

Sleep, activity, and cognition: An analysis of academic impact on university students

Monoem Haddad^{a,*}, Zied Abbas^a, Ahmed Moustafa^b, Khalid Bibi^a,
Areej Barham^c, Stefano Vando^d, Abdel-Salam G. Abdel-Salam^e

^aPhysical Education Department, College of Education, Qatar University, Doha, Qatar

^bDepartment of Human Anatomy and Physiology, the Faculty of Health Sciences, University of Johannesburg, South Africa & School of Psychology, Faculty of Society and Design, Bond University, Gold Coast, Queensland, QLD, Australia

^cDepartment of Educational Sciences, College of Education, Qatar University, Doha, Qatar

^dFiamme Oro, Polizia di Stato, Rome, Italy

^eDepartment of Mathematics and Statistics, College of Arts and Sciences, Qatar University, Doha, Qatar

Purpose: This study aimed to construct and assess a theoretical framework to elucidate the interrelationships between sleep, physical activity, cognitive function, and academic outcomes in Qatari university students.

Methods: A study involving 44 students (age: 23.59 years \pm 4.34) was conducted. The variables included “grade” (academic performance), rapid visual information processing (RVIP), sleeping efficiency (SE), and average weekly steps (WS). Changes in RVIP, SE, and WS over six weeks (two weeks before, during, and after exams) were analyzed using the Friedman test. Bivariate Spearman’s correlations and mediation and moderation analyses were performed.

Results: The Friedman test confirmed significant variations in WS over the study period, indicating fluctuating physical activity levels. A negative correlation was observed between age and physical activity, indicating decreased physical activity in older students. A positive correlation was observed between academic performance and physical activity, suggesting a beneficial impact of physical activity on academic outcomes. There was a significant indirect effect of physical activity on academic performance via cognitive functioning, highlighting cognitive mediation.

Conclusions: These findings underscore the role of physical activity in enhancing academic performance, potentially through cognitive advantages. This study establishes positive correlations between physical activity, academic performance, among university students.

Keywords: physical activity, cognitive functioning, sleep habit, academic performance, grade.

Introduction

The significance of the three key factors of sleep for optimal athletic performance and sport recovery—cognitive functioning, academic performance, and well-being—alongside reducing injury and illness risk in athletes, has been well documented¹. Decades of research have reported positive associations of physical activity and sleep with cognitive performance across the lifespan². Emerging research suggests that sleep consistency may be a strong predictor of academic success³. Sleep deficits (SD) have been associated with a lack of concentration and attention in class. While a few studies dispute these effects,⁴ most studies examining the impact of sleep quality and length on academic outcomes have found that longer, high-quality sleep is associated with improved academic outcomes, including better grades and increased study dedication⁵.

A high prevalence of sleep disturbances has been reported in the Middle East, particularly in the Kingdom of Saudi Arabia, the United Arab Emirates, and Palestine⁶. Rigorous research on SD has demonstrated that insufficient sleep not only heightens fatigue and drowsiness but also adversely affects cognitive

abilities⁷.

Several studies^{5,8} identified students as a group particularly vulnerable to sleep problems. Education-related stress and academic workload can alter a student’s sleep pattern⁹. Poor sleep quality is associated with adverse health outcomes, such as fatigue, low energy, difficulty in concentration, mood disturbances, cognitive impairment, and poor work performance¹⁰. Cross-sectional studies have established that shortened sleep duration is associated with obesity, type 2 diabetes, hypertension, and cardiovascular diseases¹¹. This demonstrates the need for a multifactorial approach to research projects examining sleep, cognitive performance, physical activity, and academic success.

A limited number of studies have evaluated the effects of physical activity on sleep quality and duration and suggest that physical activity may improve sleep quality¹². A systematic review of six clinical trials concluded that participants in exercise interventions reported improved sleep scores, reduced sleep latency, and reduced medication use. However, no differences were found between groups in other sleep outcomes such as sleep duration, sleep efficiency, or sleep disturbance.

Recent studies have indicated potential enhancements in sleep outcomes across various exercise interventions for diverse groups of healthy adults and patients. A short moderate-intensity exercise program conducted twice a week for 12 weeks was linked with noticeable improvements in self-reported sleep quality and symptoms of insomnia, as outlined by Sternfeld, Guthrie, Ensrud, LaCroix, Larson, Dunn, Anderson, Seguin, Carpenter, Newton, Reed, Freeman, Cohen, Joffe, Roberts and Caan¹³. However, the available clinical trials are insufficient to implement real-world interventions on a broad scale. Only a few studies have investigated the day-to-day relationships between physical activity and sleep using objective measures, as indicated by Dzierzewski, Buman, Giacobbi, Roberts, Aiken-Morgan, Marsiske and McCrae¹⁴.

