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The Effects of Exercise Timing, Intensity and Modality on Sleep Quality in Recreational Athletes: A Narrative Review

Authors:

Alicja Benecka
ORCID https://orcid.org/0009-0000-5110-8028
alicjabenecka@gmail.com
Prof. S. T. Dąbrowski Hospital in Puszczykowo S.A.,
Józefa Ignacego Kraszewskiego 11, 62-040 Puszczykowo, Poland

Aleksandra Blicharz
ORCID https://orcid.org/0009-0002-8423-2003
ola201420@gmail.com
Opole University in Opole
Oleska 48, 45-052 Opole, Poland

Wojciech Kozdraś
ORCID https://orcid.org/0009-0006-2770-937X
wojkoz8989@gmail.com
Medical University of Silesia in Katowice
Księcia Józefa Poniatowskiego 15, 40-055 Katowice, Poland

Gabriela Szewczyk
ORCID https://orcid.org/0009-0002-2131-9427
szewczyk.gabriela2112@gmail.com
Podhalański Szpital Specjalistyczny w Nowym Targu
Szpitalna 14 34-400 Nowy Targ, Poland

Elżbieta Bukowczan
ORCID: https://orcid.org/0009-0001-0986-4433
elzbieta.bukowczan@gmail.com
Szpital Śląski w Cieszynie, ul. Bielska 4, 43-400 Cieszyn, Poland

Ewa Wiench
ORCID https://orcid.org/0009-0002-8462-1084
ewa.wiench91@gmail.com
Medical University of Silesia, Poniatowskiego 15, 40-055 Katowice, Poland

Magdalena Kloc
ORCID https://orcid.org/0009-0000-9926-293X
magda1000v@gmail.com
Szpital Miejski w Gliwicach Sp z o. o., Zygmunta Starego 20, 44-100 Gliwice, Poland

Alicja Zając
ORCID https://orcid.org/0009-0005-3269-5921
alicjazajac21@gmail.com
University of Rzeszów, Al. Tadeusza Rejtana 16C, 35-959 Rzeszów, Poland

Bartosz Niciński
ORCID https://orcid.org/0009-0005-9380-9427
nicinskibartek@gmail.com
Szpital Śląski w Cieszynie, ul. Bielska 4, 43-400 Cieszyn, Poland

Damian Broda
ORCID https://orcid.org/0009-0003-2825-2082
damianbrodapl@gmail.com
10th Military Clinical Hospital with Polyclinic in Bydgoszcz ul. Powstańców Warszawy 5, 85-681 Bydgoszcz, Poland

Agnieszka Benecka,
ORCID https://orcid.org/0009-0004-9295-7471
abenecka@gmail.com
J Strus City Multispecialty Hospital, Szwajcarska 3, 61-285 Poznań, Poland

Corresponding Author

Alicja Benecka, E-mail: alicjabenecka@gmail.com

Abstract

Background: Sleep is essential for recovery, health and functioning. Recreational athletes often train in the evening, but exercise effects on sleep depend on timing, intensity and modality.

Aim: To summarize how exercise timing, intensity and modality influence sleep quality in recreational athletes and physically active adults.

Materials and methods: A narrative review was conducted using PubMed, Scopus and Google Scholar. The analysis included 26 publications from 1978 to April 2026 on healthy adults aged 18–65 years, recreationally active individuals or non-professional athletes. Outcomes included sleep latency, total sleep time, sleep efficiency, sleep architecture, HRV and subjective sleep quality.

Results: Moderate-intensity exercise showed the most consistent favourable association with sleep, especially when regular and not too close to bedtime. Evening exercise was not automatically harmful; light and moderate sessions were usually well tolerated. Late high-intensity or high-load exercise was more often linked with delayed sleep onset, higher nocturnal heart rate, reduced HRV and altered sleep architecture.

Conclusions: Exercise may support sleep quality as a non-pharmacological recovery strategy. The most practical approach is individualized planning based on timing, intensity, modality, fitness level and recovery time before sleep.

