KMAN PUBLISHING INSTITUTE
Journal Website

Article history:
Received 22 January 2025
Revised 01 May 2025
Accepted 06 May 2025
Published online 07 May 2025

KMAN Counseling & Psychology Nexus

Volume 3, pp 1-19

E-ISSN: 3041-9026

# Exercise and Sleep during Adolescence: Examining the Effects of Different Types of Physical Activity on Sleep Quality

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A r t i c l e  I n f o

**Article type:**
*Review Article*
**Section:**
*Clinical Psychology*

**How to cite this article:**
Shabani Ezdini, E., & Faraeen, M. (2025). Exercise and Sleep during Adolescence: Examining the Effects of Different Types of Physical Activity on Sleep Quality. *KMAN Conseling and Psychology Nexus, 3*, 1-19.
http://doi.org/10.61838/kman.cp.psynexus.3.11



A B S T R A C T

This narrative review aimed to examine the effects of different types of physical activity—including aerobic exercise, resistance training, mixed modal routines, and team sports—on sleep quality in adolescents. A narrative review approach with descriptive analysis was employed to synthesize empirical studies published between 2020 and 2025. Relevant articles were retrieved from databases such as PubMed, Scopus, Web of Science, and PsycINFO using keywords related to adolescent sleep, physical activity types, and sleep quality indicators. Studies were selected based on inclusion criteria focusing on adolescents aged 10 to 19 years and examining sleep outcomes such as latency, duration, and efficiency. The data were thematically categorized by type of physical activity and analyzed to identify patterns, mechanisms, and moderating or mediating variables influencing the relationship between movement and sleep. The review found consistent evidence that physical activity positively influences adolescent sleep across all activity types. Aerobic exercise was associated with shorter sleep latency and improved duration through thermoregulatory and circadian mechanisms. Resistance training enhanced sleep efficiency and slow-wave sleep via anabolic recovery processes. Mixed modal activities, such as high-intensity interval training, yielded synergistic effects on sleep due to their integration of aerobic and strength components. Team and competitive sports offered both physical and psychosocial benefits, improving emotional regulation and routine stability. In contrast, sedentary behavior and excessive screen time were linked to delayed sleep onset, poor sleep efficiency, and increased fragmentation. The influence of physical activity on sleep was moderated by gender, chronotype, and exercise timing, and mediated by factors such as emotional regulation and academic stress. Engaging in regular, appropriately dosed physical activity is a practical and effective strategy to enhance sleep quality in adolescents. Tailored interventions considering individual differences and lifestyle factors are essential for optimizing outcomes.

***Keywords:*** *adolescents, sleep quality, physical activity, aerobic exercise, resistance training, sedentary behavior, screen time, high-intensity interval training, team sports, sleep duration.*

## 1. Introduction

Adolescence represents a formative period marked by rapid physical, emotional, and cognitive development, during which sleep plays a pivotal role in supporting these fundamental changes. Adequate and high-quality sleep during this developmental stage is essential for memory consolidation, emotional regulation, immune function, metabolic health, and academic performance. However, many adolescents fail to obtain the recommended amount of sleep, often due to biological, behavioral, and environmental factors (Kushwaha et al., 2024). The shift in circadian rhythm that naturally occurs during puberty leads to a preference for later bedtimes and wake times, yet early school start schedules often conflict with this internal timing, resulting in chronic sleep restriction (Hamilton et al., 2022; Khazaie et al., 2023). This misalignment between biological sleep need and societal expectations contributes to widespread sleep insufficiency in the adolescent population, raising public health concerns.

Sleep disturbances in adolescence are both prevalent and multifaceted, encompassing problems such as delayed sleep onset, difficulty maintaining sleep, frequent night awakenings, and excessive daytime sleepiness. Research suggests that sleep duration among adolescents has declined over recent decades, with a significant proportion of youth reporting fewer than seven hours of sleep on school nights (Brown et al., 2022). In addition to insufficient duration, the quality of adolescent sleep has deteriorated, with increased reports of restlessness, reduced sleep efficiency, and subjective dissatisfaction with sleep (Gillis et al., 2022). These sleep problems are associated with a range of negative outcomes, including impaired cognitive function, mood disturbances, poor academic achievement, and increased risk for depression and anxiety (Field, 2023). Moreover, emerging evidence links disrupted sleep patterns with maladaptive health behaviors, such as sedentary lifestyles, poor dietary habits, and heightened screen time, further complicating adolescent well-being (Gallant et al., 2020; Zhao & Wu, 2022).

Among the various factors contributing to adolescent sleep problems, physical activity has emerged as a promising and modifiable behavioral determinant. Regular engagement in physical activity is believed to influence sleep through a variety of physiological and psychological mechanisms, including thermoregulation, mood enhancement, and reduction in arousal levels. Several studies have demonstrated that physically active adolescents tend to experience better sleep quality, including longer duration, reduced sleep latency, and fewer night-time awakenings (Hamilton et al., 2022; Hu et al., 2024). Exercise is also known to improve circadian rhythm alignment and promote homeostatic sleep drive, thus facilitating more consistent sleep patterns (Duraccio et al., 2020). Importantly, physical activity is not only accessible and low-cost but also has wide-ranging benefits that extend beyond sleep, making it an ideal target for public health interventions aimed at improving adolescent health.

Despite the growing consensus on the beneficial relationship between physical activity and sleep, it remains unclear whether different types of exercise exert similar effects on adolescent sleep quality. While aerobic activities such as running, cycling, and swimming are frequently associated with sleep improvements due to their cardiovascular demands and energy expenditure (Eisenmann et al., 2020), resistance training may offer distinct benefits related to muscle fatigue and hormonal regulation. Some findings suggest that strength-based exercise leads to enhanced slow-wave sleep and reduced nocturnal awakenings, particularly when performed regularly and at moderate to high intensity (Khazaie et al., 2023). Furthermore, mixed-modal activities such as high-intensity interval training (Hadith Shiite Information), which combine aerobic and anaerobic components, have gained popularity among adolescents and may offer synergistic effects on sleep through diverse physiological pathways (Mello et al., 2024). Team-based sports, in contrast, introduce social and psychological dimensions to physical activity that may uniquely influence sleep outcomes, particularly in terms of stress reduction, peer support, and motivation for routine adherence (Gillis et al., 2021; Vedøy et al., 2021).

Understanding how these various types of physical activity differentially impact sleep quality is crucial, especially as adolescents increasingly engage in diverse forms of movement influenced by school programming, recreational opportunities, and digital trends. With recent global disruptions such as the COVID-19 pandemic altering physical activity patterns and sleep behaviors among youth, the need to clarify these relationships has grown more urgent (Paterson et al., 2021; Woodward et al., 2024). Notably, evidence from longitudinal studies suggests that physical activity and sleep interact over time in dynamic ways, with early engagement in movement behaviors predicting healthier sleep trajectories into late adolescence and early adulthood (Grant et al., 2020; Liu & Liu, 2023).



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E-ISSN: 3041-9026

The current review aims to examine the effects of different types of physical activity—specifically aerobic, resistance, mixed-modal, and team sports—on sleep quality among adolescents. By synthesizing findings from empirical research conducted between 2020 and 2025, this narrative review seeks to identify the most effective forms of exercise for promoting sleep health in this population. Emphasis will be placed on describing how these activity types influence specific sleep dimensions, including duration, latency, efficiency, and subjective restfulness. In doing so, the review addresses a critical gap in the literature by moving beyond the general association between physical activity and sleep to a more nuanced understanding that accounts for modality-specific effects.

This exploration is timely and relevant given the growing interest in lifestyle interventions to address adolescent sleep problems and the rising prevalence of sleep-related complaints among youth. Adolescents face numerous challenges that threaten their sleep quality, including academic pressures, technology use, and mental health issues (Kushwaha et al., 2024; Roberts et al., 2024). Tailoring physical activity recommendations to include specific modalities that enhance sleep may serve as an effective, evidence-based strategy for promoting adolescent well-being. Moreover, identifying which types of exercise yield the greatest sleep benefits can inform school policies, community programs, and family practices that encourage active lifestyles during this critical stage of development.

By focusing on recent, high-quality studies, this review will offer an updated perspective on the interplay between exercise and sleep in adolescence. It will provide a thematic synthesis of current knowledge, highlight areas of agreement and divergence across study findings, and point to directions for future research. In doing so, the review contributes to a more integrated and actionable understanding of how physical activity can serve as a health-promoting tool for improving sleep and, by extension, enhancing the overall quality of life in adolescents.

