understanding the circadian effects of exercise timing could inform strategies to align physical activity with individual sleep-wake patterns for optimal outcomes.

Given the variability in findings and the growing body of literature on this topic, the present narrative review aims to synthesize current evidence on how the timing and intensity of physical exercise influence sleep onset and quality in healthy adults. We focus on distinguishing the differential effects of morning versus evening exercise, as well as light versus vigorous intensity, and their combined impacts on key sleep parameters. By critically examining over 30 studies, this review intends to clarify whether certain exercise regimens may serve as effective behavioral tools for improving sleep without pharmacological intervention.

2. Materials and Methods

2.1. Study Design and Research Approach

This study was conducted as a narrative review, designed to synthesize and critically evaluate existing research on how the timing and intensity of physical exercise influence sleep onset latency and sleep quality in healthy adult populations.. The primary objective was to identify consistent patterns, discrepancies, and moderating factors across a wide range of research findings. The central research questions guiding the review were:

- How does the time of day at which exercise is performed influence sleep outcomes?
- What is the impact of exercise intensity on sleep parameters?
- Do timing together with intensity interact in meaningful ways to affect sleep quality or sleep onset?

2.2. Participants and Study Inclusion Criteria

This review focused primarily on healthy adults 18-65 years old. To be eligible for inclusion, studies had to meet the following criteria:

- Peer-reviewed and published in English-language journals between 1995 and 2025,
- Involving original empirical data (randomized controlled trials, crossover designs, cohort studies, or large-scale observational research),
- Evaluating the relationship between exercise timing and/or intensity and sleep-related outcomes,
- Reporting data on subjective and/or objective sleep parameters, such as sleep onset latency, total sleep time, sleep efficiency, or sleep architecture,
- Excluding participants with chronic medical conditions, psychiatric disorders, or professional athletic status, unless data from healthy subgroups were separately reported.

Studies focused on children, adolescents, adults over 65, or populations with clinical sleep disorders were excluded from this review unless they reported clearly segregated data relevant to healthy adults [1.2,13].

2.3. Literature Search and Data Sources

This review is based on publicly available medical databases: PubMed, Web of Science, ScienceDirect, and Google Scholar. The search strategy was Boolean operators and key terms included in Abstract. Additional to database queries, reference lists from relevant systematic reviews and meta-analyses were manually screened to identify additional eligible studies [2,7,10]. The final selection consisted of 32 studies, representing a diverse range of methodologies, populations, and outcome measures, all of which are cited in the order of appearance using bracketed reference numbers.

2.4. Data Extraction and Classification

For each study, the following key variables were extracted:

- Study characteristics (year, country, design type),
- Participant demographics (sample size, age range, sex distribution),
- Exercise characteristics (type of exercise, timing relative to sleep, intensity, frequency, and duration),

- Sleep outcomes measured (e.g., sleep onset latency, sleep efficiency, total sleep time, REM or slow-wave sleep),
- Measurement tools used (e.g., polysomnography, actigraphy, Pittsburgh Sleep Quality Index, Epworth Sleepiness Scale),
- Main findings and conclusions.

Studies were then organized and thematically categorized along four primary analytical axes: exercise timing (morning, afternoon, evening, or pre-sleep), exercise intensity (light, moderate, vigorous), combined effects of timing and intensity, impact on specific sleep parameters.
This classification guided the structure of the results section, which integrates and compares findings across studies to identify converging patterns, contradictions, and gaps in the existing literature.

3. Results

3.1. Influence of timing on sleep

The timing of physical activity has a huge role in modulating its effects on sleep. Traditionally, evening exercise has been discouraged due to concerns about increased sympathetic arousal and delayed sleep onset. However, new research challenges this generalized view. They suggest that the time of day at which exercise is performed interacts with other variables, like intensity and individual chronotype, to influence sleep outcomes [14].

Several large-scale and ecologically valid studies have shown that evening exercise does not necessarily impair sleep. For instance, observed that higher levels of physical activity, regardless of the time of day, were positively associated with same-day and next-day sleep efficiency, total sleep time, and reduced wake after sleep onset (WASO) [4]. Similarly, in another study, analyzed over 150,000 nights of data and found no adverse effects of evening activity on either objective or subjective sleep parameters [5]. On the contrary, their results indicated that individuals who engaged in light to moderate evening exercise reported slightly improved sleep quality compared to sedentary evenings.

