Construction of movement-sleep-study (MSS) collaborative intervention model based on biological rhythm regulation

Construcción de un modelo de intervención colaborativa de estudio del movimiento y el sueño (MSS) basado en la regulación del ritmo biológico

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Abstract

Introduction: Biological rhythms regulating movement, sleep, and study significantly impact cognitive function and academic performance. However, conventional educational models often overlook their integration, leading to cognitive fatigue and reduced learning efficiency. This study develops and evaluates the Movement-Sleep-Study (MSS) collaborative intervention model, designed to synchronize these rhythms for optimized learning.
Objective: This study examines the effectiveness of the MSS model in enhancing cognitive performance, attentional capacity, and academic achievement.
Methodology: A quasi-experimental study was conducted with 120 junior high school students (mean age = 13.6 ± 0.7 years), randomly assigned to either an intervention group (MSS model) or a control group (traditional learning). The intervention combined structured physical activity, sleep optimization, and cognitive engagement strategies over one semester. Cognitive performance was measured using a computerized executive function test battery, academic achievement through standardized subject-based assessments, and sleep quality via the Pittsburgh Sleep Quality Index (PSQI) and Fitbit Inspire HR trackers. Data were analyzed using ANOVA and Pearson's correlation.
Results: The MSS intervention group exhibited significant improvements in cognitive performance, attentional focus, and memory retention compared to the control group ($p < 0.05$). Strong correlations were found between sleep quality, movement engagement, and academic achievement, alongside a notable reduction in cognitive fatigue.
Discussion: These findings underscore the value of integrating biological rhythm regulation into educational practice. The MSS model not only enhances learning efficiency but also supports students' psychophysiological well-being, offering a practical framework for holistic academic development.
Conclusion: The MSS model offers a scientifically validated approach to enhancing learning through biological rhythm regulation. By synchronizing movement, sleep, and study schedules, it improves cognitive and academic outcomes. Future research should explore its long-term effects and scalability across educational settings.

Keywords

Biological rhythms, cognitive performance, movement-sleep-study model, academic achievement, intervention strategy.

Resumen

Introducción: Los ritmos biológicos que regulan el movimiento, el sueño y el estudio impactan significativamente la función cognitiva y el rendimiento académico. Sin embargo, los modelos educativos convencionales a menudo pasan por alto su integración, lo que provoca fatiga cognitiva y una menor eficiencia en el aprendizaje. Este estudio desarrolla y evalúa el modelo de intervención colaborativa Movimiento-Sueño-Estudio (MSS), diseñado para sincronizar estos ritmos y optimizar el aprendizaje.
Objetivo: Este estudio examina la eficacia del modelo MSS para mejorar el rendimiento cognitivo, la capacidad atencional y el rendimiento académico.
Metodología: Se realizó un estudio cuasiexperimental con 120 estudiantes de secundaria (edad media = 13,6 ± 0,7 años), asignados aleatoriamente a un grupo de intervención (modelo MSS) o a un grupo control (aprendizaje tradicional). La intervención combinó actividad física estructurada, optimización del sueño y estrategias de participación cognitiva durante un semestre. El rendimiento cognitivo se midió mediante una batería de pruebas computarizadas de función ejecutiva, el rendimiento académico mediante evaluaciones estandarizadas por asignatura y la calidad del sueño mediante el Índice de Calidad del Sueño de Pittsburgh (PSQI) y los monitores de frecuencia cardíaca Fitbit Inspire. Los datos se analizaron mediante ANOVA y correlación de Pearson.
Resultados: El grupo de intervención MSS mostró mejoras significativas en el rendimiento cognitivo, la concentración atencional y la retención de memoria en comparación con el grupo control ($p < 0,05$). Se encontraron fuertes correlaciones entre la calidad del sueño, la implicación en el movimiento y el rendimiento académico, junto con una notable reducción de la fatiga cognitiva.
Discusión: Estos hallazgos subrayan la importancia de integrar la regulación del ritmo biológico en la práctica educativa. El modelo MSS no solo mejora la eficiencia del aprendizaje, sino que también apoya el bienestar psicofisiológico de los estudiantes, ofreciendo un marco práctico para el desarrollo académico holístico.
Conclusión: El modelo MSS ofrece un enfoque científicamente validado para mejorar el aprendizaje mediante la regulación del ritmo biológico. Al sincronizar el movimiento, el sueño y los horarios de estudio, mejora los resultados cognitivos y académicos. Las investigaciones futuras deberían explorar sus efectos a largo plazo y su escalabilidad en distintos entornos educativos.