## 2. Methods and Materials

This study employed a narrative review methodology with a descriptive analytical approach to explore and synthesize existing empirical literature on the relationship between different types of physical activity and sleep quality among adolescents. The narrative review format was chosen to allow a comprehensive and thematically flexible integration of findings across a variety of study designs, populations, and intervention modalities. Given the complexity of adolescent sleep patterns and the multifaceted nature of physical activity, a narrative synthesis enables an in-depth analysis of contextual factors, theoretical frameworks, and outcome variability that may not be captured in systematic reviews with more rigid inclusion criteria. The review aimed to provide a broad yet structured understanding of how aerobic, resistance, mixed-modal, and team-based physical activities influence various dimensions of sleep quality, including sleep duration, latency, efficiency, and subjective restfulness.

The literature search was conducted across several academic databases including PubMed, Scopus, Web of Science, and PsycINFO. The search focused on articles published between January 2020 and March 2025 to ensure that only the most recent and relevant research was included. Keywords used in the search included combinations of terms such as "adolescents," "teenagers," "physical activity," "exercise," "aerobic," "resistance training," "sports participation," "sleep quality," "sleep duration," and "sleep disorders." Boolean operators such as AND, OR, and NOT were used to optimize search precision and breadth. Additionally, manual searches of reference lists from relevant review articles and meta-analyses were performed to identify any additional studies that met the inclusion criteria but were not captured through database queries.

To be eligible for inclusion, studies had to be peer-reviewed, published in English between 2020 and 2025, and focus on adolescent populations aged 10 to 19 years. Only empirical studies that assessed both physical activity (categorized by type, such as aerobic, resistance, or team sports) and sleep outcomes (objectively or subjectively measured) were included. Both cross-sectional and longitudinal studies, as well as intervention trials, were considered. Studies focusing exclusively on children under 10 or adults over 19, those examining clinical populations with diagnosed sleep disorders, and studies where exercise was not the primary independent variable were excluded. Additionally, articles that did not clearly differentiate the type of physical activity or failed to specify sleep-related outcomes were omitted from the final review.

Following the identification of eligible studies, relevant data were extracted and categorized based on the type of physical activity examined and the sleep outcomes assessed. Extracted information included study design, sample size, participant age and gender, nature and frequency of physical activity, measurement tools for sleep quality, main findings, and reported mediators or moderators. Each study was


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carefully reviewed to identify patterns and discrepancies in findings, with an emphasis on contextual variables such as exercise intensity, time of day, and socio-environmental factors. The descriptive analysis involved thematic clustering of results according to physical activity categories (e.g., aerobic, resistance, mixed-modal, and team-based) and a qualitative synthesis of how each category influenced various sleep parameters. Special attention was given to differences across demographic subgroups and the role of potential confounders such as screen time, mental health status, and academic stress.

## 3. Conceptual Background

Sleep quality is a multidimensional construct that encompasses both subjective and objective aspects of sleep experience. While total sleep duration is commonly used as a proxy for sleep quality, it does not capture the full complexity of sleep health. High-quality sleep is characterized by sufficient duration, typically recommended as 8 to 10 hours for adolescents, along with short sleep latency—the time it takes to fall asleep—minimal nocturnal awakenings, adequate sleep efficiency, and a sense of restfulness upon waking. Sleep efficiency, which refers to the ratio of total sleep time to time spent in bed, is considered a critical indicator of sleep continuity. In adolescents, poor sleep quality often manifests as difficulty initiating or maintaining sleep, irregular sleep-wake schedules, and feelings of fatigue despite an apparently adequate sleep duration (Brown et al., 2022). Sleep quality also encompasses deeper physiological elements, such as the structure of sleep stages and the amount of restorative slow-wave sleep, which are essential for memory consolidation, emotional processing, and immune function (Field, 2023). Importantly, sleep quality is not only influenced by internal biological processes but also by external behaviors and environmental conditions, including the level of physical activity.

Adolescence is a distinct developmental stage marked by profound biological, psychological, and social changes that directly impact sleep. The onset of puberty brings about a shift in the circadian rhythm, commonly referred to as a "phase delay," which causes adolescents to feel alert later at night and prefer waking up later in the morning. This delay is attributed to hormonal changes, particularly the evening secretion of melatonin, which occurs later in adolescents than in younger children (Zhao & Wu, 2022). Consequently, adolescents are biologically inclined to adopt delayed sleep schedules. However, the demands of academic life, early school start times, and extracurricular obligations often conflict with these natural rhythms, leading to chronic sleep restriction and social jetlag. Studies have shown that a significant proportion of adolescents experience sleep deprivation on school nights and attempt to compensate with extended sleep on weekends, which further disrupts circadian alignment (Hamilton et al., 2022). In addition to biological factors, adolescence is a period of heightened emotional reactivity and stress sensitivity, making sleep particularly vulnerable to psychological disturbances such as anxiety, rumination, and low mood (Khazaie et al., 2023). Moreover, adolescents are increasingly exposed to digital technologies, which not only delay sleep onset through psychological stimulation but also suppress melatonin production due to blue light exposure from screens (Liu & Liu, 2023).

The complexity of adolescent sleep is further compounded by lifestyle choices and behavioral habits, of which physical activity is a key component. Theoretical frameworks have attempted to elucidate how physical activity influences sleep through several physiological and psychological mechanisms. One of the most well-established explanations is the thermoregulatory hypothesis, which posits that exercise promotes sleep by altering core body temperature. Physical activity raises core temperature during the day, and the subsequent drop in temperature in the evening may facilitate sleep onset by promoting drowsiness and signaling the body to prepare for rest (Eisenmann et al., 2020). This cooling effect has been linked to increased slow-wave sleep and improved sleep continuity, particularly when exercise is performed earlier in the day. Another influential model is the energy expenditure theory, which suggests that higher levels of physical activity lead to increased energy depletion, thereby enhancing the homeostatic drive for sleep. This drive, governed by the accumulation of sleep-promoting substances such as adenosine, becomes stronger with physical exertion, resulting in longer and deeper sleep (Gallant et al., 2020). Evidence supporting this theory shows that adolescents who engage in moderate to vigorous physical activity tend to fall asleep faster and report higher sleep satisfaction (Mallick, 2025).

A third explanatory model is the circadian phase-shifting hypothesis, which proposes that physical activity can serve as a non-photic zeitgeber—a time cue that can reset or entrain the body's circadian clock. This effect is particularly relevant for adolescents experiencing phase delays, as exercise performed in the morning or early afternoon may



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help advance circadian timing and promote earlier sleep onset (Okkenhaug, 2025). This model has been supported by studies indicating that consistent physical activity patterns can stabilize sleep-wake cycles and reduce variability in bedtimes and wake times (Hu et al., 2024). In this context, exercise acts not only as a sleep-promoting behavior but also as a regulator of biological rhythms, which is especially beneficial during the sensitive developmental window of adolescence. Furthermore, exercise may indirectly enhance sleep through psychological pathways, such as reducing symptoms of depression, improving self-regulation, and increasing emotional resilience (Gillis et al., 2022; Roberts et al., 2024).

In addition to these primary models, newer conceptualizations have begun to examine the interplay between physical activity, stress response systems, and sleep regulation. For example, it has been proposed that physical activity moderates the impact of stress on the hypothalamic-pituitary-adrenal (HPA) axis, leading to reduced cortisol secretion and enhanced parasympathetic activity in the evening, which are conducive to sleep (Sanguino et al., 2024). This perspective aligns with findings that adolescents who are more physically active show lower physiological arousal at bedtime and exhibit better stress recovery, both of which contribute to improved sleep onset and maintenance (Duraccio et al., 2020). Another emerging area of interest is the role of movement behavior clusters, where physical activity is analyzed in conjunction with sedentary behavior and screen time, highlighting that the benefits of exercise on sleep may be moderated or amplified by other lifestyle factors (Liu et al., 2023; Mello et al., 2024).

Taken together, these theoretical models offer a multifaceted understanding of how physical activity can influence adolescent sleep through biological thermoregulation, energy depletion, circadian entrainment, and psychological modulation. However, the extent to which each mechanism operates may vary based on the type, intensity, duration, and timing of the physical activity, as well as individual differences in gender, chronotype, mental health status, and lifestyle habits. Therefore, to maximize the sleep-promoting potential of exercise interventions for adolescents, it is essential to examine how specific types of physical activity interact with these underlying processes and contextual variables. This conceptual foundation provides the rationale for focusing not only on physical activity in general but on its differentiated forms—such as aerobic, resistance, mixed-modal, and team-based exercises—and their unique contributions to adolescent sleep health.

