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Preprint
not peer reviewed

Interactive associations between physical activity and sleep in relation to adolescent academic achievement

Supplementary materials: https://osf.io/fd48h/
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Please cite as: Brown, D. M. Y., Porter, C., Hamilton, F., Almanza, F., Narvid, C., Pish, M., Arizabalo, D. (2022). Interactive associations between physical activity and sleep in relation to adolescent academic achievement. *SportRχiv*.

ABSTRACT

Although research suggests inadequate amounts of physical activity and sleep are negatively associated with academic achievement during adolescence, the joint effects of these two behaviors remain unknown. Thus, the present study aimed to examine independent and interactive associations between physical activity and sleep duration with adolescent academic achievement. This cross-sectional observational study was a secondary analysis of data from the 2019 cycle of the US-based Youth Risk Behavior Surveillance System. A total of 13,677 American adolescents in grades 9 through 12 (M_{AGE} = 16.06 ± 1.24 years; 49.4% female) self-reported their sleep and physical activity behavior as well as their grades. A series of linear regression models fit with cubic splines were computed to capture potential non-linear associations. Findings for the independent effect models revealed significant curvilinear relationships between physical activity and sleep with academic achievement wherein optimal grades were associated with 7-9 hr/night of sleep and 5-7 days/week of physical activity. A significant physical activity by sleep interaction was also observed for academic achievement, which demonstrated that the association between sleep duration and academic achievement is not uniform across levels of physical activity engagement, and tradeoffs may exist. Overall,

All authors have read and approved this version of the manuscript. This article was last modified on May 25, 2022.

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the results help to identify different combinations of physical activity and sleep behavior associated with optimal academic achievement and suggest that a one-size-fits-all approach to physical activity and sleep recommendations may not be adequate for promoting academic achievement during adolescence.

INTRODUCTION

Inadequate amounts of sleep and physical activity have each been shown independently to have downstream effects on academic achievement. Specifically, studies have found that insufficient sleep is associated with cognitive deficits in concentration and memory,[1] which is known to have a detrimental effect on youths' abilities in the classroom.[2] Additionally, an abundance of evidence has established a beneficial relationship between physical activity engagement and academic performance.[3] Limited research, however, has considered the potential interactive influence of sleep and physical activity on academic achievement. A shortcoming of existing studies is that they have generally examined this relationship based on whether individuals adhere to the respective sleep and physical activity guidelines,[4] which neglects much of the variance in these behaviors by failing to consider the full range of responses. Considering academic achievement in secondary school is tied to numerous economic outcomes,[5] it is therefore important that we identify the optimal combination of sleep and physical activity to better inform recommendations that will enable students to realize their full potential.

Academic achievement is an important marker of positive adjustment during adolescence and sets the stage for future educational and occupational opportunities.[6] The most serious consequence of school failure, particularly dropping out of school, is the high risk of unemployment or underemployment in adulthood that follows. In contrast, high achievement can set the stage for college or future vocational training and opportunities. For instance, academic achievement is a primary determinant of whether a student gains acceptance to a higher education institution due to the competitive nature of college admissions.[7] Given that college graduation positively predicts future income, academic achievement in high school can set the stage for one's future economic success through facilitating social mobility.[8] Academic achievement is therefore an important area of inquiry as findings can inform the development of interventions that set students up for success during this critical life stage.

Research has demonstrated several links between the health behaviors that high school students engage in (or do not) and their academic achievement.[9] The recent emergence of the 24-hr movement paradigm has helped to garner more attention for the importance of engaging in a healthy balance of physical activity, sedentary behavior and sleep over the course of a full day for healthy development during childhood and adolescence.[10] Each of these behaviors has been independently linked with academic achievement[2,3] and researchers are just beginning to explore their interactive effects.

Among the 24-hr movement behaviors, physical activity has arguably garnered the most attention for its potential impact on academic achievement. Naturally, this may have occurred due to the inclusion of physical education within many curriculums, which promotes physical activity engagement through the school environment. Research has suggested an increased curricular emphasis on physical education at the expense of other subjects does not hinder overall academic achievement, but rather, is associated with positive albeit small benefits for grades while at the same time having the potential to provide health benefits.[11] Beyond simply focusing on school-based physical activity, a review of 41 systematic reviews and meta-analyses indicated that regular physical activity participation has a beneficial effect on academic achievement among school-aged children and adolescents.[12] However, it is becoming increasingly apparent that physical activity does not occur in isolation and other movement behaviors adolescents engage in over the course of a day can impact their academic achievement too.