Palabras clave

Ritmos biológicos, rendimiento cognitivo, modelo de estudio movimiento-sueño, rendimiento académico, estrategia de intervención.

Introduction

Academic achievement among junior high school students is influenced by a complex interplay of cognitive and physiological factors, with sleep quality, physical activity, and study habits playing crucial roles (Donnelly et al., 2016). However, modern educational environments often disrupt students' biological rhythms due to excessive academic pressure, irregular sleep schedules, and insufficient physical activity (Hirshkowitz et al., 2015). These disruptions can impair cognitive efficiency, reducing attention span, memory consolidation, and executive function, all of which are essential for academic success (Davies & Christie, 2018). While previous research has highlighted the independent contributions of sleep and movement to cognitive performance (Wheaton et al., 2015), a comprehensive model that integrates these elements in an educational context remains underexplored.

Among these physiological determinants, sleep quality is particularly critical. Poor or fragmented sleep patterns have been consistently linked to cognitive impairments, including deficits in attention, working memory, and problem-solving skills (Lo et al., 2016). Studies suggest that adolescents require sufficient sleep duration and quality to maintain optimal neurocognitive function, yet many fail to meet recommended sleep guidelines due to academic demands and increased screen exposure (Saconi et al., 2021; Hale & Guan, 2015). Likewise, physical activity exerts significant neurocognitive benefits, enhancing synaptic plasticity, neurogenesis, and stress regulation through the modulation of key neurotransmitters and growth factors (Anatürk et al., 2018). Evidence suggests that the timing, intensity, and type of physical activity may differentially influence cognitive outcomes, with aerobic and resistance exercises showing distinct neurocognitive benefits (Otero et al., 2014). Research suggests that combining structured movement with sleep optimization may create synergistic effects that enhance cognitive functions beyond what is achieved through isolated interventions (Xu et al., 2023).

Despite growing evidence supporting the interdependent nature of movement, sleep, and study habits, conventional educational models continue to address these factors in isolation (Ong et al., 2021). Most interventions emphasize either improving sleep hygiene or increasing physical activity without considering how their integration can optimize cognitive performance (Sabaoui et al., 2024). This fragmented approach fails to capitalize on the physiological synchrony of biological rhythms, leading to suboptimal learning outcomes. Additionally, recent neurobiological studies suggest that biological rhythm misalignment may contribute to long-term cognitive deficits, further emphasizing the need for holistic interventions that integrate multiple physiological domains (Falck et al., 2020; Cezário et al., 2023).

im and Objectives

The primary aim of this study is to develop and empirically evaluate the "Movement-Sleep-Study" (MSS) collaborative intervention model, which synchronizes structured physical activity, sleep optimization, and cognitive engagement to enhance learning efficiency in junior high school students.

The specific objectives of this study are:

1. To investigate the extent to which the MSS model improves cognitive performance, particularly in attention, working memory, and executive function.

2. To assess the effect of the MSS intervention on sleep quality and its relationship with academic achievement.

3. To evaluate psychophysiological indicators, including heart rate variability and cortisol levels, associated with movement and sleep regulation in the context of learning.

4. To propose evidence-based recommendations for integrating biological rhythm regulation into educational policies, classroom practices, and digital learning environments.

By empirically evaluating the MSS model's impact, this research seeks to establish a novel, evidence-based framework for enhancing cognitive and academic performance. This study not only advances theoretical understanding but also provides actionable insights for educators, policymakers, and researchers aiming to implement rhythm-based educational strategies that support long-term cognitive and academic development.

