Lower sleep variability associated with higher academic performance across the semester in college students

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Author contributions: G.R.S.-L. developed the general study concept and coordinated data collection. The data were initially analyzed by the course instructor, G.R.S.-L., and graduate teaching assistants, C.M. and P.W.. All remaining authors analyzed the data as their final examination in the course. The introduction and methods sections of the paper were initially drafted by G.R.S.-L. and were revised by C.M., P.W., A.K., H.S.S., M.M.K., R.J.S., J.M.D., C.H.Y., M.P.M., and P.P.. The results and discussion sections of the paper were written by students during the final exam. Individual student responses were combined by A.K., H.S.S., M.M.K., R.J.S., J.M.D., C.H.Y., M.P.M., and P.P. to be used in this manuscript. In summary, all authors analyzed the data and wrote the paper.

Data Availability: Data and analyses are publicly available at <https://osf.io/5egfq/>

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Abstract

The present study examined associations between physical activity, sleep, and academic outcomes in undergraduate students ($N = 52$). More consistent sleep throughout the semester (lower sleep variability) was associated with higher homework grades. The interaction between sleep variability and sleep quantity was not significant suggesting that greater sleep overall did not buffer students from the negative effects of sleep variability on grades.

Decades of research on both physical activity and sleep have revealed positive associations with cognitive performance across the life span [1,2]. Emerging research suggests that sleep consistency may be a particularly strong predictor of academic success [3-5]. The present study examined effects of physical activity and sleep on academic outcomes in undergraduate students. We expected students who took more steps per day or slept more minutes per night to have higher grades on their weekly homework assignments. We expected high sleep variability to be negatively associated with homework grades, but that the effects of sleep variability would be buffered by higher average sleep duration.

There was a non-significant association between average sleep duration and average grades on weekly homework assignments, $b = 0.002$, 95% CI = $[-8.598e-4, 0.004]$, $t_{50} = 1.325$, $p = 0.191$, $R^2 = .03\%$. There was a non-significant association between average steps taken per day and average grades on weekly homework, $b = 2.130e-5$, 95% CI = $[-4.405e-5, 8.665e-5]$, $t_{50} = 0.655$, $p = 0.516$, $R^2 = .009$.

There was a significant, negative, strong association between sleep variability and average homework grades across the semester, $b = -0.003$, 95% CI = $[-0.005, -0.001]$, $t_{50} = -3.090$, $p = 0.003$, $R^2 = .16$. Less sleep variability (more consistency) was associated with higher grades (Figure 1). There was a non-significant association between step variability and average homework grades across the semester, $b = -0.0008$, 95% CI = $[-0.0002, 0.00004]$, $t_{50} = -1.397$, $p = 0.169$, $R^2 = 0.04$.

A multiple regression analysis examined the effects of sleep variability on homework grades controlling for average daily sleep duration, average daily steps, and step variability. The effects of sleep variability remained significant, $b = -0.002$, 95% CI = $[-0.005, -0.00007]$, $t_{47} = -2.073$, $p = 0.044$, adjusted $R^2 = 0.114$ and none of the covariates were significant (all $p > .4$).

Notably, this expanded model provided a worse fit to the data explaining 11.4% of the variance (adjusted R^2), whereas the model with only sleep variability explained more variance (adjusted $R^2 = 14.4\%$). Given the skewness of the distribution of homework grades, we ran this multiple regression analysis after removing the three lowest scoring students. The effects of sleep variability remained significant, $b = -0.002$, 95% CI = $[-0.004, -0.00004]$ $t_{44} = -2.449$, $p = 0.018$, adjusted $R^2 = 0.094$ and none of the covariates were significant (all $p > .598$).