Sleep is fundamentally different from physical activity in many ways including when sleep behavior typically occurs (i.e., outside of school hours). Nevertheless, the body of literature investigating the relationship between sleep and academic achievement is rapidly developing with studies capturing the importance of various facets of sleep behavior: duration, quality, regularity and timing.[2] It should be noted that the present paper will focus on sleep duration given the time-based focus of existing public health recommendations.[10,13] Despite an earlier systematic review concluding that shorter sleep durations are negatively associated with academic achievement during adolescence,[14] more recent meta-analytic evidence from studies of US adolescents failed to observe a significant relationship ($r = 0.03$).[15] Beyond these limitations, investigating sleep independently fails to consider that the benefits of regular physical activity engagement may buffer the negative impact of inadequate sleep duration on academic achievement.

While the interactive influence of adolescent sleep and physical activity behavior has received some attention to date as it relates to mental health outcomes,[16,17] academic achievement has yet to be investigated. Research examining 24-hr movement guideline adherence lends some insight though. For example, a study of 1290 Spanish adolescents observed the most favorable associations with academic achievement among those who met the physical activity and sleep guidelines; other combinations of guideline adherence (e.g., sleep and screen time, screen time and physical activity) – including concurrent adherence to all three 24-hr movement guidelines – demonstrated weaker associations.[18] A key shortcoming of classifying adolescents into groups based on whether or not they adhere to sleep or physical activity guidelines, however, is that these dichotomized groups fail to consider potential dose-response relationships between movement behaviors and academic achievement. Additionally, there has been an overall lack of implementing non-linear approaches within the physical activity and sleep literature that may uncover instances where a "more is better" approach is not accurate, but rather, ranges or different combinations of

behaviors may be associated with optimal outcomes. Thus, examining the entire range of values for each behavior and using non-linear modeling techniques stands to help identify an optimal balance of time spent in sleep and physical activity as it relates to academic achievement.

The present study aimed to investigate the independent and interactive associations of physical activity and sleep with academic achievement among a nationally representative sample of US adolescents. We expected to observe: 1) a positive linear relationship between physical activity and academic achievement; 2) an inverted-U relationship between sleep and academic achievement with optimal grades occurring at the public health recommended range of 8-10 hr of sleep each night; and 3) a physical activity by sleep interaction whereby the beneficial association between sleep duration and academic achievement would be amplified with greater physical activity participation.

METHOD

Study sample and data collection

This cross-sectional observational study used data from the 2019 cycle of the Youth Risk Behavior Surveillance System (YRBSS). The YRBSS is a bi-annual cross-sectional survey that is designed to study many health-related behaviors in a nationally representative sample of high school students living in the United States. Detailed information about the YRBSS study design, methods, survey measures and procedures can be found at https://www.cdc.gov/healthyyouth/data/yrbs/index.htm.

The 2019 cycle of the YRBSS used a multi-stage clustered sampling design to recruit students in grades 9 through 12 (ages 12 to 18 years) in both public and private schools across the United States. A total of 13,677 participants responded to the survey. Participants were sampled from 136 schools within all 50 States and the District of Columbia.

Measures

Sleep.

Participants responded to a single item that asked: “On an average school night, how many hours of sleep do you get?” Response options included: “4 or less hours”, “5 hours”, “6 hours”, “7 hours”, “8 hours”, “9 hours” or “10 hours or more”.

Physical activity.

Participants responded to a single item that asked: “During the past 7 days, on how many days were you physically active for a total of at least 60 minutes per day? (Add up all the time you spent in any kind of physical activity that increased your heart rate and made you breathe hard some of the time.)”. Response options ranged from 0 to 7 days.

Academic Achievement.

Participants responded to a single item that asked: "During the past 12 months, how would you describe your grades in school?" Response options included: "Not sure", "None of these grades", "Mostly Fs", "Mostly Ds", "Mostly Cs", "Mostly Bs", or "Mostly A's." Participants who responded "Not sure" or "None of these grades" were removed from the analysis.

Covariates.

Covariates included school grade (9, 10, 11, 12), race/ethnicity (Hispanic, Black, White, Native American, Asian, Mixed), sex (male/female), weight status (normal, overweight, obese) and adherence to screen time guidelines for children and youth (≤2 hr per day; yes/no).