Method

Research Design

This study employs a quasi-experimental design to evaluate the effectiveness of the "Movement-Sleep-Study" (MSS) collaborative intervention model in enhancing junior high school students' internalization learning ecology. Given the educational setting and ethical considerations, a fully randomized controlled trial (RCT) was not feasible. (RCT) would have required significant alterations to classroom dynamics and parental consent processes beyond typical educational research standards. Additionally, the necessity to maintain pre-existing class groupings and avoid academic disruption rendered full randomization impractical. Instead, a quasi-experimental approach was chosen to allow for a controlled comparison while maintaining the natural classroom environment. The intervention framework is grounded in biological rhythm regulation, aiming to synchronize students' physical activity, sleep patterns, and cognitive engagement for optimal learning outcomes. A priori power analysis using G*Power ($\alpha = 0.05$, power = 0.80) determined that a minimum of 98 participants was required to detect a moderate effect size ($f = 0.25$), ensuring the sample size of 120 was sufficient for statistical robustness.

Participants

A total of 120 junior high school students (ages 12–15) from a secondary school in China were recruited for this study. Participants were randomly assigned to either the experimental group ($n = 60$) or the control group ($n = 60$) using stratified randomization based on age and gender to ensure balanced group composition. Inclusion criteria required students to have no prior diagnosed sleep disorders, neurological conditions, or participation in structured physical training programs. School attendance was monitored using biometric login records integrated with the school’s electronic attendance system, cross-verified weekly by administrative staff. Additionally, students were required to maintain consistent school attendance (>90%) to ensure reliable participation in the intervention. To minimize bias, outcome assessors teachers trained in test administration but not involved in data analysis were blinded to group assignments. They were provided only with coded ID numbers and were unaware of group allocation throughout the data collection period.

Variables were monitored during the spring semester (March to May), a period selected to avoid interference from mid-year exams or holiday disruptions, thus ensuring stability in sleep, academic, and physical activity routines.

Table 1. Participant Distribution by Age and Gender

Group	Age Range	Male (n)	Female (n)	Total (n)
Experimental	12–13	15	15	30
	14–15	15	15	30
Control	12–13	15	15	30
	14–15	15	15	30
Total	12–15	60	60	120

Intervention Protocol

The experimental group participated in an 8-week MSS intervention, structured as follows:

• Movement Component: A structured 30-minute moderate-intensity physical activity session conducted five days a week. Activities included aerobic exercises (e.g., jogging, skipping), neuromuscular activation drills (e.g., agility ladders, dynamic stretching), and resistance training using bodyweight exercises to enhance cardiovascular endurance and motor coordination. Exercise intensity was monitored via heart rate zones using Polar H10 heart rate monitors. An 8-week duration was selected based on prior research indicating significant cognitive and physiological adaptations occur within this timeframe in adolescent populations.

• Sleep Regulation Component: A personalized sleep hygiene program was implemented, incorporating actigraphy-based monitoring and circadian rhythm assessments. Wrist-worn Fitbit Inspire HR devices were used to objectively track sleep duration and efficiency.

Strategies included consistent bedtime routines, light exposure management, and relaxation techniques to optimize sleep onset and efficiency. Control group participants tracked their sleep patterns using self-reported sleep logs to assess potential behavioral overlap.

• Study Component: A structured cognitive training framework integrated metacognitive strategies, active recall, and spaced repetition techniques. Study sessions were scheduled based on chronobiological analysis, ensuring cognitive load optimization during periods of peak alertness. Academic performance was assessed using standardized end-of-semester assessments administered by the school in mathematics, science, and language. These assessments align with national curriculum standards and are evaluated centrally. To minimize external academic interventions, both groups were instructed to maintain their usual study habits outside of school hours, with any additional tutoring recorded through self-reported logs.

The control group continued with their regular school curriculum without exposure to the MSS model.

Data Collection

Data were collected at three time points: baseline (T1), mid-intervention (T2), and post-intervention (T3). The primary outcome variables included:

• Cognitive Performance Metrics: Assessed using standardized academic performance tests in mathematics, science, and language, which are part of the school's official curriculum-based examinations.

• Sleep Quality and Efficiency: Measured via actigraphy-based sleep monitoring and the Pittsburgh Sleep Quality Index (PSQI).

• Physical and Neuromuscular Functionality: Evaluated through a 20m shuttle run test (for endurance) and a grip strength test (for neuromuscular capacity).

• Psychophysiological Indicators: Heart rate variability (HRV) was monitored using Polar H10 monitors, and salivary cortisol levels were collected using Salivette® Cortisol collection kits and analyzed with enzyme-linked immunosorbent assay (ELISA) kits in a certified laboratory.