Unfortunately, a lack of knowledge remains in the field of sleep education, particularly among university students from the Middle East¹⁵. Only a few studies have investigated Middle Eastern athletes' sleep schedules and quality¹⁶, and no study has analyzed the quality and quantity of sleep among university students in the Middle East, except for one conducted in Kuwait¹⁷, in which researchers used only self-reported tools to assess sleep. While many studies have explored the connections between sleep, academic outcomes, physical activity, and cognitive performance, most have relied on self-reported data regarding sleep duration and quality. There is a notable scarcity of research that employs objective measures to assess sleep duration and quality among students. Notably, a set of interrelated recent studies have examined the immediate benefits of sleep on academic performance in university settings. In these studies, incentives such as extra credit were offered to students if they maintained an average of eight or more hours of sleep during the final week of a psychology course¹⁸, or over the five days preceding a graphics studio final project submission¹⁹. Students who maintained this sleep standard, as recorded by a wearable activity monitor, notably outperformed their peers in their final psychology exams. In another innovative study, Suardiaz-Muro, Morante-Ruiz, Ortega-Moreno, Ruiz, Martin-Plasencia and Vela-Bueno⁵ used Fitbit®—a wearable activity monitor—to track the sleep patterns of university students continuously throughout a semester. Their findings conclusively showed that superior sleep quality, longer sleep durations, and consistent sleep patterns have a robust correlation with enhanced academic results in university students.

Recent studies have relied on objective and self-reported tools made possible by the availability of sleep assessment equipment. The healthcare industry has proposed various sleep wearables and devices including Neuroon, LucidCatcher, ActiGraph, Fatigue Science RediBand, FraSen Inc. Sleep Sense Mask, SleepImage, Sproutling Baby Monitor, UP3 by Jawbone, Garmin VivoSmart, Withings Pulse Ox, and Fitbit. Recent articles studying the validation of wrist activity monitors using polysomnography (PSG) as a reference²⁰ have reported high correlations for sleep duration (i.e., .84–.90) and moderate-to-high correlations for wake time after sleep (i.e., .53–.76). Each device has specific advantages and disadvantages. PSG is currently the gold standard (highest sensitive approach) for monitoring sleep. This approach tracks many sleep variables, including sleep latency, duration, wake-up time after sleep onset, each sleep-stage type and duration, sleep efficiency, and the number of arousal events. Despite its accuracy, this approach has significant drawbacks, including movement restriction, high costs, time consumption, and the need for a high level of competence in addition to non-ecological settings (e.g., laboratory at a university or research center).

The existing scholarly literature highlights the relationship between sleep quality, physical activity, cognitive function, and academic performance in the student population. However, there is a lack of comprehensive research that explores the intricate connections within these domains and examines whether these interactions are consistent across distinct demographic subgroups, such as academic year and gender. It is crucial to gain a comprehensive understanding of these dynamic relationships, particularly within the context of Qatari university students, to provide effective mentorship and guidance to this academic cohort.

Hence, this investigation seeks to establish and rigorously assess a theoretical framework elucidating the interplay between sleep architecture, physical activity levels, cognitive abilities, and academic performance specifically within the Qatari university student population. This empirical endeavor aims to contribute significantly to the existing body of knowledge regarding these intricate associations. Ultimately, the findings will inform the development of evidence-based interventions and support systems tailored to address the unique needs of Qatari students pursuing higher education.

Methods

Participants

A total of 51 Qatar University students were recruited for this study between 05/09/2021 and 30/10/2021. However, some participants were excluded from the analysis owing to missing data, resulting in a final sample of $n = 44$ students. The sample consisted of both male (65.9%) and female (34.1%) students, with a mean age of 23.59 years ($SD = 4.34$) and an average grade of 80.8% ($SD = 11.70\%$). Prior to participation, all students provided written informed consent in agreement with the study protocol and data publication guidelines. The study was conducted in accordance with the Declaration of Helsinki, and the University Institutional Review Board approved the protocol (QU-IRB 1467-EA/21). All participants were thoroughly familiarized with the tests administered in this study and were informed that they could withdraw at any point without any repercussions.

This six-week study aimed to investigate the complex interplay between sleep quality, physical activity, cognitive function, and academic performance among university students. The study focused on three distinct phases: two weeks before final exams, two weeks during the exam period, and two weeks after exams.

Measures

The study utilized various devices to assess different measures: **Cambridge Neuropsychological Test Automated Battery (CANTAB)**²¹: A computerized tool used to evaluate a range of cognitive functions. Specifically, it was employed to measure spatial working memory between errors (SWMBE) and the paired associates learning score.

ActiGraph²²: A lightweight, wrist-worn device used to measure sleep patterns and activity levels. It tracks movements throughout the night or day to estimate sleep and wake periods or overall activity levels.

The study encompassed several measures, including:

Weight and height.

Spatial Working Memory Between Errors (SWMBE)²¹: Assessed using CANTAB. This test requires the retention and manipulation of visuospatial information. It is a self-ordered task that imposes significant demands on executive functions and provides measures of strategy as well as working memory errors.

Paired Associates Learning Score ²¹: Evaluated using CANTAB, this measure assesses visual memory and new learning capabilities.