Data analysis

All analyses were performed in R (Version 4.1.1) and R Studio (Version 2021.09.2). First, we inspected the data for missingness using the mice package.19 Data were considered missing at random and multiple imputation by chained equations was conducted using the mice package to replace missing values. A total of 25 multiply imputed datasets were created as per recommendations to set m > 100 times the highest fraction of missing information.20

For our primary analyses, a series of linear regression models fit with cubic splines were computed using the splines package to examine the independent and interactive effects of sleep and physical activity on academic achievement. Cubic splines were included in our models given that previous work has shown non-linear relationships between sleep duration and academic achievement[21] and very few studies have used non-linear approaches to investigate links between physical activity and academic achievement. A total of six and five knots were included in our physical activity and sleep models, respectively. Visual inspection of academic achievement values revealed a left skewed distribution and therefore a Gamma distribution was used for all regression models. All models were adjusted for grade, race/ethnicity, sex, weight status and screen time guideline adherence. Given that beta coefficients for cubic spline models are uninterpretable, a smoothing spline ANOVA model was computed for our interaction effect to determine statistical significance, which was set at $\alpha < .05$. The survey package was used to handle the nested structure of the YRBSS dataset (students within schools).[22]

RESULTS

Data inspection

Missingness ranged from 0.5% for age to 10.9% for weight status (see Table 1). Missingness for physical activity, sleep and academic achievement were predicted by other observed variables (e.g., more missingness among non-White participants, those with higher

body mass index, and those who do not meet the screen time guidelines), which led us to consider data missing at random and use appropriate procedures to preserve our sample size.

Descriptive statistics

Descriptive statistics for the sample demographic characteristics, physical activity, sleep and academic achievement are presented in Table 1.

Table 1. *Descriptive statistics.*

	N (%)	Missing
Sex (Female)	6892 (50.9%)	141 (1.0%)
Age		71 (0.5%)
≤14	1760 (13.0%)	
15	3470 (25.6%)	
16	3614 (26.7%)	
17	3099 (22.9%)	
≥18	1594 (11.8%)	
Grade		109 (0.8%)
9	3641 (26.9%)	
10	3719 (27.5%)	
11	3329 (24.6%)	
12	2848 (21.0%)	
Race/Ethnicity		429 (3.1%)
Hispanic	1043 (7.7%)	
White	6794 (50.2%)	
Black	2096 (15.5%)	
Asian	633 (4.7%)	
Native American	221 (1.6%)	
Multi-racial	2749 (20.3%)	
Weight Status		1497 (10.9%)
Normal	9350 (69.1%)	
Overweight	2164 (16.0%)	
Obese	2023 (14.9%)	
Screen Time Guideline Adherence (Yes)	4537 (33.5%)	947 (6.9%)
Physical Activity (days/week)		455 (3.3%)
0	2362 (17.4%)	
1	1039 (7.7%)	
2	1356 (10.0%)	
3	1671 (12.3%)	
4	1344 (9.9%)	
5	1800 (13.3%)	

6	939 (6.9%)	
7	3027 (22.4%)	
Sleep Duration (hr/night)		567 (4.1%)
≤4	1405 (10.4%)	
5	1989 (14.7%)	
6	3372 (24.9%)	
7	3748 (27.7%)	
8	2299 (17.0%)	
9	533 (3.9%)	
≥10	192 (1.4%)	
Academic Achievement		1106 (8.0%)
Mostly As	5500 (40.6%)	
Mostly Bs	5080 (37.5%)	
Mostly Cs	2286 (16.9%)	
Mostly Ds	482 (3.6%)	
Mostly Fs	189 (1.4%)	

Note: Values represent the pooled results for the multiply imputed datasets (N = 13,677).

Physical Activity

Figure 1 shows the relationship between physical activity engagement and academic achievement. Results from our physical activity ANOVA model revealed a significant effect of physical activity on academic achievement ($F(3,34) = 6.13$, $p < 0.001$).