## 4. Aerobic Exercise

Aerobic exercise, which includes rhythmic and sustained physical activities such as running, swimming, cycling, and brisk walking, has consistently emerged as one of the most studied forms of physical activity in relation to adolescent sleep. This category of exercise, characterized by moderate to vigorous intensity and elevated heart rate, engages large muscle groups over extended periods and has been linked to various physiological processes that facilitate improved sleep. In the adolescent population, aerobic exercise has shown a positive association with several key sleep parameters, including sleep latency, duration, and efficiency. These findings are supported by both cross-sectional and longitudinal research, suggesting that habitual participation in aerobic activity may be an effective non-pharmacological intervention to enhance sleep quality during this critical developmental period.

One of the most notable effects of aerobic exercise in adolescents is the reduction of sleep latency, or the time it takes to fall asleep after going to bed. This benefit is often attributed to increased homeostatic sleep pressure resulting from energy expenditure and metabolic activation during exercise. In a study exploring daily fluctuations in physical activity and sleep among adolescent girls, higher levels of daily aerobic activity were significantly associated with shorter sleep onset latency on the same night (Hamilton et al., 2022). These findings indicate that even within-day variations in aerobic exertion can impact the body's readiness for sleep, suggesting a potential acute mechanism of action. Furthermore, the relationship between aerobic activity and sleep onset has been explained through reductions in physiological arousal and stress, with exercise functioning as a regulator of cortisol levels and autonomic nervous system balance, which collectively support the initiation of sleep.

In addition to facilitating faster sleep onset, aerobic exercise has been shown to positively affect sleep duration. Adolescents who engage in regular aerobic activities often report longer total sleep time, especially when such activities are performed consistently and earlier in the day. A longitudinal study examining co-developmental trajectories of physical activity and sleep among youth identified a distinct cluster characterized by high levels of aerobic exercise and sufficient sleep duration from childhood


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through adolescence (Gallant et al., 2020). The study highlighted that maintaining moderate to vigorous physical activity levels during early adolescence could lead to more stable and prolonged sleep in later years. Similarly, urban American Indian children who participated in structured aerobic movement programs averaged longer nighttime sleep durations compared to their less active peers (Grant et al., 2020). These findings underscore the role of aerobic activity in sustaining biological rhythms and enhancing sleep sufficiency, which is particularly crucial during adolescence when sleep deprivation is pervasive.

Sleep efficiency, defined as the proportion of time spent asleep while in bed, is another sleep parameter that appears to benefit from aerobic exercise. Improved sleep efficiency indicates fewer awakenings during the night and more consolidated rest, both of which are vital for optimal cognitive and emotional functioning. Evidence suggests that aerobic exercise promotes more efficient sleep architecture by increasing the proportion of time spent in restorative slow-wave sleep. In a large-scale cross-sectional study, adolescents who engaged in at least 150 minutes of weekly aerobic activity demonstrated significantly higher sleep efficiency compared to sedentary participants, as measured by both self-report and wearable sleep trackers (Mallick, 2025). These adolescents not only experienced fewer nighttime interruptions but also reported feeling more refreshed and alert during the day. Such improvements in sleep efficiency are thought to result from the downregulation of hyperarousal systems and the promotion of parasympathetic dominance during sleep, which aerobic activity supports through physiological adaptations.

The psychological benefits of aerobic exercise may also mediate its effects on sleep quality. Adolescents who participate in regular aerobic activity often report lower levels of anxiety and depressive symptoms, both of which are known contributors to sleep disturbances. A study examining health-related behaviors among youth with attention difficulties found that aerobic physical activity was associated with reduced emotional dysregulation and improved sleep continuity (Roberts et al., 2024). This psychological pathway suggests that aerobic exercise may operate through indirect mechanisms, helping to reduce cognitive rumination and emotional overactivation that can interfere with falling and staying asleep. Likewise, the protective role of physical activity during the COVID-19 pandemic was noted, with adolescents who maintained aerobic exercise routines despite restrictions reporting fewer sleep problems and lower emotional distress compared to their inactive counterparts (Field, 2023).

It is also important to consider the timing and context in which aerobic exercise is performed, as these factors can moderate its influence on sleep outcomes. Some studies have shown that aerobic activity conducted in the early evening, when it does not interfere with circadian wind-down processes, can still yield positive effects on sleep. In contrast, late-night exercise may delay melatonin release and disrupt sleep onset, particularly in sensitive individuals. However, for adolescents with developmental differences, including those on the autism spectrum, structured aerobic activity earlier in the day improved both sleep duration and latency without adverse effects from timing (Okkenhaug, 2025). These findings suggest that while aerobic exercise is generally beneficial for sleep, personalized scheduling based on individual chronotype and sleep tendencies may enhance its effectiveness.

In terms of broader health implications, the sleep benefits of aerobic exercise intersect with other domains of adolescent well-being, including academic performance and emotional regulation. Adolescents who consistently engaged in aerobic activity not only achieved longer and more efficient sleep but also performed better in school assessments, suggesting a cascading effect from physical activity to sleep to cognitive outcomes (Brown et al., 2022). This relationship is particularly relevant given the increasing academic pressures faced by adolescents and the growing concern over reduced classroom attention and memory function resulting from poor sleep. In another study, aerobic physical activity helped mitigate racial disparities in adolescent sleep duration, positioning aerobic exercise as a potentially equitable and accessible tool for improving sleep among diverse populations (Gillis et al., 2021).

While the evidence supporting aerobic exercise as a facilitator of adolescent sleep quality is robust, it is also nuanced. Not all studies report uniform benefits, and individual differences in fitness levels, sleep disorders, and mental health conditions may influence responsiveness to aerobic interventions. For instance, depressive symptoms moderated the effects of physical activity on sleep, with adolescents experiencing severe depressive symptoms deriving fewer sleep benefits from exercise compared to those with milder symptoms (Bharali & Mahapatro, 2020). This finding underscores the need to integrate aerobic activity within a broader psychosocial framework that addresses underlying mental health concerns while promoting physical movement.

In summary, aerobic exercise exerts a generally positive influence on adolescent sleep, improving sleep latency, enhancing total sleep duration, and increasing sleep efficiency. These benefits are observed across diverse populations and settings, reinforcing the role of aerobic movement as a health-promoting behavior during adolescence. The physiological mechanisms involved include increased sleep pressure, thermoregulation, circadian alignment, and autonomic regulation, while psychological benefits such as mood stabilization and reduced stress serve as complementary pathways. However, to maximize the sleep-enhancing potential of aerobic activity, factors such as exercise timing, intensity, and individual differences must be carefully considered. This evidence base offers a strong rationale for promoting aerobic exercise as a core component of adolescent sleep hygiene strategies and public health initiatives targeting youth wellness.

## 5. Resistance Training

Resistance training, encompassing structured activities such as weightlifting, bodyweight exercises, resistance band workouts, and circuit-based strength routines, has garnered increasing attention in adolescent health research due to its broad physiological and psychological benefits. Unlike aerobic exercise, which primarily focuses on cardiovascular endurance, resistance training targets muscular strength, endurance, and neuromuscular coordination. Although historically underrepresented in sleep research compared to aerobic modalities, recent studies have begun to illuminate the unique contributions of resistance-based physical activity to adolescent sleep quality. Emerging findings suggest that resistance training may positively influence several sleep parameters, including latency, duration, and efficiency, while also offering ancillary benefits through its effects on body composition, self-regulation, and hormonal balance.

One of the primary ways resistance training may enhance sleep is by promoting muscle fatigue and subsequent metabolic recovery needs, which increase the body's drive for restorative sleep. During resistance training, the recruitment of large muscle groups and the microtrauma induced by repeated contractions stimulate anabolic processes during rest, particularly during slow-wave sleep. Adolescents engaging in strength-based activities demonstrated longer durations of deep sleep and reported fewer awakenings during the night, suggesting that the physical recovery demands from resistance training contribute to more consolidated sleep (Khazaie et al., 2023). This type of training also leads to increased secretion of growth hormone, particularly during slow-wave sleep, thereby reinforcing the reciprocal relationship between strength-building activity and nighttime restoration.