An analysis of variance (ANOVA) evaluated whether students who got more sleep (split into three groups: low, medium, high average sleep duration) were better protected from the effects of sleep variability (split into three groups: low, medium, high variability) on grades. There was a non-significant main effect of sleep duration on grades, $F(2, 43) = 0.570$, $p = 0.570$, $\eta^2_p = 0.026$, a significant, large main effect of sleep variability on grades, $F(2, 43) = 5.965$, $p = 0.005$, $\eta^2_p = 0.217$, and a non-significant interaction between average sleep duration and sleep variability on grades, $F(4, 43) = 0.645$, $p = 0.633$, $\eta^2_p = 0.057$ (Figure 1). The effect sizes remained the same after excluding the three lowest scoring students: non-significant main effect of sleep duration $F(2, 40) = 0.412$, $p = 0.665$, $\eta^2 = 0.020$, significant main effect of sleep variability, $F(2,40) = 7.094$, $p = 0.002$, $\eta^2 = 0.262$, and non-significant interaction between average sleep and variability, $F(4,40) = 0.365$, $p = 0.832$, $\eta^2 = 0.035$.

The present study revealed that neither the amount of average daily physical activity nor amount of sleep were related to academic outcomes, which is inconsistent with prior research on both physical activity [6] and sleep duration [5,7,8]. Measuring average daily steps is a coarse measure of physical activity that may not accurately assess physical fitness or exercise. More specific measures of the cardiovascular effects of physical activity in a student sample may be better related to academic performance. It is unclear why there was no association between sleep

duration and grades. Although, there was variance in sleep duration, the students in this sample had relatively high average sleep (over 7 hours per night). It is possible that a larger sample that varies more in sleep duration would reveal stronger associations between sleep amount and grades.

The most consistent and strongest effect was that sleep variability was negatively associated with weekly homework grades. More consistent sleep throughout the semester (lower sleep variability) was associated with higher homework grades. The interaction between sleep variability and sleep quantity was not significant suggesting that greater sleep overall did not buffer students from the negative effects of sleep variability on grades.

The mechanisms that explain the association between sleep variability and grades is not clear in this data set. A wealth of prior research has demonstrated that multiple measures of sleep quality have been positively associated with well-being, memory, attention, and other cognitive abilities that are essential to academic success [2, 3, 9-13]. In the present study, exploratory analyses examined associations between sleep variability and other academically relevant measures such as perceived understanding of course material and difficulty concentrating (see Supplementary Materials). Sleep variability was associated with self-reports of more difficulty concentrating while completing homework assignments, but the effect was not significant after controlling for multiple comparisons. Future studies could examine the specific cognitive processes that mediate the effects of sleep variability on academic performance.

There are a number of limitations of the current study. The sample was relatively small and we only examined academic performance within one course. A more comprehensive analysis of activity and sleep effects would assess multiple measures of academic success across courses or across semesters. Although sleep variability alone accounted for more than ten percent

of the variance in grades, the majority of variance in homework grades was unexplained. Future research could assess baseline quantitative knowledge or past experience with the course material (statistics) to examine the robustness of these effects.

Overall our results suggest that sleep consistency has a powerful influence on academic performance and that sleeping more on average does not protect students from the deleterious effects of sleep inconsistency.

Methods. Undergraduate students (N =52, 37 female) in an introductory statistics course for psychology and neuroscience majors, PSY201L, at Duke University wore activity trackers (FitBit Alta HR) for two months during the semester (see Supplementary Materials for more details). The study was reviewed and approved by the campus IRB at Duke University. Students provided consent to have their data used for research purposes by responding to an online survey; they did not provide written informed consent.

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Figure 1. Sleep variability and academic performance. Students with higher sleep variability (less consistency) had lower homework grades (left). Negative effects of variability on grades for students with high average amounts of sleep duration (most sleep), average sleep duration (medium sleep), and low average sleep durations (least sleep) (right).