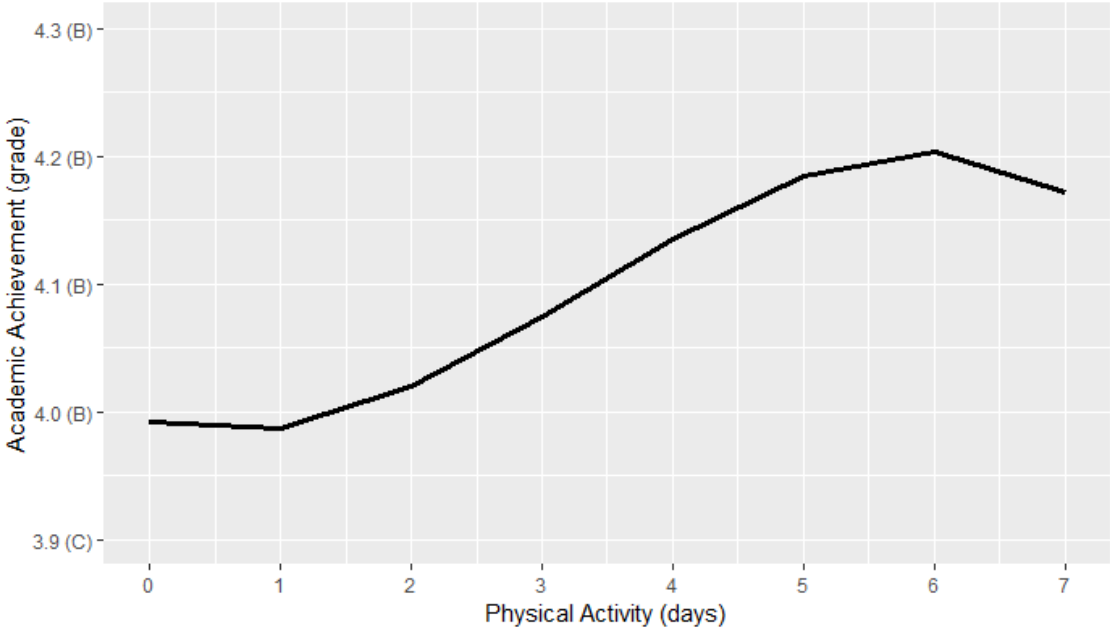

Figure 1. Relationship between physical activity and academic achievement.

Sleep

Figure 2 shows the relationship between sleep duration and academic achievement. Results from our sleep ANOVA model revealed a significant effect of sleep on academic achievement ($F(3,34) = 20.81$, $p < 0.001$).

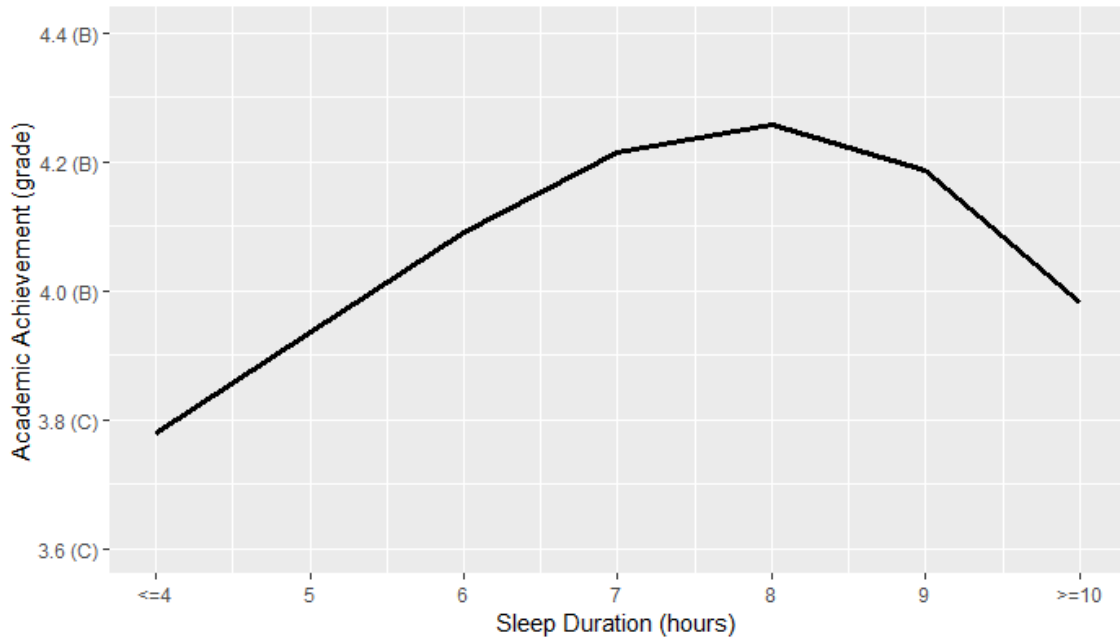

Figure 2. Relationship between sleep duration and academic achievement.

Physical Activity X Sleep Interaction

Results from our physical activity by sleep ANOVA model revealed significant main effects of sleep ($F(3,34) = 20.81$, $p < 0.001$) and physical activity ($F(3,31) = 3.53$, $p < 0.001$) as well as a significant sleep by physical activity interaction ($F(9,22) = 2.56$, $p = 0.042$). Figure 3 shows the relationship between sleep and academic achievement by level of physical activity engagement.