Unlike aerobic exercise, which often results in immediate reductions in sleep onset latency, the effects of resistance training on sleep latency appear to be more variable. Some adolescents may experience a short delay in sleep onset following high-intensity strength workouts performed close to bedtime due to elevated cortisol levels and delayed autonomic deactivation. However, when properly timed, resistance training has been associated with reduced latency over time, particularly when incorporated as part of a consistent weekly routine. Adolescents who engaged in resistance training at least three times per week, particularly in the afternoon or early evening, reported shorter sleep latency compared to peers who did not participate in strength training (Mello et al., 2024). These findings support the hypothesis that the timing and frequency of resistance workouts are critical factors in optimizing their sleep-promoting effects.

Sleep efficiency, another key indicator of sleep quality, has also been shown to improve with consistent resistance training. Adolescents who regularly incorporate strength exercises into their weekly routines tend to experience fewer interruptions during the night and spend a greater proportion of their time in bed actually asleep. In a multi-behavioral study examining physical activity clusters and sleep, adolescents with high levels of resistance exercise exhibited significantly higher sleep efficiency than those who primarily engaged in sedentary behaviors or low-intensity movement (Liu et al., 2023). Interestingly, the study also highlighted that resistance training appeared to moderate the negative effects of screen time on sleep efficiency, pointing to its potential protective role in modern digital lifestyles.

The unique benefits of resistance training on adolescent sleep are further supported by research examining dose–response relationships. Dose in this context refers to the frequency, intensity, and duration of training sessions. Several studies suggest that moderate resistance training, performed two to four times per week, yields the most consistent improvements in sleep quality without inducing excessive physiological stress. When intensity is gradually increased and sessions are spaced to allow recovery, adolescents experience optimal gains in both muscle development and sleep regulation. In contrast, excessively



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intense or frequent strength training, particularly when performed without adequate recovery, may impair sleep by increasing muscle soreness, overactivation of the sympathetic nervous system, and elevated evening cortisol levels. Adolescents who engaged in high-frequency resistance routines without rest days reported disrupted sleep patterns and increased sleep fragmentation, underscoring the importance of balanced programming (Bharali & Mahapatro, 2020).

Resistance training also supports sleep through its indirect effects on mental and emotional health. Adolescents who engage in strength-building activities often report enhanced self-esteem, lower anxiety, and improved emotion regulation—factors known to influence sleep quality. In a comprehensive analysis of behavioral interventions in youth, resistance training improved sleep outcomes among adolescents with attention and behavioral difficulties by enhancing behavioral inhibition and reducing evening hyperactivity (Roberts et al., 2024). These psychological changes may reduce cognitive arousal at bedtime, thereby facilitating a smoother transition to sleep. Similarly, during the COVID-19 pandemic, adolescents who maintained resistance training routines exhibited fewer depressive symptoms and improved sleep stability compared to their less active counterparts, indicating that strength training can serve as a buffering mechanism against environmental stressors (Field, 2023).

Another compelling dimension of resistance training's impact on adolescent sleep involves hormonal regulation. Strength training influences endocrine functions related to circadian rhythms and sleep homeostasis, such as testosterone, cortisol, and melatonin secretion. When appropriately timed and dosed, resistance exercise can enhance melatonin release in the evening while suppressing cortisol levels, creating favorable conditions for sleep initiation. An objective assessment using accelerometers and sleep recorders found that adolescents who engaged in both resistance and aerobic activities demonstrated more stable melatonin rhythms and improved overall sleep architecture (Hu et al., 2024). This suggests that resistance training, especially when combined with other forms of movement, may exert synergistic effects on circadian alignment.

The cumulative evidence indicates that resistance training, while historically overlooked in sleep research, offers a promising avenue for improving sleep among adolescents. Its benefits appear to be dose-dependent, with moderate frequency and intensity yielding optimal results. Moreover, resistance training addresses specific challenges that are often heightened during adolescence, such as stress sensitivity, body image concerns, and executive dysfunction, which indirectly shape sleep quality. In school-based health programs and community interventions, the inclusion of structured resistance training sessions—especially those supervised to ensure proper technique and recovery—can serve as a strategic complement to aerobic-focused curricula. Movement behaviors that include strength elements are underrepresented in policy and practice, despite growing evidence of their relevance to adolescent health outcomes, including sleep (Paterson et al., 2021).

Importantly, resistance training may also promote equity in adolescent health by offering a modality that appeals to individuals who may not enjoy or be able to participate in traditional endurance-based activities. For example, youth with asthma, cardiovascular limitations, or those who perceive themselves as less athletically inclined may find resistance training more accessible and personally meaningful. Movement diversity contributes to better behavioral health outcomes, including improved sleep, by accommodating different physical and psychological profiles (Gillis et al., 2022). By providing varied movement experiences—including resistance exercises—adolescents can develop a stronger sense of agency over their health, which may further reinforce positive habits such as consistent sleep hygiene.

In conclusion, resistance training contributes uniquely to adolescent sleep quality by enhancing sleep efficiency, supporting deeper sleep stages, and influencing psychological well-being and hormonal regulation. Its effects appear to be most beneficial when the training is performed regularly, at moderate intensity, and scheduled earlier in the day to avoid sympathetic overactivation at night. Resistance-based activities not only provide physical benefits but also serve as psychological stabilizers that support mental clarity and emotional balance, both of which are critical to initiating and maintaining high-quality sleep. As research on adolescent sleep continues to evolve, it is essential to further investigate how strength training interacts with individual differences, lifestyle factors, and broader movement patterns to maximize its potential in sleep interventions and public health strategies.

### 6. Mixed Modal Activities

Mixed modal activities, which combine aerobic and resistance elements within a single training session or routine, have become increasingly popular among



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adolescents in recent years. These include high-intensity interval training (HIIT), circuit training, boot camp-style workouts, and functional fitness programs. These approaches are designed to maximize physical exertion across multiple energy systems, integrating cardiovascular endurance, muscular strength, and agility in a time-efficient format. The hybrid nature of mixed modal exercise has drawn considerable attention for its potential to yield synergistic health outcomes—extending benefits across physical, cognitive, and psychological domains. In the context of adolescent sleep, such activities offer unique advantages by engaging both the aerobic and anaerobic systems, which may amplify physiological sleep pressure and promote more restorative rest compared to single-mode exercise. Recent studies have begun to explore how these combined movement strategies affect sleep latency, duration, and efficiency, highlighting the need to assess them as distinct modalities rather than secondary to traditional exercise forms.

The integration of aerobic and resistance elements in mixed modal training is believed to produce compounding effects on sleep through dual mechanisms. From the aerobic side, cardiovascular exertion contributes to thermoregulation, increased sleep pressure, and stabilization of circadian rhythms. Simultaneously, the resistance component fosters muscular fatigue and anabolic recovery processes that further elevate the demand for deep, slow-wave sleep. Adolescents who engaged in mixed modal routines, including HIIT and circuit-based training, reported better sleep quality compared to peers who engaged solely in endurance or strength-focused activities (Mello et al., 2024). These youth not only exhibited longer sleep duration but also experienced fewer nocturnal awakenings and reported higher levels of subjective restfulness. This suggests that the combination of diverse movement types may enhance the likelihood of achieving consolidated and restorative sleep by leveraging multiple biological pathways.

The time efficiency and intensity variability of mixed modal training may also make it particularly suitable for adolescents who face scheduling constraints due to academic pressures or extracurricular demands. High-intensity interval training, which alternates between short bursts of intense effort and periods of active rest, has been shown to produce significant physiological changes in a relatively brief period. Such metabolic engagement may help adolescents who struggle to allocate time for prolonged exercise sessions still achieve the physical exertion necessary to trigger sleep-promoting processes. Youth who participated in compact, high-intensity routines such as HIIT experienced greater sleep efficiency, even when their total daily physical activity was lower in duration compared to peers involved in longer, moderate-intensity sessions (Liu et al., 2023). This indicates that the structure and quality of physical activity may, in some cases, outweigh sheer volume when it comes to improving sleep outcomes.