Total Sleep Time (TST) ²³: Refers to the total duration of sleep during a designated sleep period, typically overnight. TST was estimated using the ActiGraph, which detects periods of minimal movement indicative of sleep.

Wake After Sleep Onset (WASO) ²⁴: Indicates the amount of time spent awake after initially falling asleep. WASO was measured using the ActiGraph, which tracks periods of increased movement that may signal wakefulness during the sleep period. However, the weight and height measures and SWMBE were excluded from the analysis owing to missing data. Additionally, the physical activity level (PAL) score, TST, and WASO measures were excluded because of issues with factor loading in confirmatory factor analysis, as shown in Table 1.

The final set of measures used in the study included “Grade” (academic performance), Rapid Visual Information Processing or “RVIP” (cognitive function), Sleeping Efficiency or “SE” (Sleeping Behavior), and Average Weekly Steps or “WS” (physical activity), which is calculated using the average of weekday and weekend steps variables.

Final measurement model stability over time

The stability of the final measurement model was assessed by estimating separate factor models for each week of data collection and comparing the fit indices over time. Table 2 presents the Standardized Root Mean Squared Residual (SRMR), Chi-square, and Root Mean Square Error of Approximation (RMSEA) values for each week’s factor model. The results suggest that the factor structure of the model remains relatively stable over time, as indicated by the non-significant chi-square values and the SRMR and RMSEA values that fall within the acceptable

Table 1. Factor loadings of different variables for different weekly models

Factor	Variable	Models (Weeks)						
		1	2	3	4	5	6	All
Cognitive Functions	PAL score	.901	.634	.988	.578	.134	.358	.715
	RVIP	.390	.706	.089	.977	.983	.953	.849
Sleeping Behavior	Sleeping efficiency	.949	.966	.908	.684	.262	.927	.938
	Total sleep time	.873	.646	.802	.972	.607	.427	.641
Physical Activity	Wake time after sleep	.373	.611	.545	.094	.952	.884	.032
	Weekday steps	.911	.858	.680	.968	.970	.398	.935
	Weekend steps	.897	.928	.998	.938	.972	.591	.908

PAL: Physical Activity Level; RVIP: Rapid Visual Information Processing

range. Specifically, the acceptable value for the SRMR is less than or equal to 0.08, and the acceptable value for the RMSEA is less than or equal to .08²⁵.

Table 2. Factor model fit indices for six weeks of data collection

Models	SRMR	RMSEA	Chi-square (df)	P-value
Week 1	.03	.079	2.45 (1)	.117
Week 2	.02	.078	2.82 (1)	.093
Week 3	.04	.023	.00 (1)	.984
Week 4	.04	.028	.44 (1)	.508
Week 5	.05	.022	.20 (1)	.652
Week 6	.07	.024	.82 (1)	.364

SRMR: Standardized Root Mean Squared Residual; RMSEA: Root Mean Square Error of Approximation.

Statistical Analysis

We performed various statistical analyses to examine the relationships between the study variables. First, we computed descriptive statistics for all study variables. Some variables, such as RVIP, SE, and SWS, were measured repeatedly over six weeks. The average scores of these variables across the six weeks were calculated for each participant. Additionally, we used the Friedman test to analyze the changes in RVIP, SE, and WS over the six weeks²⁶. For the final analysis, the average scores for each participant were computed by combining the six-week data on RVIP, SE, and WS. Second, bivariate Spearman correlations were conducted to explore the relationships between the study variables. Third, a mediation analysis was performed to investigate the indirect effects of physical activity and sleep on

academic performance through cognitive functioning²⁷. Finally, a moderation analysis was conducted to examine whether the relationship between sleep and academic performance persisted when controlling for cognitive functioning and physical activity.⁵⁵ All statistical analyses were conducted using R software, version 4.1.2.⁵⁶ The level of statistical significance was set at $P < .05$ for all tests.

Results

This study aimed to investigate variations in RVIP, SE, and WS across different academic periods. Linear mixed-effects models were employed to analyze the impact of exam schedules (two weeks before, two weeks during, and two weeks after exams). The analysis accounted for fixed factors such as “Period” and

“Gender,” while controlling for “Age” and “Grade Point Average (GPA).” A random intercept was included for each subject to manage the repeated-measures design.

A linear mixed-effects model was utilized to analyze the impact of various factors on RVIP among the students. The model revealed a significant baseline RVIP score (Intercept: .7231, $P < .001$), suggesting a fundamental level of RVIP in the absence of other influencing factors. However, compared to “After” exams, the “Before” and “During” exam periods did not exhibit a statistically significant change in RVIP scores (Before: increase by .0140 units, $P = .205$; During: increase by .0106 units, $P = .334$). Gender differences indicated that male students had a lower RVIP score than female students, though this difference was not statistically significant (decrease by .0309 units, $P = .182$). However, GPA were positively associated with RVIP scores; however, these relationships did not reach statistical significance (Age: increase by .0038 units per year, $P = .150$; GPA: increase by .0334 units per GPA unit, $P = .234$). Overall, the model in this study suggests that the considered variables—exam periods, gender, age, and GPA—do not have a statistically significant impact on RVIP scores among the students.