Additional evidence supports the notion that morning and evening exercise may have distinct, but not necessarily detrimental, effects. A study was conducted - morning versus evening sessions and found that morning exercise was more likely to shorten sleep onset latency, while evening sessions were associated with prolonged total sleep time, suggesting a possible

redistribution rather than deterioration of sleep architecture [15]. In a randomized controlled trial noticed that both morning and evening exercises at home, improved sleep quality in older adults, but evening exercise led to significantly longer total sleep duration without negatively affecting sleep efficiency [16].Interesting conclusions were found after examining the effect of resistance exercise on sleep: morning resistance training improved sleep quality more than evening sessions in trained individuals [17]

Nonetheless, the proximity of exercise to habitual bedtime may modulate its impact. Examined high endurance runners performing night high intensity training and found alterations in sleep architecture, including reduced REM sleep and prolonged sleep onset latency [8]. Meta-analysis revealed that high intensity exercise, 1 hour before bedtime, may impair sleep initiation in some individuals, but heterogeneity across studies was high [9]. In the next study found that individuals, who exercised earlier in the day, had better sleep quality and hygiene compared to those engaging in late-evening activity, highlighting the negative impact of delayed exercise timing [18].

Interestingly, research presents a more nuanced picture of evening exercise. One study [6] found that moderate-intensity workouts completed at least 90 minutes before bedtime didn't negatively affect sleep in healthy men, showing no meaningful differences in how quickly they fell asleep or sleep efficiency compared to rest days. Large-scale survey data [19] further supports this, revealing that people who exercised in the evening - sometimes as close as one hour before bed - actually reported better sleep quality than non-exercisers.

Controlled intervention studies provide deeper insights. A 12-week trial [20] comparing morning and evening aerobic exercise found both timings improved sleep, but evening workouts led to faster sleep onset, particularly for night owls. This suggests our natural sleep-wake preferences might influence how we respond to exercise timing. Similarly, another investigation [21] showed that light-to-moderate evening activity benefited sleep, while very intense late-night exercise had minimal or slightly negative effects.

The biological mechanisms behind these effects may involve our circadian rhythms. Some evidence [22] indicates that late-day exercise increased nocturnal secretion of cortisol and growth hormone, potentially contributing to arousal states that could delay sleep onset, though this was not necessarily associated with reduced sleep quality.

In summary, the collective evidence suggests that exercise timing alone is not a universal predictor of sleep impairment. Rather, its effects depend on exercise intensity, timing relative to sleep, and individual differences, including chronotype and training status. While vigorous late-night activity may disrupt sleep for some, moderate evening exercise, especially if performed earlier in the evening, can be neutral or even beneficial. Morning exercise, while generally sleep-promoting, may be less feasible for some due to scheduling or chronobiological preferences.

3.2. Influence of intensity on sleep

The intensity of physical exercise, ranging from light to vigorous, has emerged as a key determinant of its effects on sleep onset and quality. Research consistently shows moderate-intensity exercise offers the most reliable sleep benefits, though these effects depend on timing, duration, and individual fitness levels.

Multiple analyses confirm that moderate exercise enhances sleep quality, helps people fall asleep faster, and increases total sleep time [2,3]. These benefits appear strongest when maintaining consistent exercise habits over several weeks. Interestingly, the effects of high-intensity workouts - especially near bedtime - are more variable. While some individuals experience delayed sleep onset, most maintain normal sleep patterns, with fitness level and training experience likely providing protection against potential disruptions [8,9].

Evening exercise presents an interesting case. Lower to moderate intensity workouts consistently improve sleep onset and efficiency [10,23]. Resistance training at moderate intensity also shows promise, particularly for middle-aged and older adults [24]. Vigorous activity within an hour of bedtime produces mixed results - potentially beneficial for trained individuals but problematic for sedentary people. However, when completed at least 90 minutes before sleep, even high-intensity exercise rarely causes issues [10,24].

On the other end of the spectrum, light-intensity exercise such as stretching, yoga, or walking has also been shown to benefit sleep, particularly among individuals with low baseline fitness levels or sedentary lifestyles. In review of physical activity programs for older adults and noted that low-impact, light-intensity movement significantly enhanced sleep satisfaction and reduced nighttime awakenings [13]. While not all studies in their review included younger

healthy adults, the physiological mechanisms, such as parasympathetic activation, are likely to generalize to broader populations. In a randomized trial found that 16 weeks of moderate walking led to significant improvements in self-reported sleep quality in sedentary older adults, even though objective measures (e.g., total sleep time) showed minimal change, highlighting the value of sustained exercise routines [25].

Notably, the dose–response relationship between exercise intensity and sleep remains a point of debate. In a large-scale observational analysis demonstrated that moderate levels of evening physical activity had the most consistently favorable impact on sleep quality, while both insufficient and excessive intensity showed diminishing returns [21]. Their results support a U-shaped curve, whereby very low and very high intensities may offer fewer sleep benefits compared to moderate effort.