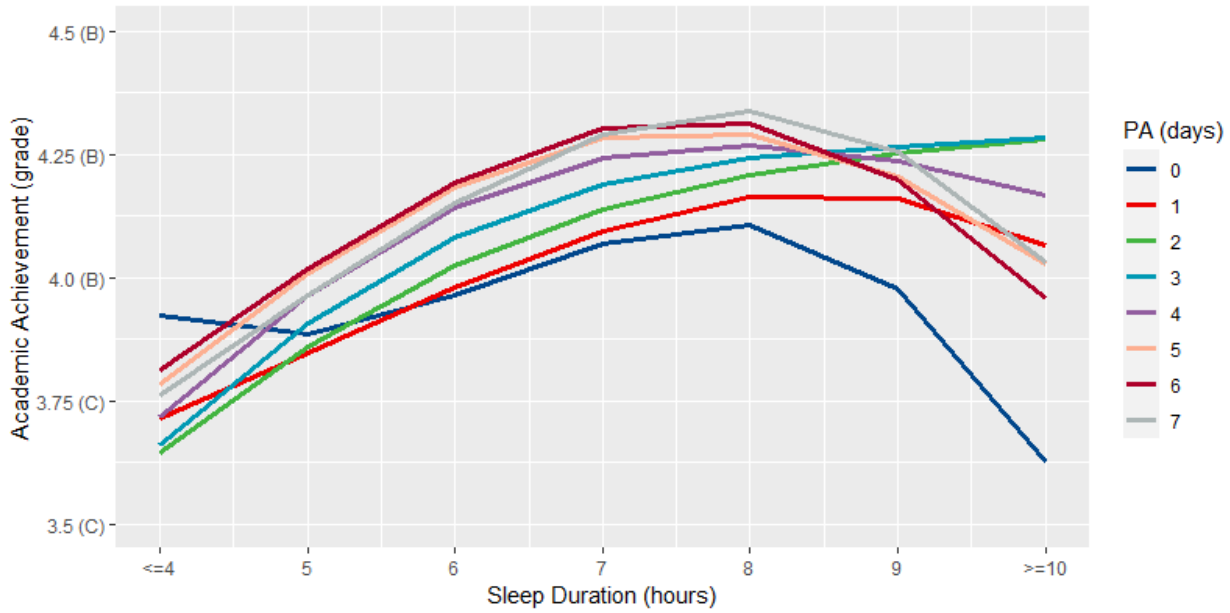

Figure 3. Interactive association between physical activity and sleep in relation to academic achievement.

DISCUSSION

The present study represents the first to examine independent and interactive effects of physical activity engagement and sleep duration in relation to adolescent academic achievement. We took a novel approach in that we included cubic splines within our models which allowed us to observe curvilinear relationships that would not have otherwise been found using traditional linear modeling techniques. Findings for the independent effect models revealed optimal academic achievement was associated with ranges of sleep (7-9 hr/night) and physical activity (5-7 days/week) that deviated slightly from respective public health guideline recommendations for adolescent health. Our interaction model was also significant, with findings suggesting that the association between sleep duration and academic achievement is not uniform across levels of physical activity engagement and tradeoffs may exist. Overall, our results help to identify different combinations of physical activity and sleep that are associated with optimal academic achievement and recognize that a one-size-fits-all approach may not exist.

With the exception of one study,[23] all non-experimental research investigating the relationship between physical activity and academic achievement has employed linear modeling approaches that generally assume "more is better".[3] We addressed this shortcoming in the literature by using cubic splines. Contrary to our prediction, our findings revealed a curvilinear relationship between physical activity and academic achievement whereby adherence to the physical activity guidelines did not predict optimal academic achievement,

but rather, grades appear to plateau with five or more days of physical activity engagement each week. One potential explanation is that the most active adolescents (i.e., those who reported 7 days/week) spend so much time in these pursuits that it takes time away from endeavors that promote better grades (e.g., studying). For instance, this may be the case for student-athletes who juggle academic responsibilities alongside daily training, practice and/or competition. Future work should consider using isotemporal substitution modeling to better understand the impact on academic achievement of replacing physical activity with studying (and vice versa); it may be possible that the effects dissipate with increasing levels of physical activity.