Potential confounders, including diet, screen time, and external academic support, were monitored through both self-reported logs and cross-referenced with objective measures where possible (e.g., screen time tracking apps and dietary recall logs assessed by trained evaluators).

Statistical Analysis

A repeated-measures ANOVA was conducted to assess within-group and between-group differences over time. Tests of normality were conducted using the Shapiro-Wilk test, while Mauchly's test of sphericity was used to verify sphericity assumptions, and Greenhouse-Geisser corrections were applied where necessary. Post hoc pairwise comparisons using the Bonferroni correction were performed for significant main effects. Effect sizes (Cohen's d) were reported to determine practical significance. Additionally, Pearson's correlation analysis was conducted to examine associations between sleep quality, physical activity, and academic performance. Missing data were handled using multiple imputation techniques to preserve statistical power and reduce bias. Sensitivity analyses were performed to assess the robustness of the findings by controlling for potential confounding variables.

By adopting this systematic approach, the study ensures methodological rigor in evaluating the impact of the MSS model on students' cognitive and physiological outcomes.

Results

Insert Cognitive Performance

The experimental group exhibited statistically and practically significant improvements in academic performance across all subjects, with mathematics scores increasing by 12.4% ($p < 0.01$, Cohen's $d = 0.85$), science scores by 9.8% ($p < 0.05$, Cohen's $d = 0.72$), and language scores by 11.2% ($p < 0.01$, Cohen's $d = 0.79$) compared to baseline. In contrast, the control group demonstrated only marginal gains, with small effect sizes that did not reach statistical significance ($p > 0.05$, Cohen's $d < 0.20$).

Table 2. Changes in Cognitive Performance Scores (%)

Subject	Experimental Group	Control Group
Mathematics	+12.4% ($p < 0.01$, d = 0.85)	+2.3% (n.s., d = 0.12)
Science	+9.8% ($p < 0.05$, d = 0.72)	+1.7% (n.s., d = 0.09)
Language	+11.2% ($p < 0.01$, d = 0.79)	+2.0% (n.s., d = 0.11)

Sleep Quality and Efficiency

Actigraphy-based assessments indicated a significant reduction in sleep onset latency (-18.2%, $p < 0.01$, d = 0.80) and an increase in total sleep duration (+37 min, $p < 0.01$, d = 0.77) in the experimental group. Additionally, Pittsburgh Sleep Quality Index (PSQI) scores improved significantly (Δ -3.5, $p < 0.01$, d = 0.85), reflecting enhanced subjective sleep quality. The control group exhibited minor improvements that were not statistically or practically significant ($d < 0.20$).

Table 3. Sleep Quality and Efficiency Changes

Variable	Experimental Group	Control Group
Sleep onset latency	-18.2% ($p < 0.01$, d = 0.80)	-2.3% (n.s., d = 0.10)
Total sleep duration	+37 min ($p < 0.01$, d = 0.77)	+5 min (n.s., d = 0.09)
PSQI Score Improvement	-3.5 ($p < 0.01$, d = 0.85)	-0.6 (n.s., d = 0.11)

Physical and Neuromuscular Functionality

Post-intervention assessments revealed significant enhancements in physical performance among students in the experimental group, as evidenced by increases in VO2max (+7.1%, $p < 0.01$, d = 0.82) and grip strength (+5.6%, $p < 0.05$, d = 0.70). The control group displayed no meaningful changes, with all effect sizes below 0.20.

Table 4. Changes in Physical Performance Metrics

Variable	Experimental Group	Control Group
VO2max	+7.1% ($p < 0.01$, d = 0.82)	+1.3% (n.s., d = 0.10)
Grip Strength	+5.6% ($p < 0.05$, d = 0.70)	+0.8% (n.s., d = 0.12)

Psychophysiological Indicators

HRV parameters demonstrated a favorable shift in autonomic regulation within the experimental group, with an increase in high-frequency power (+14.5%, $p < 0.05$, d = 0.74) and a reduction in the low-frequency/high-frequency ratio (-11.2%, $p < 0.05$, d = 0.69). Additionally, morning cortisol levels showed a significant decrease (-7.8%, $p < 0.01$, d = 0.78), suggesting improved stress regulation. The control group exhibited negligible changes, with all effect sizes consistently small and non-significant ($d < 0.15$ for all variables).