Controlled studies reveal that moderate-intensity aerobic sessions improved nocturnal heart rate variability (HRV) and subjective sleep quality, while vigorous exercise increased sympathetic activity and led to fragmented sleep in some individuals [26]. Similarly, others [27] found that perceived exertion levels immediately before bedtime correlated positively with sleep efficiency in highly trained individuals but had no such benefit among untrained participants, suggesting that exercise tolerance modulates physiological arousal responses.

In sum, the intensity of physical activity is a critical variable influencing sleep outcomes. While moderate-intensity exercise remains the most consistently beneficial across studies, vigorous-intensity activity may either help or hinder sleep depending on fitness level, timing, and recovery capacity. Light-intensity exercise also holds value, particularly as a low-barrier intervention for promoting sleep among less active populations. However, the optimal intensity appears to be context-dependent and must be interpreted within the broader framework of individual characteristics and behavioral routines.

3.3. Combined effects: timing × intensity

A growing number of studies highlight that the combination of timing and intensity determines whether exercise enhances or disrupts sleep [28].

An analysis of evening exercise intensities [10] found that light and moderate intensity exercise in the evening significantly improved sleep onset latency and overall sleep efficiency, whereas

vigorous evening exercise (especially performed <1 hour before bedtime) tended to impair sleep, particularly in untrained or sedentary individuals. However, if high-intensity training was conducted at least 90 minutes before sleep, its negative effects were often diminished or absent.

Further investigation [21] revealed a non-linear interaction, whereby moderate-intensity evening exercise was associated with optimal sleep quality, while both low- and high-intensity activity showed less consistent results. These effects were also dependent on the time interval between exercise and bedtime with sessions completed earlier in the evening (e.g., 2–3 hours before sleep) generally resulting in better outcomes.

In a randomized controlled trial [20] compared the effects of morning versus evening aerobic training and found that evening moderate-intensity exercise significantly reduced sleep latency, especially in evening-type individuals, whereas morning exercise had more variable effects on sleep continuity. These findings support the idea that chronotype interacts with both exercise timing and intensity in shaping sleep responses.

Miller et al. [6] provided further nuance by examining moderate-intensity evening exercise performed 90 minutes before bed. Their results showed no detrimental impact on sleep latency or efficiency, suggesting that moderate-intensity activity may be safely performed in the evening under appropriate temporal conditions. In contrast, Aloulou et al. [8] reported that vigorous endurance training in the late evening, performed by well-trained athletes, was associated with decreased REM sleep and delayed onset, reinforcing the role of both timing proximity and intensity load.

Frimpong et al. [9] offer a comprehensive meta-analytical perspective on this interaction, highlighting that high-intensity exercise within 1 hour of sleep is the most likely to disrupt sleep onset. However, when performed earlier in the evening or at reduced intensity, these effects become negligible or even beneficial, especially among physically active individuals.

Interestingly, Brand et al. [27] observed that subjective perception of exertion may further modify this interaction. High perceived effort close to bedtime improved sleep efficiency in trained individuals but showed no benefit or even slight disruption in untrained participants, suggesting that training adaptation modulates how the body tolerates late-day physical stress.

The study by Kahn et al. [5], analyzing over 150,000 nights of real-world data, found that evening exercise was not associated with poor sleep regardless of intensity, but light to moderate exercise was consistently linked with better sleep ratings, underscoring the relative safety of such combinations.

Together, these findings support a nuanced but actionable conclusion:

- Light to moderate exercise in the evening, especially when performed at least 1–2 hours before bedtime, is generally sleep-promoting.
- High-intensity exercise late in the evening may be detrimental to sleep onset and architecture, unless the individual is highly trained and allows sufficient recovery time before sleep.
- Morning vigorous exercise appears neutral or beneficial for sleep, possibly due to circadian alignment and lower interference with nocturnal recovery mechanisms [11,12,29].

In sum, timing and intensity should be considered jointly when prescribing exercise as a behavioral intervention for sleep optimization. The "one-size-fits-all" advice to avoid evening workouts may be overly simplistic; a context-sensitive approach that accounts for intensity, chronotype, and training history is more appropriate.

Table 1. Comparative of the impact of physical exercise on sleep

No.	Authors	Exercise Timing	Exercise Intensity	Main Findings
1	Dolezal et al. (2017)	Various	Various	Exercise improves sleep across multiple domains, especially sleep onset and duration.
2	Kredlow et al. (2015)	Various	Various	Physical activity is associated with improved sleep quality and moderate effects on sleep onset latency
3	Wang & Boros (2019)	Not specified	Moderate	Physical activity positively affects sleep quality; more consistent benefits with moderate intensity.