Keywords: sleep quality; recreational athletes; exercise timing; exercise intensity; exercise modality; recovery; HRV

1.Introduction

Sleep is essential for health, recovery and proper daily functioning. Adults are generally advised to obtain 7–9 hours of sleep per night, although this recommendation has become increasingly difficult to meet in today's fast-paced lifestyle. Insufficient sleep may negatively affect cognitive performance, immune and endocrine function, physical recovery and mental well-being. This issue is also relevant for recreational athletes, who often combine training with work, study, family responsibilities and other daily obligations. As a result, many of them perform physical activity in the evening, raising an important question: does every type of exercise before bedtime affect sleep in the same way?

The relationship between exercise and sleep is not determined only by the presence of physical activity, but also by its timing, intensity and modality. Aerobic, anaerobic and combined training may influence sleep differently, particularly when performed later in the day. For many years, evening exercise was discouraged in sleep hygiene recommendations because it was believed to increase physiological arousal and delay sleep onset. However, recent evidence suggests that this effect is not universal. Evening exercise does not appear to impair sleep when performed at a moderate intensity and with sufficient time before bedtime (Stutz et al. 2019; Miller et al. 2020; Kahn et al. 2021). In contrast, vigorous exercise undertaken shortly before sleep may negatively affect sleep onset, sleep architecture or perceived sleep quality in some individuals (Aloulou et al. 2020; Frimpong et al. 2021; Yue et al. 2022). These findings indicate that exercise may either support or disturb sleep depending on several interacting factors, including training type, intensity and the interval between exercise and bedtime. Therefore, this narrative review discusses current evidence on the effects of exercise timing, intensity and modality on sleep quality in recreational athletes, with particular attention to morning versus evening training and low-, moderate- and high-intensity exercise. The aim is to clarify whether specific exercise patterns, may support sleep quality in recreational athletes and physically active adults as a non-pharmacological recovery strategy.

2.Research materials and methods

2.1. Study design

This article was prepared as a narrative review. The included publications comprised experimental studies, randomized crossover trials, observational studies, ecological studies, systematic reviews and meta-analyses. The main analysis focused on three aspects of physical activity that may affect sleep: the time of day at which training is performed, exercise intensity and type of activity. Particular attention was given to studies involving healthy adults, physically active individuals, recreational athletes, endurance runners and regularly training individuals. Studies involving clinical populations were not included in the main analysis unless their findings were relevant only as theoretical background.

2.2. Data sources and search strategy

The literature search was conducted using PubMed, Scopus and Google Scholar.
The scope was then narrowed to studies addressing exercise timing, exercise intensity, type of physical activity, evening training, sleep onset latency, sleep efficiency, sleep architecture and recovery. The following keywords and combinations were used:
- exercise timing, recreational athletes, physically active adults, evening exercise, morning exercise, exercise intensity, aerobic exercise, resistance training, high-intensity exercise, sleep latency, sleep efficiency, sleep architecture, REM, slow-wave, recovery, quality, wearables.

2.3 Inclusion criteria

Studies were included in the analysis if they met most of the following criteria:

1. Adults aged 18–65 years;
2. Healthy, physically active individuals, recreationally training individuals or non-professional athletes;
3. Exercise timing, exercise intensity, type of physical activity or training load;
4. Sleep quality, sleep onset latency, sleep efficiency, total sleep time, REM sleep, slow-wave sleep, wake after sleep onset or subjective recovery;
5. Were published in a peer-reviewed scientific journal or constituted a high-quality review or meta-analysis directly related to the topic.

2.4. Exclusion criteria

Studies were excluded from the main analysis if they focused primarily on:

1.children and adolescents;
2.individuals over 65 years of age;
3.patients with chronic diseases;
4.cancer patients;
5.individuals diagnosed with insomnia;
6.individuals with sleep-related breathing disorders;
7.individuals with obesity;
8.professional athletes.

Studies concerning the general population of healthy adults were included only when their findings directly referred to exercise timing, intensity or type and their effect on sleep.

2.5. Study selection process

The study selection process was conducted in several stages. In the first stage, a broad search was carried out to identify publications concerning the general relationship between physical activity and sleep. In the second stage, each study was assessed for its relevance to the main variables analysed in this review. In the third stage, publications were assessed in terms of participant characteristics.