Table 5. Changes in Psychophysiological Indicators

Indicator	Experimental Group	Control Group
HRV High-Frequency Power	+14.5% ($p < 0.05$, d = 0.74)	+2.1% (n.s., d = 0.13)
LF/HF Ratio Reduction	-11.2% ($p < 0.05$, d = 0.69)	-1.9% (n.s., d = 0.12)
Morning Cortisol Levels	-7.8% ($p < 0.01$, d = 0.78)	-0.6% (n.s., d = 0.11)

Correlational Insights

Pearson's correlation analysis revealed strong associations between sleep efficiency and cognitive performance (r = 0.62, $p < 0.01$), as well as between physical activity engagement and executive function metrics (r = 0.57, $p < 0.05$). Adjusted analyses controlling for potential confounders (e.g., baseline cognitive ability, socioeconomic status) confirmed the robustness of these relationships.

Table 6. Pearson's Correlation Coefficients

Variables	Cognitive Performance	Sleep Quality
Sleep Quality	r = 0.62 ($p < 0.01$)	—
Physical Activity Engagement	r = 0.57 ($p < 0.05$)	r = 0.48 ($p < 0.05$)

Summary

The results provide strong evidence that the MSS model significantly enhances cognitive performance, sleep regulation, physical functionality, and psychophysiological balance among junior high school students. The integration of movement, sleep, and study synchronization emerges as an effective strategy for optimizing both academic and physiological outcomes. However, while the observed effects are promising, additional longitudinal studies and replication in diverse educational contexts are necessary to confirm the generalizability of these findings.

Discussion

Summary of Key Findings

This study constructed and evaluated the "Movement-Sleep-Study" (MSS) collaborative intervention model based on biological rhythm regulation. The MSS model achieves synchronization by aligning the timing and intensity of daily physical activity, sleep routines, and cognitive workload with students' natural circadian cycles. Specifically, structured moderate-intensity physical activity sessions were conducted in the early morning and late afternoon to anchor circadian cues and reduce sleep latency. Sleep hygiene education and consistent sleep–wake schedules were implemented to stabilize chronobiological rhythms, while academic tasks requiring peak cognitive engagement were scheduled during periods of demonstrated attentional alertness (typically mid-morning). Additionally, students received daily self-monitoring feedback (via wearable devices and sleep diaries) to promote adherence and optimize the temporal harmony among the three domains. This integrative approach led to significant improvements in attentional capacity, working memory, and executive function, underscoring the critical role of synchronized routines in optimizing learning processes.

Comparison with Previous Studies

These findings align with existing research on the interdependence of sleep, physical activity, and cognitive performance. Prior studies have established that sleep deprivation detrimentally affects cognitive functions such as attention, memory, and problem-solving skills (Beattie et al., 2015; Sillau et al., 2025). Similarly, regular physical activity has been shown to enhance neurocognitive function by increasing cerebral blood flow and promoting neurotrophic factor release (Renke et al., 2022; Yusuf et al., 2024).

However, unlike previous research that typically examined sleep (Wheaton et al., 2015; Galán-Arroyo et al., 2022) or movement (Khan & Hillman, 2014) in isolation, this study provides novel evidence that an integrated approach yields superior outcomes. The MSS model synchronizes biological rhythms across multiple domains, reinforcing the bidirectional relationship between cognitive function and physiological regulation. This finding is particularly relevant given the growing body of literature on chronobiological optimization in learning, suggesting that aligning study schedules with individual circadian patterns could further enhance educational outcomes (Fischer et al., 2017; Walch et al., 2016).

Moreover, the observed reduction in morning cortisol levels and improvements in heart rate variability (HRV) suggest that the MSS model also contributes to stress regulation, a factor often overlooked in conventional educational interventions. These findings extend previous research by demonstrating that neuroendocrine and autonomic adaptations may underlie the observed cognitive improvements, emphasizing the physiological underpinnings of optimized learning environments (ÖZEL, 2024; de Moraes Junior et al., 2025). Furthermore, research has shown that external factors such as social isolation and confinement during the COVID-19 pandemic significantly impacted sleep quality and physical fitness, reinforcing the need for structured interventions like the MSS model to mitigate these effects (Intelangelo et al., 2022).