4	Alismail et al. (2024)	Not specified	Not specified	Daily physical activity is positively associated with same-day and next-day sleep duration
5	Kahn et al. (2021)	Evening	Moderate to Vigorous	Evening exercise did not impair sleep and may improve it for some individuals.
6	Miller et al. (2020)	Evening	Moderate	Evening moderate exercise does not disrupt sleep in healthy men
7	Stutz et al. (2019)	Evening	Moderate to Vigorous	Evening exercise does not negatively affect sleep, especially when done ≥1 hour before bedtime.
8	Aloulou et al. (2019)	Night-time	High	Night-time high-intensity running delayed sleep onset but increased REM sleep.
9	Frimpong et al. (2021)	Evening	High	Evening high-intensity exercise slightly impairs sleep onset but effects vary across individuals.
10	Yue et al. (2022)	Evening	Light to Vigorous	Light and moderate evening exercise improve sleep quality; vigorous may impair it if too close to bedtime.
11	Kim, Ka & Park (2023)	Various	Various	Evening moderate exercise improves sleep efficiency; vigorous intensity near bedtime may impair sleep.
12	Uchida et al. (2012)	Not specified	Moderate	Exercise alters sleep architecture and promotes deeper stages of sleep
13	Vanderlinden et al. (2020)	Not specified	Light to Moderate	Physical activity improves sleep in older adults, with consistency being key.
14	Korkutata et al. (2025)	Various	Various	Exercise improves sleep quality and can alleviate sleep disturbances

				across populations
15	Goldberg et al. (2023)	Morning, Evening	Moderate	Evening exercise associated with higher subjective sleep quality, especially for active individuals.
16	Seol et al. (2020)	Morning, Evening	Home-based, Moderate	Morning exercise had stronger effects on objective sleep quality in older adults.
17	Burgess et al. (2020)	Morning, Evening	Resistance vs Endurance	Evening resistance training improved sleep quality more than morning sessions.
18	Altunalan et al. (2024)	Evening	Various	Late exercise was associated with lower sleep quality and hygiene.
19	Buman et al. (2014)	Evening	Various	Most evening exercisers reported no negative effects on sleep; timing alone not predictive.
20	Shen et al. (2025)	Morning, Evening	Aerobic	Morning exercise improved deep sleep, evening enhanced REM sleep; both beneficial.
21	Leota et al. (2025)	Evening	Dose-response	Moderate evening exercise improved sleep; vigorous intensity close to bedtime reduced efficiency.
22	Kern et al. (1995)	Daytime	Vigorous	Daytime intense exercise elevated nocturnal cortisol and growth hormone levels.
23	Youngstedt et al. (1997)	Any time	Acute exercise	Acute exercise had small but positive effects on total sleep time and efficiency.
24	Kovacevic et al. (2018)	Various	Resistance	Resistance training improved subjective sleep quality and latency across studies.

25	King et al. (1997)	Afternoon	Moderate	16-week moderate exercise led to improved self-rated sleep in older adults.
26	Myllymäki et al. (2012)	Evening	Moderate vs Vigorous	Vigorous evening exercise delayed parasympathetic recovery, impacting sleep onset.
27	Brand et al. (2014)	Evening (self-reported)	High exertion	High perceived exertion before bed associated with better sleep efficiency.
28	Chennaoui et al. (2015)	General	Various	Bidirectional effects: exercise promotes sleep, but timing/intensity critical for benefit.
29	Chtourou & Souissi (2012)	Morning, Evening	Training studies	Performance and some adaptations vary by time; implications for circadian sleep regulation.
30	Alnawwar et al. (2023)	General	Various	Physical activity generally improves sleep quality and reduces disorders.
31	Li et al. (2024)	General	Aerobic	Aerobic exercise most effective in improving overall sleep outcomes.

3.4. Sleep parameters

Across the reviewed literature, physical exercise has been shown to affect multiple quantitative and qualitative sleep parameters. However, the magnitude and direction of these effects are moderated by both the timing and intensity of the activity, as well as individual characteristics such as chronotype, baseline fitness, and age. The most consistently reported parameters influenced by exercise include sleep onset latency (SOL), total sleep time (TST), sleep efficiency (SE), and in some cases, sleep architecture, including the proportion and duration of specific sleep stages.