Although our finding of a curvilinear relationship between physical activity and academic achievement is in contrast to a previous study that observed a linear relationship despite testing non-linear terms,[23] closer inspection of our results suggest relatively linear improvements in academic achievement are observed between one to five days of weekly physical activity engagement. Moreover, results from both studies, and the overarching body of literature indicates that a physically inactive lifestyle or engaging in very low amounts of physical activity is linked to the poorest levels of academic achievement. Taken together, existing evidence provides partial support for the notion that "every move counts",[24] but physical activity promotion efforts should recognize that guideline adherence may be unnecessary for optimal benefits depending on the outcome of interest – academic achievement in this case. Setting lower physical activity targets could address the knowledge translation issue of an all-or-nothing threshold-based approach and provide many adolescents with knowledge that they can act upon to improve their grades.[25]

Akin to our findings for physical activity, optimal academic achievement was associated with amounts of sleep that deviated slightly from public health recommendations. Our hypothesis was partially supported in that we found an inverse-U relationship in which optimal scores for academic achievement were reported by adolescents accruing seven to nine hours of sleep each night as opposed to eight to ten hours as per our predictions based on the American Academy of Sleep Medicine recommendations.[26] The highest grades were observed among adolescents meeting the lower bound of the sleep recommendations (i.e., 8 hr). However, sleeping one hour less than recommended (i.e., 7 hr) was associated with slightly higher grades than getting nine hours of sleep. This is surprising given that research has shown sacrificing sleep for studying can have negative academic consequences.[27] It was also notable that adolescents who reported sleeping for ten or more hours each night also reported comparable grades to those who slept only five hours. One plausible reason for this may be due to the limited range of response options in the YRBSS; ten or more hours is the highest possible choice and as a result, adolescents who met the upper bound of the sleep recommendations were intermixed with those who exceeded it. Given that empirical evidence has established links between long sleep duration and depression[28] as well as depression and poorer academic achievement,[29] our findings for ten or more hours should be interpreted with

caution. Considered in light of this limitation, our findings suggest getting slightly less than recommended amounts of sleep may not be a detriment to academic performance, but rather, too much sleep is of greater concern.

Findings from the present study are also the first to demonstrate that physical activity and sleep interact to influence academic achievement. These results suggest potential trade-offs exist in that optimal academic achievement was observed with 7-8 hr of sleep duration alongside 5-7 days of weekly physical activity participation, whereas for lower amounts of physical activity (i.e., 1-2 days/week), grades were highest among adolescents accruing at least nine hr of sleep each night. Outside of these optimal ranges, however, we found that any level of physical activity cannot buffer the detrimental effects of low amounts of sleep or too much sleep. Similarly, even at optimal amounts of sleep, low amounts of physical activity are associated with poor grades compared to those engaging in greater amounts of physical activity. Collectively, this evidence further underscores the fact that focusing on one movement behavior is short-sighted and thus adopting an integrative approach that considers multiple movement behaviors may help provide better insight into the range of amounts that may contribute to optimal academic achievement. It should be acknowledged, however, that while engaging in amounts of physical activity and sleep that deviate slightly from public health recommendations may not have a discernable impact on academic achievement, doing so may limit the variety of benefits for healthy development known to be associated with meeting these guidelines during adolescence.[10]

Despite several strengths such as using multiple imputation to handle missing data, generalizability through the use of a nationally representative sample and employing non-linear modeling techniques, this study has limitations that should be acknowledged. First, sleep and physical activity behavior as well as grades were self-reported and as a result may be biased or prone to recall errors.[30] Second, our sleep measure only considered sleep duration, which is but one facet of sleep behavior among many linked to academic achievement. Finally, our study employed a cross-sectional design which limits causal inference.

Overall, the findings from this study highlight the importance of moving beyond traditional linear approaches to understand independent and joint associations between physical activity and sleep duration with academic achievement. Doing so helped to recognize that adherence to physical activity and sleep-specific public health guidelines may not be necessary for optimal academic achievement, but rather, amounts slightly below the recommendations may be sufficient. Moving forward, school officials should consider knowledge mobilization efforts that will empower students to engage in greater amounts of physical activity and sleep knowing that they do not need to meet the guidelines to see benefits for their grades.

Contributions

Conceptualization (DB), Methodology (DB), Formal Analysis (DB), Data Curation (DB), Writing – Original Draft (DB, CP, FA, DA, FH, CN, MP), Supervision (DB)

Funding information

None

Data and Supplementary Material Accessibility

The YRBS dataset is available at https://www.cdc.gov/healthyyouth/data/yrbs/data.htm. All R code for the analyses is available at https://osf.io/fd48h/.

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