In the analysis of sleep quality (SE) reported, a linear mixed-effects model was employed to examine the influence of academic periods, gender, age, and GPA on sleep quality among the students. The model accounted for individual variability by including random intercepts for subjects.

The results indicated a significant baseline level of sleep quality (Intercept = 95.2621, $P < .001$), reflecting the average sleep quality score when other variables are zero. Regarding time period, the “Before” and “During” exam periods did not demonstrate a statistically significant impact on sleep quality compared to the “After” exam period (Before: increase by .5248 units, $P = .188$; During: decrease by .0355 units, $P = .929$).

Gender differences were observed, with male students exhibiting significantly lower sleep quality scores compared to female students (decrease by 1.1935 units, $P = .042$). However, age and GPA did not show a significant association with sleep quality (Age: decrease by 0.0211 units per year, $P = .745$; GPA: increase by .1321 units per GPA unit, $P = .849$).

A linear mixed-effects model was employed to elucidate the determinants of WS among the students, considering the influence of academic periods, gender, age, and GPA. The analysis revealed a substantial baseline activity level, as indicated by the significant intercept (36855.56 steps, $P < .001$). This value represents the WS for a typical female student during the “After” exam period, with baseline age and GPA.

Significant variations in WS were observed across different academic periods. Specifically, the “Before” exam period saw a marked decrease in steps (6456.86 fewer steps, $P < .001$) compared to the “After” period, suggesting reduced physical activity as exams approached. Similarly, during exam weeks, a significant reduction in activity was noted (4033.95 fewer steps, $P = .021$), aligning with the notion that academic demands might contribute to decreased physical activity.

Gender differences emerged as a notable factor, with male students engaging in significantly fewer WS than their female counterparts (a decrease of 10427.55 steps, $P < .00001$). This finding points to gender-specific patterns in physical activity among the students. Age and GPA, while included as covariates, did not demonstrate a statistically significant association with WS (Age: $P = .075$; GPA: $P = .622$).

The relationships between the study variables were examined through a Spearman correlation analysis, exploring the associations between age, academic performance (Grade),

cognitive function (RVIP), sleeping behavior (SE), and physical activity (WS) in a sample of 44 college students.

The results also revealed a significant positive correlation between sleeping behavior and physical activity ($R = .337$, $P = .025$). However, no significant correlations were found between cognitive function and the other study variables. These findings suggest that physical activity may positively influence academic performance and sleeping behavior, and that age is negatively associated with PAL and academic performance. As previously mentioned, one research question hypothesized whether a relationship between physical activity, sleep, and cognitive functioning was necessary for better academic performance. To explore this question, a mediation analysis was conducted to examine the indirect effects of physical activity and sleep on academic performance through cognitive functioning.

A mediation analysis was conducted to explore the indirect effects of physical activity and sleep on academic performance through cognitive functioning for students in the sample. The analysis revealed a significant positive direct effect of physical activity on academic performance ($\beta = .0006$, $P = .016$) and no significant direct effect of sleep on academic performance ($\beta = .000001$, $P = .972$). However, the indirect effect of physical activity on academic performance through cognitive functioning was found to be significant ($\beta = .0007$, $P = .018$). These results suggest that the relationship between physical activity and academic performance was partially mediated by cognitive functioning, whereas sleep did not seem to have a significant direct or indirect effect on academic performance of the students. This study also aimed to investigate the relationships between physical activity, sleep, cognitive functioning, and academic performance in college students. Specifically, the study sought to explore the indirect effects of physical activity and sleep on academic performance through cognitive functioning, and the direct causative relationship between sleep and academic performance.

Based on the causal mediation analysis results, the average causal mediation effect estimate was $-.075$, indicating that the indirect effect of sleeping behavior on academic performance through cognitive function was not significant ($P = .74$). The average direct effect was $.604$, suggesting that the direct effect of sleeping behavior on academic performance was not significant after controlling for cognitive function. The total effect of sleeping behavior on academic performance (total effect) was $.528$, which was not statistically significant, with a p-value of $.61$. The proportion mediated (Prop. Mediated) was $-.001$, suggesting that cognitive function did not mediate the relationship between sleeping behavior and academic performance.

Discussion

This study aimed to investigate the complex relationships between academic performance, cognitive function, sleep quality, and physical activity patterns among 44 university students. The findings of this six-week study offer valuable insights into the dynamics of these associations and their potential implications for academic settings.

Regarding cognitive function, the analysis commenced by scrutinizing the RVIP scores across the six-week study period. The model revealed a significant baseline RVIP score (Intercept: .7231, $P < .001$), suggesting a fundamental level of RVIP in the absence of other influencing factors. However, compared to “After” exams, the “Before” and “During” exam periods did not show a statistically significant change in RVIP scores (Before: increase by .0140 units, $P = .205$; During: increase by

.0106 units, $P = .334$). This observed stability in RVIP suggests that cognitive function, in relation to physical activity, remained relatively stable throughout the study.