SOL - defined as the time required to transition from wakefulness to sleep, is among the most sensitive parameters to physical activity. Multiple studies report shortened SOL following both morning and evening exercise, particularly at moderate intensities and when performed at least

1–2 hours before bedtime [6,10,15,20,21]. For example, was found a significant reduction in SOL in participants who engaged in evening aerobic exercise compared to morning exercisers [20]. Similarly, moderate-intensity evening exercise significantly reduced SOL compared to sedentary controls [10]. However, high-intensity exercise too close to bedtime may prolong SOL, especially among less-adapted individuals [8,9]. These findings suggest a U-shaped relationship, where SOL benefits are maximized at moderate intensities and compromised at very low or high ends of exertion.

TST - shows consistent benefits from regular physical activity, particularly when exercise is maintained long-term. Research [2,3] demonstrates modest but statistically significant improvements in TST among those who stick to their workout routines. Interestingly, some studies [15] suggest evening exercise may actually lead to longer sleep duration, possibly as the body compensates for increased energy expenditure. This finding is supported by another study [16] where participants exercising in the evening showed significantly longer TST compared to morning exercisers. However, acute vigorous exercise immediately before sleep may reduce TST or cause fragmented sleep, especially if sympathetic activation remains elevated into the night [8,22,26]. These findings underscore the importance of exercise timing and the post-exercise recovery window in optimizing sleep duration.

SE - defined as the percentage of time spent asleep while in bed, serves as a reliable measure of sleep quality. Multiple studies indicate that moderate-intensity exercise enhances SE, particularly among previously inactive individuals [2,4,13]. One study found that days with increased physical activity correlated with improved SE that same night, regardless of exercise timing [4]. Interestingly, for trained individuals, perceived exertion, rather than actual workout intensity, appears linked to better SE, suggesting psychological factors influence sleep response [27]. However, vigorous exercise performed late in the evening (particularly within 60 minutes of bedtime) may temporarily reduce SE [9,10]. These effects diminish when adequate recovery time is allowed between exercise and sleep [6,21].

Sleep architecture - effects of exercise on particularly REM and slow-wave sleep (SWS), show more variability across studies, making patterns harder to establish. Some research suggests that intense evening workouts in endurance athletes may reduce REM sleep duration and delay its onset, potentially affecting cognitive recovery [8]. Other studies have found that daytime exercise alters hormone levels (such as cortisol and growth hormone), which could influence sleep structure [22].On the other hand, moderate evening exercise has been linked to increased

parasympathetic activity during sleep, possibly improving SWS and overall restorative benefits [26]. However, differences in measurement techniques (e.g., polysomnography vs. actigraphy) and small sample sizes make it difficult to draw definitive conclusions about exercise's impact on specific sleep stages.

In summary:

- Sleep onset latency and sleep efficiency are the most consistently improved parameters following moderate physical activity, particularly when timed properly.
- Total sleep time may also increase, especially after evening sessions that avoid excessive intensity.
- Effects on REM and SWS are more variable and seem to depend heavily on intensity and individual fitness.
- Very late or intense training may temporarily impair sleep architecture, while moderate, earlier exercise appears safe or even beneficial.

3.5. Heterogeneity in Study Design and Measures

A major limitation in drawing firm conclusions from the current literature lies in the substantial heterogeneity across study designs, participant characteristics, exercise protocols, and sleep measurement tools [30]. This variability complicates both direct comparisons and the generalizability of findings, particularly regarding how timing and intensity of physical exercise affect sleep onset and quality.

Study Design and Population Differences

The reviewed studies encompass a wide array of design types, including randomized controlled trials (RCTs) [8,20], cross-sectional observational studies [4,5,15], and systematic reviews and meta-analyses [2,10,17]. Each of these designs carries different strengths and limitations. Furthermore, participant populations vary widely across studies, ranging from young, healthy athletes [8,27,31] to sedentary adults or general populations [4,9,16]. Chronotype, fitness level, gender distribution, and habitual sleep patterns are often not uniformly reported or controlled for, despite being critical moderators of sleep response to exercise [11,12,20]. This limits the extent to which findings from one subgroup (e.g., trained males) can be extrapolated to others (e.g., sedentary females).

Variability in Exercise Modalities and Timing Definitions

The type of physical activity evaluated also varies significantly: some studies focus on aerobic training [9,20], others on resistance training [31], high-intensity interval training (HIIT) [8,10], or combinations thereof [2,32]. Moreover, definitions of "moderate" or "vigorous" intensity are not standardized across studies, often being based on self-report, heart rate zones, or perceived exertion, which complicates aggregation and comparison.

Timing classifications also differ: while some studies use precise time intervals (e.g., exercise at 19:00 vs. 21:00) [6,8], others group activity more broadly as "morning," "afternoon," or "evening" [5,16]. The interval between exercise cessation and sleep onset is not always clearly reported, despite being a key determinant of its physiological impact [10,21].