The analysis included 26 selected publications. These included experimental studies, observational studies, ecological studies, systematic reviews and meta-analyses. The articles were published between 1978 and April 2026, with a clear increase in the number of recent studies after 2020. The empirical studies included at least 29,835 participants, excluding reviews and meta-analyses to avoid double counting. The largest samples came from studies using wearable devices: Kahn et al. analysed 153,154 nights in 12,638 adults aged 18–60 years, while Leota et al. included 14,689 physically active individuals. Xu et al. additionally monitored recreational runners for one year using Garmin devices, providing real-world data on training load and sleep recovery.

Where possible, information on participants' age and sex was also considered. However, not all studies reported detailed sex distribution or exact age ranges in a way that allowed direct comparison. Some studies included only men, while others involved mixed samples, but data on women and men were not always presented in a way that allowed pooled analysis. For this reason, the total number of women and men across all studies was not calculated. This limitation was taken into account when interpreting the results.

Subjective sleep quality was most often assessed using questionnaires or sleep diaries, whereas objective sleep parameters were measured using polysomnography, actigraphy, accelerometry or wearable devices.

2.6. Characteristics of the included studies

The table presents the selected and analysed studies whose findings will be discussed in the next section.

Table 1. Exercise intensity and type, and sleep quality in healthy active adults.

No.	Authors, year	Participants	Exercise / timing / intensity	Main effect on sleep
1	Walker et al., 1978	Adult runners	Running; timing and intensity not specified	Altered sleep architecture, including reduced REM sleep.
2	Kern et al., 1995	Healthy adults	Daytime high-intensity exercise	Increased nocturnal cortisol and growth hormone secretion.
3	Myllymäki et al., 2012	Healthy adults	Evening aerobic exercise; moderate vs vigorous intensity	Vigorous exercise delayed autonomic recovery and could affect sleep onset.
4	Brand et al., 2014	Active young adults	Evening exercise; high subjective perceived exertion	Higher perceived exertion was associated with better sleep efficiency.
5	Buman et al., 2014	Adult exercisers	Evening/night activity; various intensity	Most participants did not report impaired sleep after evening exercise.
6	Oda & Shirakawa, 2014	Active young men	Pre-sleep exercise; moderate vs high intensity	High-intensity exercise delayed sleep onset.
7	Stutz et al., 2019	Healthy adults; meta-analysis	Evening exercise; moderate to high intensity	Evening exercise generally did not impair sleep if it was not performed too close to bedtime.
8	Aloulou et al., 2020	Endurance runners	Night-time running; high intensity	Delayed sleep onset and changes in sleep architecture.

9	Burgess et al., 2020	Recreational athletes / training individuals	Resistance and endurance training; morning vs evening	Exercise type and timing influenced sleep quality.
10	Miller et al., 2020	Healthy young men	Evening exercise; moderate intensity	It did not impair sleep quality or sleep efficiency.
11	Saidi et al., 2020	Healthy young adults	Evening running; moderate intensity	Exercise completed 4 hours before bedtime improved sleep efficiency and reduced wake after sleep onset.
12	Thomas et al., 2020	Endurance runners	Early-evening running; low vs high intensity	High-intensity evening exercise did not disrupt sleep.
13	Kahn et al., 2021	Active adults, wearable device users	Evening activity; moderate to high intensity	Evening activity was not associated with poorer sleep.
14	Wang & Boros, 2021	Adults; systematic review	Physical activity; mainly moderate intensity	Physical activity had a positive effect on sleep quality.
15	Goldberg et al., 2023	Healthy active adults	Morning vs evening exercise; mainly moderate intensity	Evening exercise was associated with better subjective sleep quality.
16	Kim et al., 2023	Healthy adults; review	Different timing and intensity of exercise	Moderate evening exercise may improve sleep, whereas intense late exercise may impair it.
17	Altunalan et al., 2024	Healthy active adults	Timing of physical activity; various intensity	Late activity was associated with lower sleep quality and poorer sleep hygiene.
18	Gale et al., 2024	Healthy adults	Evening resistance exercise breaks; light/moderate intensity	Increased total sleep time without reducing sleep quality.
19	Obeidat et al., 2024	Healthy adults	Morning, afternoon and evening activity; various intensity	Vigorous evening activity was associated with poorer sleep quality.
20	Alismail et al., 2025	Adults with accelerometry data	Daily physical activity; timing not specified	Activity was positively associated with sleep duration on