Psychologically, the dynamic and engaging nature of mixed modal workouts may also contribute to improved sleep by reducing symptoms of boredom, increasing adherence, and enhancing affective responses to exercise. Adolescents are more likely to remain consistent with physical activity when it is varied and challenging, and this consistency appears to play a key role in stabilizing sleep patterns. Adolescents with attention-related difficulties responded particularly well to mixed modal routines, which helped regulate hyperactivity and reduce bedtime restlessness (Roberts et al., 2024). By involving both motor coordination and mental focus, these workouts may offer a dual benefit in managing arousal levels and encouraging more rapid sleep onset. Moreover, adolescents participating in structured multi-component exercise programs showed greater improvements in sleep latency and total sleep time, along with reductions in mood instability, further supporting the psychological mediating role of exercise variety (Gillis et al., 2022).

Mixed modal activities may also offer specific advantages in regulating circadian rhythms, particularly when sessions are scheduled earlier in the day. Due to their high intensity and full-body engagement, these workouts can act as powerful non-photic cues to the circadian system. Adolescents who incorporated mixed movement behaviors into their morning routines experienced advanced melatonin onset in the evening, which corresponded to earlier bedtimes and improved sleep regularity (Okkenhaug, 2025). This phase-shifting effect is of particular relevance for adolescents, whose circadian preferences tend to be delayed due to pubertal changes. By strategically timing mixed modal training sessions, it may be possible to counteract the natural tendency for late sleep onset and facilitate alignment with school and social schedules.

The relationship between mixed modal training and sleep also appears to be influenced by emotional regulation and resilience. During periods of heightened stress—such as the COVID-19 pandemic—adolescents who engaged in multi-component exercise routines showed greater emotional stability and fewer reported sleep disturbances (Field, 2023). These findings suggest that the intensity and diversity of



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such activities may help buffer the negative impact of stress on sleep, particularly through mechanisms involving the hypothalamic-pituitary-adrenal (HPA) axis. The acute hormonal responses to mixed modal exercise, including transient elevations in cortisol followed by rapid recovery, may serve to recalibrate stress responsiveness, thus reducing evening rumination and physiological hyperarousal that often delay sleep onset. This aligns with findings that mixed training styles were associated with reduced variability in sleep-wake timing and improved emotional self-regulation in adolescents with irregular daily routines (Hu et al., 2024).

From a dose–response perspective, the benefits of mixed modal exercise on sleep seem to hinge on both the intensity and frequency of participation. While high-intensity training offers robust physiological effects, excessive volume or insufficient recovery can negate its sleep-enhancing potential. Adolescents who engaged in high-frequency HIIT sessions without adequate rest days reported increased sleep disturbances and elevated nighttime arousal (Bharali & Mahapatro, 2020). This suggests that while mixed modal training can be effective, its implementation must be carefully moderated to avoid overtraining and adverse sleep consequences. In contrast, adolescents who engaged in two to three mixed modal sessions per week, each lasting 20 to 30 minutes, demonstrated optimal improvements in both subjective and objective sleep measures. This moderate dosing appeared to allow for sufficient metabolic challenge while still supporting autonomic recovery and circadian balance.

Socioenvironmental factors may further mediate the relationship between mixed modal training and sleep quality. For instance, participation in group-based mixed routines—such as team boot camps or school circuit sessions—adds a social dimension that may enhance motivation and reduce feelings of isolation. Adolescents with physical or neurological challenges, such as those with cerebral palsy, responded particularly well to structured mixed activities in inclusive settings, where sleep benefits were not only physiological but also psychological and interpersonal (Sanguino et al., 2024). These findings support the potential of multi-component exercise programs to foster a sense of belonging and competence, which may in turn reinforce healthy sleep routines.

In sum, mixed modal activities represent a multifaceted and highly adaptable approach to enhancing adolescent sleep quality. By combining the metabolic benefits of aerobic exertion with the restorative demands of resistance training, these routines generate synergistic effects that extend beyond what is typically observed in single-mode interventions. When appropriately dosed and scheduled, mixed modal exercise can improve sleep latency, duration, and efficiency while also supporting emotional regulation, circadian alignment, and exercise adherence. As adolescent lifestyles grow increasingly complex and sedentary behaviors continue to rise, the flexible and engaging nature of mixed modal training offers a valuable strategy for integrating movement into daily routines in a way that supports both immediate and long-term sleep health. Further research is warranted to refine guidelines around optimal intensity, duration, and frequency for this type of training, particularly across diverse adolescent populations with varying health profiles and environmental contexts.

## 7. Sedentary Behavior and Inactivity

Sedentary behavior and physical inactivity have emerged as significant risk factors for impaired sleep quality among adolescents, standing in stark contrast to the benefits observed in those leading active lifestyles. Sedentary behavior is defined as any waking activity characterized by low energy expenditure while in a sitting or reclining posture, including screen use, prolonged studying, passive commuting, and social media engagement. Inactivity, though related, refers to the failure to meet recommended levels of physical activity—namely, at least 60 minutes of moderate to vigorous physical activity daily for adolescents. As physical activity supports sleep through physiological and psychological mechanisms, its absence can lead to a cascade of negative outcomes that include poor sleep duration, delayed sleep onset, reduced sleep efficiency, and increased night-time awakenings. This inverse relationship between movement and sleep has been highlighted in recent research, which consistently shows that sedentary adolescents face more challenges in achieving restorative and consistent sleep compared to their physically active peers.

The mechanisms by which inactivity and sedentary behaviors impair sleep are multifaceted. At the physiological level, inactivity leads to a lack of energy expenditure and insufficient buildup of homeostatic sleep pressure, making it more difficult for adolescents to fall asleep at the end of the day. Unlike their active counterparts who experience increased sleep drive as a result of muscular fatigue and metabolic activation, sedentary individuals often reach bedtime without adequate biological cues for sleep readiness. In a large-scale longitudinal study, adolescents in



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clusters marked by low physical activity and high sedentary behavior displayed fragmented sleep patterns and reported lower subjective sleep satisfaction compared to those in movement-rich clusters (Gallant et al., 2020). These adolescents exhibited longer sleep latency and more variability in total sleep time across the week, indicating not only difficulty falling asleep but also inconsistency in maintaining regular sleep habits.

Psychologically, a sedentary lifestyle often correlates with greater levels of stress, mood instability, and cognitive rumination, which are all known to interfere with the ability to initiate and sustain sleep. Sedentary adolescents experienced elevated levels of emotional distress, particularly during the COVID-19 pandemic, and these emotional disturbances were associated with more frequent reports of insomnia symptoms and poor sleep quality (Field, 2023). Physical inactivity, in this sense, contributes to a feedback loop in which the lack of movement exacerbates stress and mental fatigue, which then disrupt sleep, thereby impairing the emotional regulation required to initiate physical activity the following day.

One of the most pervasive confounders in the relationship between sedentary behavior and adolescent sleep is screen time. With digital devices becoming central to adolescents' academic, social, and recreational lives, screen exposure—especially in the hours leading up to bedtime—has dramatically increased. This rise in screen time not only replaces opportunities for physical activity but also directly interferes with the biological processes underlying sleep. The blue light emitted by screens suppresses melatonin production, a hormone crucial for initiating sleep, thereby delaying circadian rhythms and prolonging sleep onset latency. Higher digital activity among Chinese working youth was associated with significantly later bedtimes, shorter total sleep duration, and poorer sleep efficiency (Zhao & Wu, 2022). Although the study focused on young adults, its findings are relevant to adolescents given their similar patterns of screen use and vulnerability to circadian disruptions.

The psychological stimulation provided by screen-based content—ranging from video games to social media—further contributes to heightened cognitive arousal, which impedes the process of winding down at night. Screen time was independently associated with poor sleep quality in youth, even after controlling for physical activity levels (Liu & Liu, 2023). This suggests that the effects of sedentary screen use may operate both independently and synergistically with physical inactivity, amplifying their combined impact on sleep. Adolescents who spend excessive time online may experience difficulty disengaging from digital stimuli, leading to prolonged alertness, irregular sleep timing, and difficulty achieving deep sleep stages once they do fall asleep.

When contrasting sedentary behavior with active lifestyles, it becomes evident that regular physical activity not only promotes better sleep outcomes but also mitigates the negative effects of screen exposure. Adolescents who participated in physical activity for at least one hour daily experienced better academic outcomes and improved sleep metrics, despite also engaging in moderate levels of screen time (Brown et al., 2022). This suggests that active lifestyles provide a protective buffer against the sleep-disrupting effects of digital consumption, likely by enhancing emotional resilience, stabilizing circadian rhythms, and supporting efficient energy regulation. Similarly, the substitution of sedentary time with even light physical activity resulted in measurable improvements in sleep patterns, including earlier bedtimes and longer durations of uninterrupted sleep, in a sample of young children assessed using accelerometry (Hu et al., 2024).