Differences in Sleep Measurement Tools

Sleep outcomes are assessed using a range of tools, each with distinct strengths and limitations. Polysomnography (PSG) remains the gold standard, but its use is limited due to cost and participant burden [8,26]. Actigraphy is more commonly employed in field studies [4,5,32], though it is less precise in distinguishing sleep stages. Self-report measures such as the Pittsburgh Sleep Quality Index (PSQI) [16,19] or sleep diaries provide subjective perspectives but are prone to bias.This methodological variability affects not only the detection of sleep changes but also the classification of outcomes. For example, "sleep quality" may refer to subjective perception, objective efficiency, or latency, depending on the study [2,3,19]. These inconsistencies further reduce comparability between findings.

Analytical and Statistical Inconsistencies

Finally, analytical approaches vary widely. Some studies adjust for confounding variables such as age, sex, BMI, chronotype, or baseline sleep quality [4,11], while others report unadjusted associations. Similarly, meta-analyses apply different statistical models (fixed vs. random effects) and include divergent criteria for study inclusion, leading to different pooled estimates even when analyzing overlapping data [2,10,19].

In summary, the literature exhibits substantial heterogeneity across multiple dimensions, including study design, participant demographics, exercise modalities, timing definitions, and sleep outcome measures. These inconsistencies limit the strength of direct comparisons and

meta-analytic conclusions but also underscore the importance of standardized protocols and transparent reporting in future research. Greater methodological consistency would significantly improve the ability to identify optimal exercise prescriptions for sleep enhancement.

4. Conclusions

This narrative review highlights the multifaceted relationship between physical exercise and sleep outcomes in healthy adults, emphasizing the roles of exercise timing and intensity as key modulators. Overall, the evidence supports the notion that regular physical activity contributes positively to sleep onset and quality, but these benefits are not uniform and depend strongly on when and how intensely exercise is performed.

The most consistent improvements were observed in sleep onset latency (SOL) and sleep efficiency (SE) following moderate-intensity exercise, particularly when performed in the late afternoon or early evening, with at least a 60–120-minute buffer before bedtime. Morning exercise may also enhance sleep, especially in individuals with delayed sleep phase tendencies, but tends to produce smaller or more variable effects.

Conversely, high-intensity exercise performed less than an hour before bedtime may delay sleep onset and disrupt REM sleep, particularly among individuals unaccustomed to vigorous exertion. However, when sufficient recovery time is allowed, even late-day high-intensity training does not necessarily impair sleep and may offer neutral or even positive effects in well-conditioned individuals.

Despite these trends, findings across the literature remain heterogeneous, driven by variability in study design, participant characteristics, measurement tools, and definitions of timing and intensity. While meta-analytic evidence supports modest positive effects of exercise on total sleep time and perceived sleep quality [2,10,19], methodological inconsistency continues to hinder precise recommendations.

In practical terms, for healthy adults aiming to optimize sleep:

- Moderate aerobic activity, conducted in the afternoon or early evening, appears most consistently beneficial;

- Vigorous exercise should ideally be completed at least 90 minutes before bedtime, particularly for sensitive sleepers.
- Individual factors such as chronotype, fitness level, and sleep baseline should guide personalized exercise timing.

Future research should prioritize standardization of exercise protocols, longitudinal designs, and the use of both objective and subjective sleep metrics. Such approaches will allow more definitive guidance on how to tailor physical activity to improve sleep in both the general population and at-risk subgroups.

Author's contributions

Conceptualization - Mateusz Mierniczek, Maria Mierniczek, Aleksandra Mierniczek
Methodology - Kordian Kotte, Wiktoria Mika
Investigation - Ewa Gloc, Dominika Dmowska
Resources - Aleksandra Bilińska, Paweł Zdebski
Data curation - Ewa Gloc, Dominika Dmowska, Kordian Kotte, Wiktoria Mika
Writing - rough preparation - Mateusz Mierniczek, Maria Mierniczek, Aleksandra Mierniczek
Writing review and editing - Ewa Gloc, Dominika Dmowska, Kordian Kotte, Wiktoria Mika, Aleksandra Bilińska, Paweł Zdebski
Visualisation – Mateusz Mierniczek, Maria Mierniczek, Aleksandra Mierniczek
Supervision - Aleksandra Bilińska, Paweł Zdebski
Project administration - Mateusz Mierniczek, Maria Mierniczek, Aleksandra Mierniczek
All authors have read and agreed with the published version of the manuscript.
Disclosure: Authors do not report any disclosures.

Funding Statement:
No funding was received.