				the same and following day.
21	da Silva et al., 2025	Physically active adults	Regular physical activity; chronotype considered	Longer and regular activity was associated with better sleep quality.
22	Leota et al., 2025	Physically active adults, wearable data	Evening exercise; dose-response relationship	Later and harder exercise shortened sleep and reduced its quality.
23	Wang et al., 2025	Adults in intervention studies	Aerobic training, Pilates, combined training	Several forms of activity improved sleep quality, especially aerobic and combined training.
24	Liang et al., 2026	Adults in intervention studies	Various exercise interventions	Exercise improved subjective sleep quality; the effect depended on activity type and dose.
25	Mănescu et al., 2026	Athletes / active adults	Exercise timing in sport; review	Exercise timing may affect recovery, autonomic regulation and sleep-related mechanisms.
26	Xu et al., 2026	Recreational runners	Running load; real-world monitoring	High training load worsened sleep stages and recovery markers.

2.7. Methodological considerations

Laboratory studies allow a more precise assessment of physiological sleep parameters, such as sleep architecture, REM sleep, slow-wave sleep and nocturnal autonomic activity. At the same time, they often include small samples and do not always reflect the everyday behaviour of recreational athletes. In contrast, ecological studies and studies based on wearable devices include larger groups of participants and real-world training conditions, but their sleep measurements may be less accurate than polysomnography.

3. Results

3.1 Exercise timing and sleep quality

Physical activity during the day influences sleep quality. The common belief that training immediately before bedtime has a negative effect is not entirely accurate. A closer analysis shows that sleep after morning, afternoon or evening exercise depends on at least four additional factors: exercise load, duration, type of activity and the time required for thermoregulatory and autonomic downregulation before sleep. When these moderators are overlooked, the literature appears inconsistent. Moderate exercise performed earlier in the evening is usually neutral or slightly beneficial for sleep, whereas very intense exercise performed immediately before bedtime is most often associated with impaired sleep onset or poorer nocturnal recovery quality (Stutz et al. 2019; Saidi et al. 2020; Kahn et al. 2021; Leota et al. 2025; Liang et al. 2026).

In the actigraphy study by Burgess et al., individuals who exercised in the morning and in the evening did not differ significantly in terms of TST (total sleep time), SOL (sleep onset latency), SE (sleep efficiency) or WASO (wake after sleep onset) during a week of monitoring under everyday conditions. Mean values were almost identical in both groups, suggesting that exercise timing itself was not a strong factor differentiating sleep in regularly training recreational individuals. A similar result was reported by Altunalan et al., who found no significant differences in subjective sleep quality or sleep hygiene between individuals who were active in the morning, afternoon and evening. In contrast, Goldberg et al. showed an advantage of evening exercise in recreational runners with regard to subjective sleep quality, suggesting that, in real-world conditions, evening training may be not only acceptable but even beneficial for some individuals (Burgess et al. 2020; Goldberg et al. 2023; Altunalan et al. 2024).

On the other hand, Saidi et al. compared running at an intensity of 60% HRmax completed four hours versus two hours before bedtime. Both sessions were generally well tolerated, but only the session completed four hours before bedtime improved SE and WASO. In endurance runners, Thomas et al. showed that even a one-hour high-intensity interval training session may be well tolerated if it ends 3.5 hours before bedtime. Leota et al. defined this threshold even more precisely: when exercise ended at least four hours before habitual sleep onset, no impairment was observed, whereas later and harder exercise was associated with gradually increasing adverse changes in sleep quality (Stutz et al. 2019; Saidi et al. 2020; Thomas et al. 2020; Leota et al. 2025).