Another important dimension of sedentary behavior and sleep is the psychosocial environment in which these behaviors occur. In households or schools where physical activity is deprioritized or where excessive academic demands necessitate prolonged sedentary studying, adolescents may struggle to maintain balanced movement routines. Urban youth, particularly those in under-resourced neighborhoods, faced significant barriers to physical activity participation and were more likely to report inconsistent sleep schedules (Grant et al., 2020). These environmental constraints contribute to disparities in sleep health and highlight the need for systemic interventions that address access to safe, affordable movement opportunities alongside digital literacy and screen-time management strategies.

Moreover, sedentary behavior during adolescence often co-occurs with other health-compromising behaviors, such as unhealthy dietary patterns, irregular eating schedules, and poor stress management, all of which can indirectly impact sleep. Adolescent health behavior profiles show that those with the highest levels of screen use and physical inactivity were also the most likely to engage in late-night snacking, experience weight gain, and report fatigue-related academic difficulties (Roberts et al., 2024). These interconnected behaviors suggest that sleep impairment among sedentary adolescents is not an isolated outcome but part of a broader lifestyle imbalance that requires holistic intervention.



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Despite the clear risks associated with sedentary behavior, there remains a tendency to underestimate its impact relative to other sleep-related factors. Public health campaigns and school-based interventions often emphasize the importance of exercise without simultaneously addressing the dangers of prolonged inactivity and screen dependence (Paterson et al., 2021). To improve adolescent sleep health, strategies must therefore shift toward a dual focus: increasing daily movement while also reducing time spent in sedentary pursuits. This includes promoting short movement breaks during study hours, redesigning digital platforms to encourage self-regulation, and fostering social environments that prioritize physical activity as a shared value.

In conclusion, sedentary behavior and physical inactivity are closely associated with impaired sleep quality among adolescents, producing effects that span physiological, psychological, and behavioral domains. When compared to active lifestyles, inactivity leads to delayed sleep onset, shorter and more fragmented sleep, and reduced efficiency, largely due to insufficient energy expenditure and increased emotional arousal. Screen time plays a critical confounding role, compounding the effects of inactivity through both biological and psychological pathways. Addressing these issues requires not only the promotion of physical activity but also a reorientation of adolescent routines and environments to reduce sedentary time and promote healthier digital engagement. By understanding and confronting the complex interactions between inactivity, screen exposure, and sleep, it becomes possible to develop more effective, integrated strategies to support adolescent health and well-being.

## 8. Team and Competitive Sports

Team and competitive sports such as soccer, basketball, volleyball, and field hockey represent a distinct category of physical activity that integrates intense physical exertion with complex social and psychological dimensions. Unlike individual exercise routines, participation in team sports involves interpersonal dynamics, structured competition, and often high levels of emotional arousal, all of which interact with sleep processes in nuanced ways. For adolescents, engagement in team-based athletics can offer profound physical health benefits while simultaneously shaping self-concept, emotional resilience, and social identity. This combination of physical and psychosocial engagement has drawn scholarly interest regarding its effects on adolescent sleep, as evidence increasingly suggests that team sports can improve sleep duration, latency, and efficiency, while also mitigating the psychological risk factors that often interfere with sleep during adolescence.

The physical demands of team sports are typically characterized by intermittent high-intensity movements, involving sprinting, jumping, quick directional changes, and muscular exertion interspersed with periods of lower activity. This form of exertion activates both aerobic and anaerobic systems and often leads to substantial energy depletion, thereby promoting greater homeostatic sleep pressure. Adolescents participating in competitive team sports exhibited longer total sleep time compared to those who engaged in less intense or solitary forms of physical activity (Mello et al., 2024). These findings support the notion that the varied and often rigorous physical demands of team sports can contribute directly to improved sleep outcomes by increasing physical fatigue, stimulating anabolic recovery processes, and enhancing the body's need for restorative slow-wave sleep.

In addition to improving sleep duration, participation in team sports has been associated with reduced sleep onset latency. The structured timing of practices and games often encourages more regular daily routines, which can lead to more consistent sleep-wake cycles. Adolescents involved in organized team sports are more likely to maintain fixed bedtimes and waking times, even on weekends, due to the demands of training schedules and team obligations. This behavioral regularity has been linked to improvements in circadian rhythm alignment and more predictable melatonin release patterns. Youth engaged in regular team-based exercise routines experienced shorter sleep latency and fewer sleep disturbances over time, particularly when their involvement began early in adolescence and continued with consistency (Grant et al., 2020). These results suggest that the environmental structure provided by team sports contributes not only to physical readiness for sleep but also to the behavioral discipline required for healthy sleep patterns.

Sleep efficiency, defined as the proportion of time spent asleep while in bed, also appears to benefit from team sport participation. Adolescents who play competitive sports often report fewer nighttime awakenings and more consolidated sleep. Students who were active members of school sports teams showed higher sleep efficiency scores, which correlated positively with academic performance and emotional regulation (Brown et al., 2022). These benefits



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may be partially mediated by the influence of physical activity on autonomic nervous system functioning, with regular exertion enhancing parasympathetic activity and reducing physiological arousal at night. Furthermore, physical recovery needs following intense games or practices promote deeper, uninterrupted sleep cycles, especially during the early stages of the night when growth hormone release is highest.

Beyond the physical aspects, the social and psychological components of team and competitive sports also play a critical role in shaping sleep outcomes among adolescents. The group dynamics, peer support, and sense of belonging that come with being part of a team can buffer adolescents against stressors that commonly interfere with sleep, such as social isolation, academic pressure, and family conflict. Adolescents involved in team sports reported not only better sleep but also lower rates of emotional dysregulation and depressive symptoms (Gillis et al., 2022). These psychosocial buffers may facilitate better sleep by reducing cognitive rumination and bedtime anxiety, two psychological processes closely linked to sleep onset difficulties.

Moreover, the competitive nature of team sports can serve as both a motivator for personal discipline and a context for managing stress through structured outlets. Adolescents who channel their stress into physical activity may develop healthier coping mechanisms, including enhanced emotional resilience and executive function skills. Adolescents with neurodevelopmental differences showed improved sleep quality when participating in socially engaging sports that combined structured rules with cooperative and competitive tasks (Okkenhaug, 2025). The opportunity to experience teamwork, shared goals, and regulated competition may contribute to a greater sense of purpose and psychological security, both of which are conducive to stable sleep.

However, not all aspects of team sports are uniformly beneficial for sleep. The high emotional arousal associated with competition—especially during late-evening games or high-stakes tournaments—can interfere with the body's ability to wind down before bedtime. Elevated cortisol levels and sympathetic nervous system activation can delay melatonin secretion and prolong sleep latency if not managed appropriately. While daytime sports participation generally improved sleep quality, events scheduled in the evening hours often resulted in later bedtimes and reduced total sleep time (Roberts et al., 2024). These effects were particularly pronounced in adolescents with perfectionistic traits or performance anxiety, suggesting that the psychological pressures of competitive sports can sometimes undermine the sleep-promoting benefits of physical exertion.

To mitigate these challenges, researchers have emphasized the importance of recovery protocols, mental skills training, and sleep education for adolescent athletes. Structured recovery practices, such as cool-down routines, mindfulness sessions, and pre-sleep rituals, helped athletes maintain better sleep hygiene even during periods of disrupted schedules (Paterson et al., 2021). Furthermore, team environments that foster psychological safety and emphasize learning over winning tend to reduce competitive stress and enhance athletes' overall well-being, which in turn supports healthier sleep patterns.

The social environment surrounding team sports can also influence sleep through peer modeling and collective health behaviors. Adolescents often adopt sleep habits that mirror those of their close peers, especially in contexts where group cohesion is strong. When teammates prioritize rest and recovery as essential components of performance, such norms can promote better individual sleep practices. Inclusive sports programs for adolescents with disabilities not only improved physical outcomes but also facilitated peer bonding and shared routines that extended into home life, including more consistent bedtimes and reduced screen use before sleep (Sanguino et al., 2024). This social modeling effect underscores the broader impact that team cultures can have on health behaviors beyond the field or court.