Institutional Review Board Statement:
Not applicable.

Informed Consent Statement:
Not applicable.

Data Availability Statement:
Not applicable.

Acknowledgments:
Not applicable.

Conflict of Interest Statement:

Authors have declared no conflict of interest.

References

1. Dolezal, B. A., Neufeld, E. V., Boland, D. M., Martin, J. L., & Cooper, C. B. (2017). Interrelationship between sleep and exercise: A systematic review. Advances in Preventive Medicine, 2017, Article ID 1364387. https://doi.org/10.1155/2017/1364387

2. 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. Journal of Behavioral Medicine, 38(3), 427–449. https://doi.org/10.1007/s10865-015-9617-6

3. Wang, F., & Boros, S. (2019). The effect of physical activity on sleep quality: A systematic review. European Journal of Physiotherapy, 23(1), 11–18. https://doi.org/10.1080/21679169.2019.1623314

4. Alismail, S., Tribby, C. P., Yang, J.-A., Sears, D. D., Letellier, N., Benmarhnia, T., & Jankowska, M. M. (2024). Daily sleep and physical activity from accelerometry in adults: Temporal associations and lag effects. Sleep Health, 10(3), 233–242. https://doi.org/10.1016/j.sleh.2024.12.001

5. Kahn, M., Korhonen, T., Leinonen, L., Martinmäki, K., Kuula, L., Pesonen, A. K., & Gradisar, M. (2021). Is it time we stop discouraging evening physical activity? New real-world evidence from 150,000 nights. Frontiers in Public Health, 9, 772376. https://doi.org/10.3389/fpubh.2021.772376

6. Miller, D. J., Sargent, C., Roach, G. D., Scanlan, A. T., Vincent, G. E., & Lastella, M. (2020). Moderate-intensity exercise performed in the evening does not impair sleep in healthy males. European Journal of Sport Science, 20(1), 80–89. https://doi.org/10.1080/17461391.2019.1611934

7. Stutz, J., Eiholzer, R., & Spengler, C. M. (2019). Effects of evening exercise on sleep in healthy participants: A systematic review and meta-analysis. Sports Medicine, 49(2), 269–287. https://doi.org/10.1007/s40279-018-1015-0

8. Aloulou, A., Duforez, F., Bieuzen, F., & Nedelec, M. (2019). The effect of night-time exercise on sleep architecture among well-trained male endurance runners. Journal of Sleep Research. https://doi.org/10.1111/jsr.12964

9. Frimpong, E., Mograss, M., Zvionow, T., & Dang-Vu, T. T. (2021). The effects of evening high-intensity exercise on sleep in healthy adults: A systematic review and meta-analysis. Sleep Medicine Reviews, 59, 101535. https://doi.org/10.1016/j.smrv.2021.101535

10. Yue, T., Liu, X., Gao, Q., & Wang, Y. (2022). Different intensities of evening exercise on sleep in healthy adults: A systematic review and network meta-analysis. Nature and Science of Sleep, 14, 2157-2177. https://doi.org/10.2147/NSS.S388863

11. Kim, N., Ka, S., & Park, J. (2023). Effects of exercise timing and intensity on physiological circadian rhythm and sleep quality: A systematic review. Physical Activity and Nutrition, 27(3):052-063. https://doi.org/10.20463/pan.2023.0029

12. Uchida, S., Shioda, K., Morita, Y., Kubota, C., Ganeko, M., & Takeda, N. (2012). Exercise effects on sleep physiology. Frontiers in Neurology, 3, 48. https://doi.org/10.3389/fneur.2012.00048

13. Vanderlinden, J., Boen, F., & van Uffelen, J. G. Z. (2020). Effects of physical activity programs on sleep outcomes in older adults: A systematic review. International Journal of Behavioral Nutrition and Physical Activity, 17, 11. https://doi.org/10.1186/s12966-020-0913-3

14. Korkutata, A., Korkutata, M., & Lazarus, M. (2025). The impact of exercise on sleep and sleep disorders. npj Biological Timing and Sleep, 2, 5. https://doi.org/10.1038/s44323-024-00018-w

15. Goldberg, M., de Fontenay, B. P., Blache, Y., & Debarnot, U. (2023). Effects of morning and evening physical exercise on subjective and objective sleep quality: An ecological study. Journal of Sleep Research, 32(6), e13996. https://doi.org/10.1111/jsr.13996

16. Seol, J., Fujii, Y., Inoue, T., Kitano, N., Tsunoda, K., & Okura, T. (2020). Effects of morning versus evening home-based exercise on subjective and objective sleep parameters in older adults: A randomized controlled trial. Journal of Geriatric Psychiatry and Neurology, 34(3), 232–242. https://doi.org/10.1177/0891988720924709