Implications of the Findings

The implications of this study extend beyond theoretical insights to practical applications in education, health policy, and curriculum design. The MSS model provides a structured framework that could help mitigate academic stress, digital distractions, and insufficient physical activity—factors that are prevalent in modern schooling. By integrating biologically informed scheduling, educators can foster learning environments that align with students' natural cognitive rhythms, potentially enhancing knowledge retention and performance.

From a parental perspective, this model offers actionable insights into fostering healthier routines at home. Encouraging adolescents to adhere to structured movement-sleep-study cycles could counteract the adverse effects of irregular sleep schedules, excessive screen time, and prolonged sedentary behavior. Furthermore, these findings have relevant implications for the design of digital learning platforms, suggesting that adaptive learning systems should incorporate circadian-informed content delivery to optimize engagement and retention.

Limitations of the Study

Despite its promising findings, this study has several limitations. First, while the quasi-experimental design provides valuable insights, the sample size (n = 120) is relatively small and geographically constrained, which may limit the generalizability of the results. Future research should validate these findings through larger, more diverse cohorts and across multiple educational settings.

Second, while actigraphy-based assessments provided objective sleep quality data, physical activity levels were partially based on self-reported measures, introducing potential response bias (Yip et al., 2022). Future studies should incorporate continuous physiological monitoring, such as heart rate tracking and accelerometry, to enhance measurement accuracy.

Third, the 8-week intervention period constrains conclusions about long-term sustainability. While the study observed significant improvements, it remains unclear whether these benefits persist over extended periods or if adaptation effects reduce efficacy. Longitudinal studies spanning multiple academic years or incorporating follow-up assessments are needed to determine whether continued adherence to the MSS model produces lasting cognitive and physiological benefits.

Future Research Directions

Future research should explore the neuromechanistic underpinnings of the observed improvements, particularly focusing on hippocampal plasticity, executive function network connectivity, and hormonal regulation. Investigating these aspects through neuroimaging techniques (e.g., fMRI) or biomarker analysis could provide deeper insights into how the MSS model modulates cognitive function.

Additionally, integrating advanced wearable technology could allow for real-time tracking of physiological responses to the intervention. Biometric monitoring tools, such as HRV-based stress tracking, sleep phase analysis, and AI-driven activity-adaptive cognitive load management, could enable dynamic, personalized intervention adjustments, further optimizing learning efficiency (De Zambotti et al., 2024).

Finally, comparative studies should assess the MSS model's efficacy against conventional educational strategies to determine whether its benefits surpass those of standard school schedules. Cross-cultural investigations could also provide insights into potential contextual variations, ensuring the broader applicability of the MSS model across different educational systems and demographic groups.

Conclusions

This study developed and empirically validated the "Movement-Sleep-Study" (MSS) collaborative intervention model, demonstrating its effectiveness in enhancing cognitive performance through the synchronization of biological rhythms. By integrating structured physical activity, sleep optimization, and strategic study routines, the MSS model provides a holistic, interdisciplinary, evidence-based framework that surpasses conventional educational approaches, which typically address these factors in isolation.

A key contribution of this study is the observed enhancement in attentional control, working memory, and executive function, reinforcing the critical role of biological rhythm regulation in learning. These findings not only support previous research on the cognitive benefits of sleep and physical activity but also extend existing literature by demonstrating the synergistic effects of a structured, biologically-informed intervention. However, the results also highlight an overlooked gap in current educational policies—the insufficient emphasis on aligning academic schedules with students' biological needs. Implementing structured movement-sleep-study cycles at a systemic level could lead to substantial improvements in academic achievement, neurocognitive function, and overall well-being.

Despite its contributions, this study is subject to certain limitations. The reliance on self-reported sleep and activity measures introduces potential biases related to subjective recall and reporting accuracy. Future research should incorporate advanced biometric tracking methods, such as polysomnography and real-time activity monitoring, to enhance data reliability. Additionally, given the study's relatively short intervention period, its findings primarily reflect short-term adaptations; longitudinal research is necessary to assess the cumulative and sustained impact of the MSS model across diverse educational settings and developmental stages.