Furthermore, evidence from controlled and sport-specific studies suggests that sleep impairment is mainly linked to high physiological arousal after late intense exercise. Oda and Shirakawa showed that only high-intensity pre-sleep exercise delayed sleep onset and increased autonomic activation, while Aloulou et al. observed altered sleep architecture after an intense night-time trail run. Recent findings in recreational runners further indicate that high training loads may reduce deep and REM sleep, increase wake time and lower HRV, suggesting poorer nocturnal recovery (Oda & Shirakawa 2014; Aloulou et al. 2020; Xu et al. 2026; Liang et al. 2026).

In summary, subjective sleep quality and basic indicators of sleep continuity are not disturbed by light and moderate evening exercise may even improve it, whereas high-load exercise performed close to bedtime is more often reflected in objective indicators such as prolonged sleep latency, elevated nocturnal heart rate, reduced HRV and altered distribution of sleep stages (Oda & Shirakawa 2014; Stutz et al. 2019; Kahn et al. 2021; Leota et al. 2025).

3.2 Exercise intensity and sleep quality

Exercise intensity appears to be one of the key variables explaining why physical activity sometimes improves sleep and, in other cases, has little effect or may even disturb recovery. The analysed studies suggest that the relationship is not simply linear: more intense exercise does not automatically lead to better sleep. Moderate-intensity activity seems to offer the most stable sleep-related benefits, especially when it is performed regularly and not too close to bedtime. In this range, exercise may support sleep onset, improve sleep efficiency and increase total sleep time, probably because it creates enough physiological fatigue to promote sleep without causing excessive arousal. (Kredlow et al. 2015; Stutz et al. 2019; Saidi et al. 2020).

This is particularly important for recreational athletes, who often train after work and do not always have full control over recovery time. A moderate evening session may be a reasonable compromise: it allows the athlete to train, but usually does not overload the nervous system before sleep. For example, Saidi et al. showed that running at 60% HRmax was well tolerated, and when it ended four hours before bedtime, it improved sleep efficiency and reduced wake after sleep onset. This suggests that moderate exercise may work almost like a “controlled stressor”: strong enough to support recovery processes, but not strong enough to disturb sleep continuity (Saidi et al. 2020; Stutz et al. 2019).

High-intensity exercise gives a more complicated picture. It should not be described as harmful in every case, because trained individuals may tolerate it surprisingly well when the session ends early enough. Thomas et al. showed that endurance runners were able to complete a one-hour high-intensity interval session in the early evening without subsequent sleep disruption. However, this does not mean that intensity is irrelevant. Other studies indicate that when high-intensity exercise is performed close to bedtime, it may delay sleep onset, increase nocturnal heart rate, reduce HRV and disturb the normal process of autonomic downregulation. In practice, the problem is not intensity alone, but intensity combined with insufficient time for the body to calm down (Thomas et al. 2020; Oda & Shirakawa 2014; Aloulou et al. 2020; Leota et al. 2025).

The most recent wearable-based evidence strengthens this conclusion. Leota et al. showed a clear dose-response pattern: the later and harder the exercise session, the greater the risk of shorter sleep, lower sleep quality, higher nocturnal resting heart rate and lower HRV. Similarly, Xu et al. found that in recreational runners, higher training load was associated with changes in sleep architecture, including less deep and REM sleep, more light sleep and more wake time. Therefore, for recreational athletes, the safest conclusion is practical rather than extreme: light and moderate exercise can usually support sleep, while high-intensity or high-load sessions should be planned with enough recovery time before bedtime and with attention to accumulated fatigue (Leota et al. 2025; Xu et al. 2026; Kredlow et al. 2015; Stutz et al. 2019).

3.3 Exercise modality: aerobic, anaerobic/resistance and mixed training

The type of exercise performed may substantially influence nocturnal recovery. The clearest pattern can be observed for aerobic exercise, such as running, cycling or swimming. Regular endurance training is most often associated with better sleep quality, easier sleep initiation and improved sleep continuity, especially when it is performed systematically and at moderate intensity. In practical terms, classic endurance exercise may be considered a relatively safe strategy for supporting sleep, provided that it does not become a very late, highly demanding session performed shortly before bedtime. Meta-analyses and reviews indicate that physical activity may improve total sleep time, sleep efficiency, sleep onset latency and subjective sleep quality, although these effects depend on how training is structured, not merely on the fact that exercise is performed (Kredlow et al. 2015; Wang & Boros 2021; Saidi et al. 2020; Thomas et al. 2020).