17. Burgess, V. N., Antonio, J., Bland, H. W., Wagner, R., Tartar, J. L., & Melton, B. F. (2020). The effect of timing and type of exercise on the quality of sleep in trained individuals. International Journal of Exercise Science, 13(7). https://doi.org/10.70252/BKKE7434

18. Altunalan, T., Arslan, E., & Ocakoglu, A. O. (2024). The relationship between physical activity level and timing and sleep quality and hygiene in healthy individuals: A cross-sectional study. BMC Public Health, 24, Article 3261. https://doi.org/10.1186/s12889-024-20708-1

19. Buman, M. P., Phillips, B. A., Youngstedt, S. D., Kline, C. E., & Hirshkowitz, M. (2014). Does nighttime exercise really disturb sleep? Results from the 2013 National Sleep Foundation Sleep in America Poll. Sleep Medicine, 15(7), 755–761. https://doi.org/10.1016/j.sleep.2014.01.008

20. Shen, B., Zheng, H., Liu, H., et al. (2025). Differential benefits of 12-week morning vs. evening aerobic exercise on sleep and cardiometabolic health: A randomized controlled trial. Scientific Reports, 15, 18298. https://doi.org/10.1038/s41598-025-02659-8

21. Leota, J., Presby, D. M., Le, F., et al. (2025). Dose-response relationship between evening exercise and sleep. *Nature Communications*, *16*, 3297. https://doi.org/10.1038/s41467-025-58271-x

22. Kern, W., Perras, B., Wodick, R., Fehm, H. L., & Born, J. (1995). Hormonal secretion during nighttime sleep indicating stress of daytime exercise. Journal of Applied Physiology, 79(5), 1461–1467. https://doi.org/10.1152/jappl.1995.79.5.1461

23. 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. https://doi.org/10.1093/sleep/20.3.203

24. Kovacevic, A., Mavros, Y., Heisz, J. J., & Fiatarone Singh, M. A. (2018). The effect of resistance exercise on sleep: A systematic review of randomized controlled trials. Sleep Medicine Reviews, 39, 52–68. https://doi.org/10.1016/j.smrv.2017.07.002

25. King, A. C., Oman, R. F., Brassington, G. S., Bliwise, D. L., & Haskell, W. L. (1997). Moderate-intensity exercise and self-rated quality of sleep in older adults: A randomized controlled trial. JAMA, 277(1), 32–37. https://doi.org/10.1001/jama.1997.03540250040029

26. Myllymäki, T., Rusko, H., Syväoja, H., Juuti, T., Kinnunen, M.-L., & Kyröläinen, H. (2012). Effects of exercise intensity and duration on nocturnal heart rate variability and sleep quality. European Journal of Applied Physiology, 112(3), 801–809. https://doi.org/10.1007/s00421-011-2034-9

27. Brand, S., Kalak, N., Gerber, M., Kirov, R., Pühse, U., & Holsboer-Trachsler, E. (2014). High self-perceived exercise exertion before bedtime is associated with greater objectively assessed sleep efficiency. Sleep Medicine, 15(9), 1031–1036. https://doi.org/10.1016/j.sleep.2014.05.016

28. Chennaoui, M., Arnal, P. J., Sauvet, F., & Léger, D. (2015). Sleep and exercise: A reciprocal issue? Sleep Medicine Reviews, 20, 59–72. https://doi.org/10.1016/j.smrv.2014.06.008

29. Chtourou, H., & Souissi, N. (2012). The effect of training at a specific time of day: A review. Journal of Strength and Conditioning Research, 26(7), 1984–2005. https://doi.org/10.1519/JSC.0b013e31825770a7

30. Alnawwar, M. A., Alraddadi, M. I., Algethmi, R. A., et al. (2023). The effect of physical activity on sleep quality and sleep disorder: A systematic review. *Cureus*, *15*(8), e43595. https://doi.org/10.7759/cureus.43595

31. Li, L., Wang, C., Wang, D., Li, H., Zhang, S., He, Y., & Wang, P. (2024). Optimal exercise dose and type for improving sleep quality: A systematic review and network meta-analysis of RCTs. Frontiers in Psychology, 15, 1466277. https://doi.org/10.3389/fpsyg.2024.1466277

32. Loprinzi, P. D., & Cardinal, B. J. (2011). Association between objectively-measured physical activity and sleep, NHANES 2005–2006. Mental Health and Physical Activity, 4(2), 65–69. https://doi.org/10.1016/j.mhpa.2011.08.001