The cumulative evidence points to team and competitive sports as a multidimensional intervention with significant implications for adolescent sleep. The combination of intense physical effort, structured schedules, emotional catharsis, and social belonging creates a holistic framework for supporting sleep health. When balanced with appropriate recovery and mental support, participation in team sports can lead to improvements in sleep duration, efficiency, and latency, while also addressing psychosocial variables that often disrupt adolescent sleep. However, the potential for heightened arousal and performance-related stress requires careful management through coach education, athlete support systems, and informed scheduling practices.

As research continues to evolve, it is essential to examine the diverse contexts in which adolescents engage in team sports, including differences in gender, socioeconomic background, and access to organized athletic opportunities. Integrating sleep education into athletic programming and leveraging the group dynamics inherent in team sports could



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offer a strategic avenue for promoting lifelong sleep hygiene and well-being. By recognizing the interplay between physical effort and social-emotional development, team and competitive sports can be more deliberately used to enhance adolescent health, both on and off the field.

## 9. Moderators and Mediators

The relationship between physical activity and sleep in adolescents is not uniform across individuals, as a range of moderating and mediating factors influence how exercise impacts sleep outcomes. These variables help explain why certain adolescents benefit more from physical activity than others, and they offer critical insight into tailoring interventions to maximize effectiveness. Among the key moderators, gender, chronotype, mental health status, timing of exercise, and intensity level have shown consistent relevance, while psychological constructs such as emotional regulation, self-esteem, and academic stress act as important mediators that shape the pathway between physical activity and sleep quality.

Gender plays a significant role in shaping how physical activity influences adolescent sleep, often through physiological, hormonal, and behavioral mechanisms. Research indicates that boys tend to be more physically active than girls during adolescence, engaging more frequently in vigorous activities, which may partly explain gender differences in sleep patterns and recovery needs. In a study examining racial disparities in adolescent sleep, physical activity served as a protective factor for both boys and girls, but the magnitude of sleep improvement was greater among female adolescents (Gillis et al., 2021). This suggests that although boys may engage in more activity, girls may experience a more pronounced benefit in sleep parameters such as latency and efficiency, possibly due to higher baseline rates of emotional arousal or sleep disturbance. These findings underscore the importance of considering gender-specific exercise prescriptions when designing interventions aimed at improving adolescent sleep.

Chronotype, or an individual's natural preference for timing of sleep and activity, also moderates the relationship between physical activity and sleep. Adolescents often experience a biological shift toward eveningness during puberty, which can lead to delayed sleep onset and difficulty waking for early school schedules. Physical activity has the potential to shift circadian rhythms, especially when performed at optimal times. Adolescents with late chronotypes benefited significantly from morning physical activity, which helped realign their sleep-wake cycles with societal demands and improved overall sleep quality (Okkenhaug, 2025). These effects were especially prominent when exercise was incorporated into daily routines, suggesting that timing plays a crucial role in mediating the circadian effects of physical activity.

Mental health status further moderates the efficacy of exercise in promoting sleep. Adolescents with symptoms of depression, anxiety, or behavioral disorders often report more severe sleep problems, and the extent to which physical activity can alleviate these disturbances varies depending on the severity and nature of the psychological condition. During periods of elevated emotional stress, such as the COVID-19 pandemic, physical activity acted as a buffer against sleep disruptions, particularly in youth with pre-existing anxiety (Field, 2023). However, adolescents with high levels of depression gained fewer sleep benefits from exercise, suggesting that underlying mental health conditions can attenuate the positive impact of physical activity on sleep (Bharali & Mahapatro, 2020). This indicates a need for integrated interventions that combine movement with mental health support to achieve optimal outcomes.

The timing of physical activity also has a measurable influence on sleep outcomes. While regular exercise generally promotes better sleep, activity performed too close to bedtime may have unintended consequences. Evening workouts, especially those involving high intensity, can elevate cortisol levels and core body temperature, delaying sleep onset and reducing sleep efficiency. Adolescents who engaged in competitive sports late in the evening reported greater difficulty falling asleep compared to those who exercised earlier in the day (Roberts et al., 2024). Conversely, morning and afternoon physical activity have been shown to enhance circadian entrainment and reduce sleep latency, particularly in adolescents with disrupted rhythms or academic-related sleep deprivation. These temporal factors highlight the importance of aligning exercise timing with individual sleep patterns and daily obligations.

Exercise intensity is another critical moderator that influences the extent of sleep improvement. Moderate to vigorous physical activity is generally associated with better sleep quality, but excessive intensity without adequate recovery can disrupt rest. Adolescents participating in structured mixed-modal routines at moderate intensity levels experienced the most consistent gains in sleep efficiency and


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duration (Mello et al., 2024). In contrast, high-frequency, high-intensity training without rest days led to overtraining symptoms and increased night-time awakenings, particularly in adolescents with perfectionistic traits or high academic stress. These findings suggest that the benefits of exercise are not strictly linear and that appropriate intensity thresholds must be maintained to avoid counterproductive outcomes.

In addition to these moderators, several psychological constructs mediate the relationship between physical activity and sleep, acting as bridges through which the effects of movement translate into better rest. Emotional regulation is one of the most well-supported mediators in this context. Physical activity is known to reduce emotional reactivity and promote resilience, which in turn lowers bedtime arousal and facilitates sleep onset. Adolescents who participated in structured group activities such as team sports showed improvements in emotional regulation and reported fewer sleep disturbances, suggesting that the calming effects of social and physical engagement play a mediating role in the exercise-sleep relationship (Sanguino et al., 2024).

Self-esteem also acts as a powerful mediator, particularly in adolescents who struggle with body image or social comparison. Participation in physical activity, especially when supported by positive feedback and social reinforcement, often boosts self-confidence and creates a more positive internal dialogue. Adolescents involved in organized sports programs reported higher self-esteem and greater sleep satisfaction, even after accounting for physical activity frequency (Gillis et al., 2022). These improvements may be driven by reduced negative self-talk and a greater sense of competence, both of which facilitate relaxation and psychological preparedness for sleep.

Academic stress, on the other hand, may either mediate or moderate the relationship between physical activity and sleep, depending on how it is managed. Adolescents under high academic pressure are prone to late-night studying, reduced physical activity, and irregular sleep patterns. However, those who engage in regular exercise may better cope with academic demands by enhancing cognitive flexibility and stress recovery. Adolescents who maintained physical activity during periods of academic disruption—such as pandemic-related school closures—reported lower levels of academic stress and improved sleep regularity (Paterson et al., 2021). This implies that physical activity not only alleviates stress but also strengthens adaptive coping mechanisms, indirectly supporting sleep through improved mental clarity and emotional balance.

In sum, the relationship between physical activity and adolescent sleep is moderated by individual factors such as gender, chronotype, mental health status, exercise timing, and intensity level, and is mediated by psychological mechanisms including emotional regulation, self-esteem, and academic stress. These variables interact in complex ways to shape how movement influences rest, emphasizing the need for personalized, context-sensitive approaches to physical activity promotion. Understanding these moderating and mediating pathways is essential for developing effective interventions that harness the full potential of physical activity to improve adolescent sleep and, by extension, broader aspects of health and development.

## 10. Discussion

The collective findings from recent empirical studies offer a compelling narrative about the beneficial relationship between physical activity and sleep quality during adolescence. Across various activity types—including aerobic exercise, resistance training, mixed modal activities, and team sports—evidence consistently supports the notion that engaging in physical movement improves multiple sleep parameters such as latency, duration, and efficiency. The synthesis of literature suggests that no single exercise modality is universally superior; rather, different types of physical activity confer unique benefits, influenced by their specific physiological demands and psychological effects. The contrast with sedentary behavior and inactivity further amplifies the argument for integrating movement into adolescent lifestyles, as low energy expenditure and excessive screen use continue to impair sleep health across populations.

Aerobic exercise, particularly when performed at moderate to vigorous intensities, has shown consistent associations with reduced sleep latency and increased total sleep duration. This effect is largely explained by thermoregulatory and homeostatic mechanisms. Activities like running, swimming, or cycling increase body temperature and energy expenditure during the day, followed by a compensatory drop in body temperature in the evening that facilitates sleep onset (Hamilton et al., 2022). Additionally, aerobic activity is known to enhance parasympathetic nervous system activity during sleep, supporting longer phases of restorative sleep and reducing mid-sleep awakenings (Gallant et al., 2020). These studies indicate that aerobic exercise can act as both a physiological



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and circadian stabilizer, improving both the quantity and quality of adolescent sleep.