Resistance training and more anaerobic forms of exercise present a less straightforward, but still interesting, picture. On the one hand, strength exercise may support sleep, probably through reduced tension, muscular fatigue and improved overall physiological regulation. On the other hand, its effects may change more easily when training volume or intensity increases, or when the session takes place late in the evening. In studies involving resistance exercise, short and moderate evening stimuli did not necessarily impair sleep and, in some cases, even increased total sleep time. The problem appears more likely when strength or interval training is heavy, prolonged and leaves the body in a state of elevated arousal, with insufficient time to downregulate before sleep (Burgess et al. 2020; Gale et al. 2024; Oda & Shirakawa 2014; Leota et al. 2025).

Mixed training is probably the closest to the real-life routine of recreational athletes. From the perspective of sleep, the key issue is not choosing one “best” discipline, but organizing the training week sensibly: more demanding sessions earlier in the day, calmer sessions in the evening and mixed training without accumulating high intensity day after day. In recreational athletes, a mixed training model may support sleep and recovery, provided that it does not lead to chronic overload and allows enough time for physiological downregulation before bedtime (Wang et al. 2025; Liang et al. 2026; Xu et al. 2026; Leota et al. 2025).

3.4. Sleep parameters affected by exercise

Across the analysed studies, physical activity influenced both quantitative and qualitative sleep parameters, although the direction of this effect depended on how the training session was planned. The most frequently assessed outcomes were sleep onset latency (SOL), total sleep time (TST), sleep efficiency (SE), wake after sleep onset (WASO), heart rate variability (HRV) and, in more detailed studies, sleep architecture. In general, moderate and regular activity was associated with better sleep continuity, whereas late, strenuous or accumulated exercise load more often affected objective recovery markers. This distinction is important because recreational athletes may report good subjective well-being even when physiological indicators suggest incomplete nocturnal recovery (Kredlow et al. 2015; Stutz et al. 2019; Kahn et al. 2021; Leota et al. 2025).

SOL and SE appear to be particularly sensitive to exercise timing and intensity. Moderate evening exercise may shorten the time needed to fall asleep, especially when there is an adequate interval between exercise and bedtime. Saidi et al. showed that a moderate run completed four hours before bedtime improved SE and reduced WASO, while Stutz et al. indicated that evening exercise generally does not disturb sleep unless it is very intense and performed shortly before bedtime. This mechanism was further supported by Oda and

Shirakawa, who found that high-intensity pre-sleep exercise delayed sleep onset and increased physiological arousal (Oda & Shirakawa 2014; Stutz et al. 2019; Saidi et al. 2020).

TST and sleep architecture show a more complex pattern. Late and demanding exercise may shorten sleep duration and reduce sleep quality, particularly when the body has insufficient time to downregulate before bedtime. Studies using physiological markers also suggest that high training load may alter sleep structure, reduce deep and REM sleep, increase wake time and lower HRV. Exercise can therefore support sleep, but this effect is most likely when activity is regular, moderate and followed by sufficient recovery time before bedtime (Kahn et al. 2021; Leota et al. 2025; Xu et al. 2026; Liang et al. 2026).

4. Limitations

This review has several limitations. First, it was designed as a narrative review; therefore, its conclusions should be interpreted as a structured synthesis of the available evidence rather than as definitive training recommendations.

Second, the included studies differed in terms of study populations, exercise protocols and methods of sleep assessment. Some studies involved healthy adults, others recreational athletes, endurance runners or regularly trained individuals, which means that not all findings can be directly generalized to the whole population of recreational athletes. Sleep was also assessed using different methods, including questionnaires, sleep diaries, polysomnography, actigraphy, accelerometry and wearable devices, which makes direct comparison between studies difficult. Third, important modifying factors were not reported or controlled in a uniform way. Chronotype, sex distribution, training status, habitual sleep patterns, caffeine intake, psychological stress and the exact interval between exercise and bedtime may all influence the sleep response to physical activity, but they were not assessed consistently across the included studies. Definitions of exercise timing also varied; for example, "evening exercise" could refer both to exercise completed several hours before bedtime and to activity performed shortly before sleep.