The investigation then focused on SE. The results revealed a significant baseline level of sleep quality (Intercept = 95.2621, $P < .001$), reflecting the average sleep quality score when the other variables were zero. However, when comparing the “Before” and “During” exam periods to the “After” exam period, there was no statistically significant impact on sleep quality (Before: increase by .5248 units, $P = .188$; During: decrease by .0355 units, $P = .929$). This finding underscores the notion that the participants’ sleeping efficiency exhibited a consistent pattern and was not significantly affected by the study’s temporal progression.

Further scrutiny was directed toward WS, a measure quantifying physical activity. Significant variations in WS were observed across different academic periods. Specifically, the “Before” exam period saw a marked decrease in steps (6456.86 fewer steps, $P < .001$) compared to the “After” period, suggesting reduced physical activity as exams approached. Similarly, during the exam weeks, a significant reduction in activity was noted (4033.95 fewer steps, $P = .021$), aligning with the notion that academic demands might contribute to decreased physical activity. These findings emphasize the temporal variability in physical activity levels among the participants, with specific periods displaying divergent mean step counts. These fluctuations in physical activity levels have implications for the dynamic nature of the relationship between physical activity and the variables under investigation, including academic performance and cognitive function.

It is important to recognize that physical activity levels are influenced by multiple factors, as outlined by Cavill et al.⁵⁷ While age, gender, and socioeconomic status represent non-modifiable determinants, they are not the sole factors shaping physical activity patterns. Modifiable determinants include personal characteristics, such as attitudes, motivation, and self-efficacy; the social environment, including family, friends, and social support; and the physical environment, comprising variables such as weather conditions, access to athletic facilities, and transportation infrastructure. Understanding the multifaceted nature of these factors is crucial for devising effective strategies to promote physical activity and overall well-being among university students.

In our analysis, we observed a notable positive correlation between academic performance and physical activity levels, suggesting that engagement in physical activity may have a positive influence on academic outcomes. It is imperative to acknowledge contrasting results reported by Hattie and Clinton²⁸ who found no significant association between academic success and physical activity. Moreover, von Hippel and Bradbury²⁹ posted that a direct link between academic performance and physical activity may not be entirely valid, as both academic outcomes and physical activity can be influenced by various socioeconomic factors. Additionally, Tomporowski, Davis, Miller and Naglieri³⁰ explored the relationship between physical activity and academic achievement and suggested minimal to negligible impacts of physical activity on academic success. However, Redondo-Flórez, Ramos-Campo and Clemente-Suárez³¹ identified a positive correlation between students’ academic accomplishments and their PAL, particularly among those engaged in high-intensity physical activities. These varied findings underscore the complexity of the relationship between physical activity and academic performance, warranting further investigation to elucidate the underlying mechanisms and contextual factors influencing this association.

Mediation analyses were employed to gain a deeper understanding of the complex relationships between physical activity, sleep, cognitive functioning, and academic performance. The initial mediation analysis sought to elucidate the indirect effects of physical activity and sleep on academic performance, with cognitive functioning serving as a mediating variable. The outcomes revealed a statistically significant indirect effect of physical activity on academic performance, through the mediation of cognitive functioning. This implies that the relationship between physical activity and academic performance can be partially attributed to the influence of physical activity on cognitive function. Conversely, our analysis observed no significant direct or indirect effects of sleep on academic performance.

Our findings align with a cross-sectional study conducted by McPherson, Mackay, Kunkel and Duncan³² which demonstrated a significant association between physical activity and academic outcomes ($R = .225$). However, upon introducing cognitive function into the model, this direct relationship attenuated ($R = .121$), highlighting the mediating role of cognition in this association. Our study also revealed a robust correlation between cognitive abilities and academic achievement ($R = .750$), emphasizing the critical role of cognition in academic performance. A modest yet noteworthy correlation was also identified between physical activity and cognitive abilities ($R = .138$). These collective findings underscore the complexity of the relationship between physical activity, cognitive function, and academic performance, emphasizing the mediating role of cognitive function in the association between physical activity and academic outcomes.

The second mediation analysis aimed to investigate the mediating role of cognitive functioning in the relationship between sleeping behavior and academic performance. The results revealed that cognitive function did not mediate this relationship. According to Okano et al.,¹² college students’ academic performance is significantly correlated with their sleep quality and quantity. Sufficient sleep positively affects grades, a measure of academic performance,⁶⁴ and promotes cognitive function. Consequently, insufficient sleep is associated with poor student performance³³. This study also explored the potential moderating effects of age and gender on the relationships between sleep, physical activity, cognition, and academic performance. The results showed no significant moderation effects of age and gender, except for a marginal effect of age on the relationship between sleep and academic performance. İri, Ibis and Aktuğ³⁴ found no significant correlation between academic success and physical activity in female and male students. Additionally, studies by Liu, Li and Li³⁵ support the findings reported in this study; they also indicate that there is no significant correlation between academic success and physical activity in female and male students.