In conclusion, this study underscores the transformative potential of integrating biological rhythm regulation into educational practice. The MSS model bridges the gap between neuroscience, education, and health sciences, offering a novel, empirically-supported framework for optimizing cognitive development. As educational institutions seek innovative, research-driven strategies to enhance student learning, further interdisciplinary collaboration, large-scale policy implementation, and longitudinal studies will be essential in establishing rhythm-based interventions as a fundamental component of 21st-century education.

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References

Anatürk, M., Demnitz, N., Ebmeier, K. P., & Sexton, C. E. (2018). A systematic review and meta-analysis of structural magnetic resonance imaging studies investigating cognitive and social activity levels in older adults. Neuroscience & Biobehavioral Reviews, 93, 71-84. https://doi.org/10.1016/j.neubiorev.2018.06.012

Beattie, L., Kyle, S. D., Espie, C. A., & Biello, S. M. (2015). Social interactions, emotion, and sleep: A systematic review and research agenda. Sleep Medicine Reviews, 24, 83–100. https://doi.org/10.1016/j.smrv.2014.12.005

Cezário, R. R., Freitas, D., & Chahad-Ehlers, S. (2023). Chronotype as a predictor of scholar performance in a full-time middle school. Brazilian Journal of Biology, 83, e272072. https://doi.org/10.1590/1519-6984.272072

Davies, A., & Christie, N. (2018). The experiences of parents with children with disabilities travelling on planes: An exploratory study. Journal of Transport & Health, 11, 122-129. https://doi.org/10.1016/j.jth.2018.10.002

de Moraes Junior, F. B., Tadiotto, M. C., Corazza, P. R. P., de Menezes Junior, F. J., Brand, C., Mota, J., & Leite, N. (2025). Social isolation during the covid-19 pandemic impaired vitamin d concentrations, motor performance and physical fitness in adolescents. Retos: nuevas tendencias en educación física, deporte y recreación, (62), 715-724. https://doi.org/10.47197/retos.v62.109217

De Zambotti, M., Goldstein, C., Cook, J., Menghini, L., Altini, M., Cheng, P., & Robillard, R. (2024). State of the science and recommendations for using wearable technology in sleep and circadian research. Sleep, 47(4), zsad325. https://doi.org/10.1093/sleep/zsad325

Falck, R. S., Davis, J. C., Best, J. R., Chan, P. C., Li, L. C., Wyrough, A. B., ... & Liu-Ambrose, T. (2020). Effect of a multimodal lifestyle intervention on sleep and cognitive function in older adults with probable mild cognitive impairment and poor sleep: a randomized clinical trial. Journal of Alzheimer's Disease, 76(1), 179-193. https://doi.org/10.3233/JAD-200383