Supplementary Materials

Supplementary Methods

There were no specific inclusion or exclusion criteria. Students were given course participation credit for generating data but also had the option to opt out of the study and complete alternative activities for participation credit. Two students opted out and the remaining 52 students participated in activity and sleep tracking. Students were also incentivized to wear the activity tracker; they could keep the device if they generated data for more than 90% of the days during the tracking period. Seventy-seven percent of students ($N = 40$) generated data for more than 90% of the days and could keep the device at the end of the semester. Students started wearing a Fitbit Alta HR on February 14th, 2018, and we collected sleep and activity data starting that day until April 21st, 2018. Data were aggregated using Fitabase, which regularly extracted data from each individual student's Fitbit user account. Students received an email invitation to share their user data with Fitabase authorizing the website to access their Fitbit user account. The study profile in Fitabase was set to anonymous so that no personal identifying information (e.g., name, contact information) was collected from individual Fitbit user accounts. Measures of step and sleep variability were computed using mean-squared successive differences (MSSD) across adjacent days with available data. MSSD is a statistic used to quantify variability of time-series data in which there may be mean shifts over time.

To examine associations with objective measures of academic performance, we standardized (z-scored) scores on each individually-completed homework assignment across the semester (excluding one assignment completed in small groups). We calculated the mean of these standardized scores across all assignments as the primary objective measure of academic performance in the class.

For more exploratory analyses, we also collected several in-class, ungraded measures of understanding of course material (assessed with a single self-report question asking about level of understanding of the concept of standard error and average errors playing one round of guessthecorrelation.com during lecture), self-reported stress levels before exams across all courses in general, and difficulty concentrating while doing homework or during lectures across all courses in general.

Supplementary Results

In this student sample, the average number of steps taken per day was 10,437 (SD = 2,435), the average step variability was 5,515 (SD = 1,286), the average sleep duration per day was 423.5 minutes (just over 7 hours) (SD = 62.13 minutes), and the average sleep variability was 192.0 (SD = 72.37).

Self-reports of academic performance from students in the class who participated were measured on a 1-7 Likert-type scale. This showed that the average understanding of the concept of ‘standard error’ was 4.59 (SD = 1.57), average concentration while doing a homework assignment was 4.25 (SD = 1.44), average difficulty in concentration in a lecture class was 4.33 (SD = 1.53), average tiredness at the beginning of class was 4.61 (SD = 1.50), and average stress before an exam was 4.78 (SD = 1.26). In addition, during lecture one day students played a game on guessthecorrelation.com and reported their average errors (deviation between actual correlation depicted and student guess), which on average was 0.11 (SD = 0.04).

To further explore effects of sleep variability on related academic measures, we performed correlation analyses between sleep variability and various self-report questions collected during the class regarding understanding of material or cognitive performance

including (1) perceived understanding of the concept of standard error, (2) difficulty paying attention during class lectures in general, (3) tiredness at the beginning of particular PSY201 lecture, (4) stress level before an exam. In addition, we correlated (5) objective performance using average errors on a game of Guess the Correlation (<http://www.guessthecorrelation.com>) with sleep variability and (6) difficulty concentrating while doing homework assignments.

Sleep variability was non-significantly associated with how well students reported understanding the concept of standard error, $r(39) = 0.077$, 95% CI = [-0.236, 0.376], $p = 0.633$, non-significantly associated with difficulty concentrating during lectures in general, $r(47) = 0.102$, 95% CI = [-0.185, 0.372], $p = 0.486$, non-significantly associated with tiredness at the beginning of a particular PSY201 lecture, $r(44) = 0.050$, 95% CI = [-0.243, 0.336], $p = 0.740$, non-significantly associated with pre-exam stress level, $r(47) = -0.026$, 95% CI = [-0.305, 0.257], $p = 0.860$, and non-significantly associated with average error on a correlation guessing game, $r(41) = -0.006$ [95% CI = -0.306, 0.0.295], $p = 0.969$. However, sleep variability was significantly, weakly, positively associated with difficulty concentrating while doing homework assignments, $r(47) = 0.286$ [95% CI = 0.005, 0.525], $p = 0.046$. Sleep variability explained 8.2% of the variance in student concentration when doing homework assignments. These analyses were exploratory. After using a Bonferroni correction for multiple comparisons ($p = .05/6 = .0083$), the effect of sleep variability on homework concentration was not significant.