Finally, a comprehensive multiple regression analysis was undertaken to rigorously assess whether the connection between sleep and academic performance retained significance while accounting for the potential effects of cognitive function and physical activity. The analysis revealed no significant relationship between sleep and academic performance. This study’s unexpected finding that sleep did not show a significant direct or indirect effect on academic performance could be attributed to several factors. One possible explanation is the methodological limitations inherent in our study design. Our reliance on self-reported measures of sleep quality, which are inherently subjective, might have introduced variability and inaccuracies that obscure the true relationship between sleep and academic performance. Objective measures of sleep, such

as polysomnography or actigraphy, could provide more reliable data and potentially reveal associations not detected by self-reports.

Additionally, the focus of our mediation analysis on cognitive function as a mediator in the physical activity-academic performance relationship may have overshadowed the potential mediating role of sleep. It is possible that sleep influences academic performance through complex interactions with cognitive function, which were not fully captured in our analysis. Moreover, the six-week study period may have been insufficient to observe the long-term effects of sleep patterns on academic outcomes.

These results contrast with some existing literature that suggests a direct correlation between sleep quality and academic performance. However, it aligns with other studies that have found no significant relationship, suggesting that the impact of sleep on academic performance may vary depending on factors such as measurement methods, sample characteristics, and study design.

Future research should consider larger, more diverse samples and employ objective sleep measures to enhance the accuracy of findings. Additionally, a more comprehensive exploration of potential mediating variables, including both cognitive function and sleep, is needed to better understand the complexities of how sleep may influence academic achievement. This approach would provide a more nuanced understanding of the interplay between sleep and academic success. In contrast, physical activity continued to exhibit a significant association with academic performance, even after adjusting for the potential influences of sleep and cognitive function.

Limitation

This study provides valuable insights into the relationship between sleep patterns and academic performance; however, several limitations warrant consideration. First, the six-week observation period may not be enough to capture the long-term effects of sleep patterns on academic performance. Chronic sleep issues, which develop over longer periods, may exert more substantial impacts that are not evident within the short timeframe of this study. Additionally, while we focused on sleep efficiency (SE) as the primary measure of sleep quality, this does not fully capture the complexity of sleep. Other factors such as total sleep duration, sleep architecture (including different sleep stages), and daytime sleepiness could also significantly influence academic performance, yet these were not comprehensively assessed in our study.

Furthermore, any missing data could potentially weaken our conclusions about the impact of sleep on academic performance. Although we employed methods to handle missing data, a significant amount of missing data could still affect the robustness of our findings. The relatively small sample size of 44 university students and the specific population studied also limit the generalizability of our results. This sample may not represent broader student populations, reducing the applicability of our findings to other groups.

Our choice of outcome measures was based on relevance and feasibility, which necessitated the exclusion of other potentially informative measures due to constraints in time and resources. This selection could have influenced the scope and depth of our findings. Lastly, both qualitative and quantitative assessments used in the study have inherent limitations. Quantitative assessments, while providing precise data, may not capture the nuances of individual experiences and behaviors.

In contrast, qualitative assessments, though rich in detail, can be subjective and harder to generalize. Future research should consider extending the observation period, incorporating a more comprehensive range of sleep measures, and involving larger and more diverse samples. These steps would help in better understanding the complex interactions between sleep and academic performance.

Practical Applications

In summary, these findings substantially enhance our understanding of the intricate dynamics underpinning the interrelationships between academic performance, cognitive function, sleep, and physical activity within a university student population over a six-week period (before, during, and after exams). The results highlight the pivotal role of physical activity in enhancing academic performance, implying that regular exercise may bestow cognitive benefits that may contribute to improved academic outcomes. However, it is worth noting that this study did not discern a direct impact of sleep on academic performance. Consequently, future research should delve deeper into elucidating the mechanisms through which physical activity influence's cognitive function and academic performance, while also exploring additional potential factors that may mediate or moderate these multifaceted relationships. These investigations will undoubtedly further enrich our understanding of the intricate interplay between lifestyle factors and academic success in university students.

Conclusions

Our investigation revealed noteworthy findings regarding the complex interplay between physical activity, sleep, age, and academic performance among college students. Notably, a positive association was identified between physical activity and both academic performance and sleeping behavior, underscoring the potential cognitive benefits of regular exercise contributing to improved academic outcomes. Conversely, age exhibited a negative association with both physical activity and academic performance, suggesting a potential age-related decline in these domains. These findings enhance our understanding of the multifaceted interactions between lifestyle factors, age, and academic performance in college students. Further research should explore the underlying mechanisms linking physical activity, cognitive function, sleep, and academic performance to inform interventions and support strategies tailored to the unique needs of the student population.

Acknowledgments

The authors would like to thank all the participants for taking part in this study.

Ethical Committee approval

The study was conducted in accordance with the Declaration of Helsinki, and the University Institutional Review Board approved the protocol (QU-IRB 1467-EA/21).