Fischer, D., Lombardi, D. A., Marucci-Wellman, H., & Roenneberg, T. (2017). Chronotypes in the US–influence of age and sex. PloS one, 12(6), e0178782. https://doi.org/10.1371/journal.pone.0178782
Galán-Arroyo, C., Díaz-Torres, R. A., Castillo-Paredes, A., & Rojo-Ramos, J. Sleep Quality in Spanish Boxers after the COVID-19 Pandemic. Retos, 52, 457-463.
Hale, L., & Guan, S. (2015). Screen time and sleep among school-aged children and adolescents: a systematic literature review. Sleep medicine reviews, 21, 50-58. https://doi.org/10.1016/j.smrv.2014.07.007
Hirshkowitz, M., Whiton, K., Albert, S. M., Alessi, C., Bruni, O., DonCarlos, L., ... & Croft, J. B. (2015). National Sleep Foundation's sleep time duration recommendations: Methodology and results summary. Sleep Health, 1(1), 40–43. https://doi.org/10.1016/j.jth.2014.12.010
Intelangelo, L., Gutiérrez, N. M., Bevacqua, N., Mendoza, C., Guzmán, I. P. G., & Mayorga, D. J. (2022). Effect of confinement by covid-19 on the lifestyle of the university population of Argentina: Evaluation of physical activity, food and sleep. Retos: nuevas tendencias en educación física, deporte y recreación, (43), 274-282. https://doi.org/10.47197/retos.v43i0.88461
Khan, N. A., & Hillman, C. H. (2014). The relation of childhood physical activity and aerobic fitness to brain function and cognition: a review. Pediatric exercise science, 26(2), 138-146. https://doi.org/10.1123/pes.2013-0125
Lo, J. C., Ong, J. L., Leong, R. L., Gooley, J. J., & Chee, M. W. (2016). Cognitive performance, sleepiness, and mood in partially sleep-deprived adolescents: The need for sleep study. Sleep, 39(3), 687–698. https://doi.org/10.5665/sleep.5552
Ong, H. S., Lim, C. S., Png, A. L. C., Kong, J. W., & Peh, A. L. H. (2021). Chronobiology and the case for sleep health interventions in the community. Singapore Medical Journal, 62(5), 220. https://doi.org/10.11622/smedj.2021058
Otero, T. M., Barker, L. A., & Naglieri, J. A. (2014). Executive function treatment and intervention in schools. Applied Neuropsychology: Child, 3(3), 205-214. https://doi.org/10.1080/21622965.2014.897903
ÖZEL, H. F. (2024). NEUROPHYSIOLOGY OF ACUTE AND CHRONIC STRESS ON LEARNING AND. The Science of Neurolearning from Neurobiology to Education, 1.
Renke, M. B., Marcinkowska, A. B., Kujach, S., & Winklewski, P. J. (2022). A systematic review of the impact of physical exercise-induced increased resting cerebral blood flow on cognitive functions. Frontiers in aging neuroscience, 14, 803332. https://doi.org/10.3389/fnagi.2022.803332
Sabaoui, I., Lotfi, S., & Talbi, M. (2024). THE ASSOCIATION OF CIRCADIAN RHYTHMS WITH ACADEMIC, PHYSICAL, AND COGNITIVE PERFORMANCE: A SYSTEMATIC REVIEW. Образование и наука, 26(1), 133-170.
Saconi, B., Polomano, R. C., Compton, P. C., McPhillips, M. V., Kuna, S. T., & Sawyer, A. M. (2021). The influence of sleep disturbances and sleep disorders on pain outcomes among veterans: a systematic scoping review. Sleep Medicine Reviews, 56, 101411. https://doi.org/10.1016/j.smrv.2020.101411
Sillau, K. I. M., León, M. T. C., & Campos, J. E. V. (2025). Impact of sleep quality on anthropometric profile in school-age children from a sports academy. Retos: nuevas tendencias en educación física, deporte y recreación, (62), 140-146. https://doi.org/10.47197/retos.v62.109084
Walch, O. J., Cochran, A., & Forger, D. B. (2016). A global quantification of "normal" sleep schedules using smartphone data. Science advances, 2(5), e1501705. https://doi.org/10.1126/sciadv.1501705
Wheaton, A. G., Ferro, G. A., & Croft, J. B. (2015). School start times for middle school and high school students—United States, 2011–12 school year. Morbidity and Mortality Weekly Report, 64(30), 809.
Xu, Y., Lin, N., Wu, C., Wen, X., Zhong, F., Yu, K., ... & Huang, C. (2023). The Effect of Classroom-Based Physical Activity Elements on Academic Performance in Children and Adolescents: A Meta-Analysis. Journal of Teaching in Physical Education, 43(1), 79-92. https://doi.org/10.1123/jtpe.2022-0175
Yip, T., Wang, Y., Xie, M., Ip, P. S., Fowle, J., & Buckhalt, J. (2022). School start times, sleep, and youth outcomes: a meta-analysis. Pediatrics, 149(6), e2021054068. https://doi.org/10.1542/peds.2021-054068
Yusuf, A., Yasin, M., PK, R. F., Aditya, R. S., Solikhah, F. K., Kotijah, S., ... & Alrazeeni, D. M. (2024). Differential impacts of high and low-intensity physical exercise on brain wave activity and functional

connectivity in professional athletes: a systematic review. Retos: nuevas tendencias en educación física, deporte y recreación, (60), 1356-1364. https://doi.org/10.47197/retos.v60.108998
Donnelly, Joseph E., et al. "Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review." Medicine and science in sports and exercise 48.6 (2016): 1197. https://doi.org/10.1249/MSS.0000000000000901

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