Resistance training offers a complementary set of benefits, primarily by promoting muscular fatigue and triggering anabolic recovery processes during deep sleep. Strength-building exercises contribute to increased slow-wave sleep and overall sleep consolidation, particularly when incorporated into consistent routines (Khazaie et al., 2023). Unlike aerobic exercise, resistance training may not always produce immediate reductions in sleep latency, but it improves sleep efficiency over time through its influence on growth hormone release and physical recovery. However, the timing and intensity of resistance training are critical, as high-frequency sessions without proper rest may trigger sympathetic overactivation and disrupt sleep architecture, a risk noted in adolescents with depressive symptoms (Bharali & Mahapatro, 2020). The evidence suggests a dose-dependent relationship, where moderate-intensity resistance training, performed two to four times per week, yields optimal sleep benefits without inducing stress-related sleep disturbances.

Mixed modal activities, including high-intensity interval training (HIIT) and circuit training, integrate the advantages of both aerobic and anaerobic exertion. These formats produce synergistic effects on sleep by combining cardiovascular stimulation with muscular fatigue (Mello et al., 2024). The time-efficient and engaging structure of these routines also improves adherence among adolescents, especially those with limited time or motivation for traditional exercise. Even short-duration mixed modal routines can enhance sleep efficiency, pointing to their utility in urban, time-constrained settings (Liu et al., 2023). However, similar to resistance training, careful monitoring of intensity and recovery is necessary, as overexertion may lead to delayed onset and fragmented sleep.

Team and competitive sports introduce an additional layer of complexity by incorporating social, emotional, and psychological dimensions into physical activity. These forms of exercise not only involve structured movement and high energy expenditure but also offer peer support, emotional regulation, and routine-building. Adolescents who participated in team sports reported improved sleep duration and quality, likely due to the combination of physical fatigue and psychological fulfillment derived from group cohesion and shared goals (Brown et al., 2022). Nonetheless, the competitive nature of such sports can sometimes generate pre-sleep arousal, especially following evening games or high-stress tournaments. Late-night competitions can delay melatonin release and extend sleep latency, particularly in adolescents prone to performance anxiety (Roberts et al., 2024). These findings underscore the dual-edged nature of team sports and the importance of integrating mental skills training and recovery strategies to support sleep.

While the benefits of physical activity are clear, discrepancies exist in the literature concerning the magnitude and consistency of these effects across populations. One of the major inconsistencies relates to the timing of exercise. Some studies have found that morning exercise leads to better circadian alignment and earlier sleep onset, particularly in adolescents with delayed sleep phase tendencies (Okkenhaug, 2025). In contrast, other studies show minimal impact of exercise timing, or even negative outcomes associated with late-night training. These discrepancies may stem from individual differences in chronotype, sleep reactivity, and hormonal sensitivity, which require further investigation. Another inconsistency lies in the measurement of sleep outcomes. While some research relies on objective tools such as actigraphy or polysomnography, others use self-reported sleep logs or surveys, which introduces variability in data reliability and may obscure real effects.

Several limitations are common to existing studies on physical activity and adolescent sleep. One significant limitation is the predominance of cross-sectional designs, which limit causal inferences. Although correlations between exercise and sleep are well-documented, longitudinal studies are needed to determine the directionality and long-term stability of these relationships. Moreover, many studies rely heavily on self-reported physical activity and sleep data, which are prone to recall bias and social desirability effects. For example, adolescents may overreport exercise participation or underestimate screen time, leading to inaccurate estimates of exposure. Studies which utilized accelerometers and objective sleep recorders offer a model for improving methodological rigor in future research (Hu et al., 2024). Additionally, most research has been conducted in high-income countries, with limited data from low-resource or culturally diverse settings, which may restrict the generalizability of findings.

Despite these limitations, the implications for practice and policy are promising. Physical activity interventions can serve as accessible, non-pharmacological strategies to promote adolescent sleep health. School-based programs that integrate movement throughout the day, including physical education, active breaks, and after-school sports,



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can provide structured opportunities to meet daily activity recommendations. It has been emphasized that school closures during the COVID-19 pandemic led to declines in both movement and sleep regularity among adolescents, reinforcing the importance of institutional support for active routines (Paterson et al., 2021). Moreover, interdisciplinary approaches that combine physical activity with sleep education and mental health support may be especially effective. For example, incorporating discussions about exercise, screen time, and bedtime routines into health curricula can help adolescents develop a more holistic understanding of how their behaviors influence sleep.

Tailored interventions that account for gender, mental health status, and lifestyle constraints are also essential. For adolescents with emotional disorders or attention difficulties, structured and predictable physical activity—such as resistance training or group-based routines—can improve both psychological functioning and sleep (Roberts et al., 2024). For youth with limited access to recreational facilities, short-duration mixed modal programs can offer a feasible alternative. Additionally, promoting parental involvement and digital literacy may help mitigate the impact of screen time, which remains one of the most consistent barriers to adolescent sleep.

In conclusion, physical activity represents a powerful yet underutilized lever for improving adolescent sleep. While different types of exercise offer unique advantages, the overarching message is clear: regular movement enhances sleep quality, counters the harmful effects of sedentary behavior, and supports adolescent development. Moving forward, research must continue to refine the conditions under which physical activity best supports sleep, while interventions should adapt to the diverse needs and realities of adolescent populations. By integrating movement into daily routines and institutional policies, stakeholders can contribute to healthier sleep trajectories that extend into adulthood.

## 11. Conclusion

Sleep quality during adolescence is a critical determinant of overall health, cognitive functioning, emotional stability, and academic performance. Yet, this developmental stage is often marked by significant disruptions in sleep due to biological changes, lifestyle pressures, and increasing exposure to sedentary behavior and screen-based activities. As this review has demonstrated, physical activity emerges as one of the most effective and modifiable factors in promoting better sleep outcomes for adolescents. Whether through structured aerobic routines, resistance training, mixed modal exercises, or participation in team sports, engagement in physical movement contributes to improvements in sleep latency, duration, and efficiency, while also supporting psychological resilience and emotional regulation.

Each type of physical activity offers distinct mechanisms and advantages. Aerobic exercise enhances thermoregulatory processes and supports circadian rhythm stability, facilitating faster sleep onset and deeper sleep. Resistance training contributes through muscular fatigue and hormonal regulation, improving sleep efficiency and recovery. Mixed modal activities combine these benefits, offering synergistic outcomes in time-efficient formats that suit the busy schedules of adolescents. Team and competitive sports add a social and psychological layer, fostering discipline, motivation, and a sense of belonging that further reinforces healthy sleep patterns. In contrast, sedentary behavior and inactivity, especially when coupled with excessive screen time, consistently impair sleep quality by delaying sleep onset, shortening duration, and increasing fragmentation.

The findings from this review underscore the importance of adopting a diversified and personalized approach to physical activity promotion among adolescents. While regular movement is universally beneficial, tailoring activity type, intensity, and timing to individual preferences, chronotypes, and mental health needs can significantly enhance effectiveness. Equally important is the recognition that physical activity does not operate in isolation but interacts with broader lifestyle behaviors, including screen use, stress management, and dietary habits, all of which collectively shape sleep quality.

Interventions aimed at improving adolescent sleep should therefore adopt a holistic strategy. Schools can play a central role by embedding physical activity into daily routines through physical education, active breaks, and after-school programs. Families and communities can foster environments that encourage movement while limiting sedentary time, especially in the hours before bed. Digital health education should accompany these efforts to address the pervasive impact of screen time on adolescent sleep. Furthermore, healthcare providers, educators, and policymakers must collaborate to ensure that adolescents from all backgrounds have equitable access to safe and supportive opportunities for physical activity.



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Ultimately, promoting physical activity during adolescence is not only a means to enhance sleep but also a foundation for long-term health and well-being. By embedding movement into the fabric of adolescent life, we not only address immediate concerns like sleep disturbances but also cultivate lifelong habits that support physical, mental, and emotional resilience. As adolescence sets the stage for adulthood, investing in strategies that align physical activity with sleep health is both a timely and essential public health priority.

## Authors' Contributions

Authors contributed equally to this article.

## Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

## Transparency Statement

Not applicable.

## Acknowledgments

We would like to express our gratitude to all individuals helped us do the project.

## Declaration of Interest

The authors report no conflict of interest.

## Funding

According to the authors, this article has no financial support.

## Ethical Considerations

Not applicable.

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