Topic

Sport Psychology

Conflicts of interest

The authors declare that the research was conducted in the

absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of *Acta Kinesiologica*, at the time of submission. This had no impact on the peer review process and the final decision.

Funding

This work was supported by Qatar University under Collaborative Grants QUCG-CED-21-22-1 and QUCG-CED- 24/25-495.

Author-s contribution

Conceptualization: M. H. and Z. A. Methodology: M. H. and Z. A. Formal analysis: A. S. G. Investigation, Z. A., and M. H. Writing—review and editing: Z. A., A. S. G., S. M., K. B., S. V., and M. H. Supervision: M. H. Funding acquisition: M. H. All authors have read and approved the published version of the manuscript.

References

1. Fullagar HH, Skorski S, Duffield R, Hammes D, Coutts AJ, Meyer T. Sleep and athletic performance: the effects of sleep loss on exercise performance, and physiological and cognitive responses to exercise. *Sports Med.* Feb 2015;45(2):161-86. doi:10.1007/s40279-014-0260-0
2. Erickson KI, Hillman CH, Kramer AF. Physical activity, brain, and cognition. *Current Opinion in Behavioral Sciences.* 2015/08/01/ 2015;4:27-32. doi:https://doi.org/10.1016/j.cobeha.2015.01.005
3. Okano K, Kaczmarzyk JR, Dave N, Gabrieli JDE, Grossman JC. Sleep quality, duration, and consistency are associated with better academic performance in college students. *NPJ Sci Learn.* 2019;4:16. doi:10.1038/s41539-019-0055-z
4. Eliasson A, Eliasson A, King J, Gould B, Eliasson A. Association of sleep and academic performance. *Sleep Breath.* Mar 2002;6(1):45-8. doi:10.1007/s11325-002-0045-9
5. Suardiaz-Muro M, Morante-Ruiz M, Ortega-Moreno M, Ruiz MA, Martín-Plasencia P, Vela-Bueno A. [Sleep and academic performance in university students: a systematic review]. *Rev Neurol.* Jul 16 2020;71(2):43-53. Sueño y rendimiento académico en estudiantes universitarios: revisión sistemática. doi:10.33588/rn.7102.2020015
6. Talaat W, AlRozzi B, Kawas SA. Sleep medicine education and knowledge among undergraduate dental students in Middle East universities. *Cranio.* May 2016;34(3):163-8. doi:10.1179/2151090315y.0000000019
7. Brownlow JA, Miller KE, Gehrman PR. Insomnia and Cognitive Performance. *Sleep Med Clin.* Mar 2020;15(1):71-76. doi:10.1016/j.jsmc.2019.10.002
8. Carney CE, Edinger JD, Meyer B, Lindman L, Istre T. Daily activities and sleep quality in college students. *Chronobiol Int.* 2006;23(3):623-37. doi:10.1080/07420520600650695
9. Fukuda K, Ishihara K. Age-related changes of sleeping pattern during adolescence. *Psychiatry Clin Neurosci.* Jun 2001;55(3):231-2. doi:10.1046/j.1440-1819.2001.00837.x
10. Alonzo R, Hussain J, Stranges S, Anderson KK. Interplay