Finally, the analysed literature included both small laboratory studies and large real-world wearable-based studies. Laboratory studies allow a more precise assessment of physiological sleep parameters, but they often involve small and specific samples. Wearable-based studies better reflect everyday training routines, but their sleep measurements may be less accurate than polysomnography. For this reason, one universal recommendation is difficult to formulate. The most reasonable conclusion is that physical activity should be individualized according to exercise intensity, modality, training status and the time interval required to allow recovery before sleep (Myllymäki et al. 2012; Oda & Shirakawa 2014; Stutz et al. 2019; Burgess et al. 2020; Kahn et al. 2021; Leota et al. 2025; Xu et al. 2026).

5. Conclusions

This narrative review shows that exercise can support sleep quality in recreational athletes, but its effect depends on how the training session is placed within the day, how demanding it is and what type of activity is performed. The relationship between exercise and sleep should therefore not be reduced to a simple rule that evening training is either good or bad. A more accurate conclusion is that sleep response depends on the interaction between timing, intensity, modality, accumulated fatigue and the time available for physiological downregulation before bedtime.

The most consistent benefits were observed after regular, moderate-intensity activity, which was generally associated with better sleep continuity, higher sleep efficiency and easier sleep initiation. Evening exercise should not be treated as automatically harmful, because light and moderate sessions are usually well tolerated and may even improve sleep when enough recovery time is allowed. In contrast, late high-intensity or high-load exercise may delay sleep onset, increase nocturnal heart rate, reduce HRV and disturb sleep architecture, especially when performed close to habitual sleep time. Exercise modality also matters: aerobic and mixed training appear most favourable when performed regularly and at a moderate load, while resistance or anaerobic exercise may require more careful scheduling when the session is heavy or late.

In practical terms, light and moderate evening exercise can usually be continued without fear of sleep disruption. More demanding endurance sessions, intense intervals and heavy resistance training should preferably be completed several hours before bedtime, with the safest practical threshold appearing to be around four hours for harder sessions. When late training is unavoidable, reducing intensity and adding a clear cool-down period may help limit physiological arousal. Athletes should also observe their own response, including sleep onset latency, sleep efficiency, subjective sleep quality, morning fatigue and, when available, nocturnal heart rate or HRV.

Future recommendations should consider individual factors such as fitness level, chronotype, accumulated fatigue, caffeine use, stress and personal sleep response. More studies are needed specifically in recreational athletes, because this group trains under everyday life constraints that differ from both sedentary adults and professional athletes. Overall, physical activity may be a valuable non-pharmacological recovery strategy, but the best results are likely to come from individualized planning rather than universal rules (Kredlow et al. 2015; Myllymäki et al. 2012; Oda & Shirakawa 2014; Stutz et al. 2019; Saidi et al. 2020; Thomas et al. 2020; Kahn et al. 2021; Leota et al. 2025; Xu et al. 2026; Liang et al. 2026).

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Author's contribution:

Conceptualization: Alicja Benecka, Gabriela Szewczyk

Methodology: Aleksandra Blicharz, Wojciech Kozdraś

Investigation: Elżbieta Bukowczan, Ewa Wiench

Software: Magdalena Kloc, Alicja Zając

Check: Bartosz Niciński, Damian Broda

Formal analysis: Alicja Zając

Resources: Alicja Benecka, Agnieszka Benecka

Data curation: Elżbieta Bukowczan

Writing- rough preparation: Ewa Wiench, Elżbieta Bukowczan, Alicja Zając, Bartosz Niciński, Damian Broda, Alicja Benecka, Gabriela Szewczyk, Magdalena Kloc, Aleksandra Blicharz, Wojciech Kozdraś, Agnieszka Benecka

Writing- review and editing:

Supervision: Alicja Benecka

Project administration:

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