11. between social media use, sleep quality, and mental health in youth: A systematic review. *Sleep Med Rev.* Apr 2021;56:101414. doi:10.1016/j.smrv.2020.101414
12. Meurling IJ, Shea DO, Garvey JF. Obesity and sleep: a growing concern. *Curr Opin Pulm Med.* Nov 2019;25(6):602-608. doi:10.1097/mcp.0000000000000627
13. Sejbuk M, Mirończuk-Chodakowska I, Witkowska AM. Sleep Quality: A Narrative Review on Nutrition, Stimulants, and Physical Activity as Important Factors. *Nutrients.* May 2 2022;14(9)doi:10.3390/nu14091912
14. Sternfeld B, Guthrie KA, Ensrud KE, et al. Efficacy of exercise for menopausal symptoms: a randomized controlled trial. *Menopause.* Apr 2014;21(4):330-8. doi:10.1097/GME.0b013e31829e4089
15. Dzierzewski JM, Buman MP, Giacobbi PR, Jr., et al. Exercise and sleep in community-dwelling older adults: evidence for a reciprocal relationship. *J Sleep Res.* Feb 2014;23(1):61-8. doi:10.1111/jsr.12078
16. El-Kharoubi AR. Sleep disorders and excessive daytime sleepiness in the Palestinian population. *Neurosciences (Riyadh).* Jan 2004;9(1):46-8.
17. Chamari K, Briki W, Farooq A, Patrick T, Belfekih T, Herrera CP. Impact of Ramadan intermittent fasting on cognitive function in trained cyclists: a pilot study. *Biol Sport.* Mar 2016;33(1):49-56. doi:10.5604/20831862.1185888
18. Al-Kandari S, Alsalem A, Al-Mutairi S, Al-Lumai D, Dawoud A, Moussa M. Association between sleep hygiene awareness and practice with sleep quality among Kuwait University students. *Sleep Health.* Oct 2017;3(5):342-347. doi:10.1016/j.sleh.2017.06.004
19. Scullin MK, Jones WE, Phenix R, et al. Using smartphone technology to improve prospective memory functioning: A randomized controlled trial. *J Am Geriatr Soc.* Feb 2022;70(2):459-469. doi:10.1111/jgs.17551
20. King E, Scullin MK. The 8-Hour Challenge: Incentivizing Sleep during End-of-Term Assessments. *J Inter Des.* Jun 2019;44(2):85-99. doi:10.1111/joid.12135
21. Kosmadopoulos A, Sargent C, Darwent D, Zhou X, Roach GD. Alternatives to polysomnography (PSG): a validation of wrist actigraphy and a partial-PSG system. *Behav Res Methods.* Dec 2014;46(4):1032-41. doi:10.3758/s13428-013-0438-7
22. Smith PJ, Need AC, Cirulli ET, Chiba-Falek O, Attix DK. A comparison of the Cambridge Automated Neuropsychological Test Battery (CANTAB) with "traditional" neuropsychological testing instruments. *J Clin Exp Neuropsychol.* 2013;35(3):319-28. doi:10.1080/13803395.2013.771618
23. Fekedulegn D, Andrew ME, Shi M, Violanti JM, Knox S, Innes KE. Actigraphy-Based Assessment of Sleep Parameters. *Ann Work Expo Health.* Apr 30 2020;64(4):350-367. doi:10.1093/annweh/wxaa007
24. Zolovska B, Shatkin JP. Key Differences in Pediatric versus Adult Sleep. In: Kushida CA, ed. *Encyclopedia of Sleep.* Academic Press; 2013:573-578.
25. Chang F, Berenz EC, Ajilore O, et al. Actigraphic Wake after Sleep Onset and Symptom Severity Correspond with Rumination in Trauma-Exposed Individuals. *Brain Sci.* Jan 13 2023;13(1)doi:10.3390/brainsci13010139
26. Hu Lt, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling:*

- A Multidisciplinary Journal*. 1999/01/01 1999;6(1):1-55. doi:10.1080/10705519909540118
26. Marín-García A, Fossion R, Müller MF, Ríos-Herrera W, Rivera AL. A non-parametric model: free analysis of actigraphic recordings of acute insomnia patients. *R Soc Open Sci*. Feb 2022;9(2):210463. doi:10.1098/rsos.210463
 27. Igartua JJ, Hayes AF. Mediation, Moderation, and Conditional Process Analysis: Concepts, Computations, and Some Common Confusions. *Span J Psychol*. Oct 14 2021;24:e49. doi:10.1017/sjp.2021.46
 28. Hattie J, Clinton J. Physical activity is not related to performance at school. *Arch Pediatr Adolesc Med*. Jul 1 2012;166(7):678-9; author reply 679. doi:10.1001/archpediatrics.2012.334
 29. von Hippel PT, Bradbury WK. The effects of school physical education grants on obesity, fitness, and academic achievement. *Prev Med*. Sep 2015;78:44-51. doi:10.1016/j.ypmed.2015.06.011
 30. Tomporowski PD, Davis CL, Miller PH, Naglieri JA. Exercise and Children's Intelligence, Cognition, and Academic Achievement. *Educ Psychol Rev*. Jun 1 2008;20(2):111-131. doi:10.1007/s10648-007-9057-0
 31. Redondo-Flórez L, Ramos-Campo DJ, Clemente-Suárez VJ. Relationship between Physical Fitness and Academic Performance in University Students. *Int J Environ Res Public Health*. Nov 10 2022;19(22)doi:10.3390/ijerph192214750
 32. McPherson A, Mackay L, Kunkel J, Duncan S. Physical activity, cognition and academic performance: an analysis of mediating and confounding relationships in primary school children. *BMC Public Health*. Jul 31 2018;18(1):936. doi:10.1186/s12889-018-5863-1
 33. Hedin G, Norell-Clarke A, Hagell P, Tønnesen H, Westergren A, Garmy P. Insomnia in Relation to Academic Performance, Self-Reported Health, Physical Activity, and Substance Use Among Adolescents. *Int J Environ Res Public Health*. Sep 3 2020;17(17) doi:10.3390/ijerph17176433
 34. İri R, Ibis S, Aktuğ Z. The Investigation of the Relation between Physical Activity and Academic Success. *Journal of Education and Learning*. 11/10 2016;6:122. doi:10.5539/jel.v6n1p122
 35. Liu G, Li W, Li X. Striking a balance: how long physical activity is ideal for academic success? Based on cognitive and physical fitness mediation analysis. *Front Psychol*. 2023;14:1226007. doi:10.3389/fpsyg.2023.1226007

Corresponding information:

Received: 19.05.2024.

Accepted: 10.06.2024.

Correspondence to: *Monoem Haddad

University: Physical Education Department, College of Education, Qatar University, PO Box 2713, Doha, Qatar

E-mail: mhaddad@qu.edu.qa