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Short Sleep and Late Bedtimes are Detrimental to Educational Learning and Knowledge Transfer: An Investigation of Individual Differences in Susceptibility

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Abstract

Good sleep hygiene practices, including consistent bedtimes and 7–9 hours of sleep/night, are theorized to benefit educational learning. However, individuals differ in how much sleep they need, as well as in their chronotype preference. Therefore, some students may be more vulnerable to the cognitive effects of sleep loss, later bedtimes, and nonpreferred times of learning than others. One prominent example is the debate regarding whether sleep loss and later bedtimes affect classroom learning more in female or male students. To inform this gender-and-sleep-loss debate, we developed a virtual college-level lecture to use in a controlled, laboratory setting. During Session 1, 78 undergraduate students were randomly assigned to take the lecture at 12:00 (noon condition) or 19:30 (evening condition). Then participants wore wristband actigraphy for one week to monitor average and intra-individual variability in sleep duration, bedtime, and midpoint of sleep. During Session 2, participants completed a test at the same time of day as Session 1. The test included basic questions that were similar to trained concepts during the lecture (trained items) as well as integration questions that required application of learned concepts (knowledge-transfer items). Bayesian analyses supported the null hypothesis that time of learning did not affect test performance. Collapsed across time of testing, regression analyses showed that shorter sleep durations and later bedtimes explained 13% of the variance in test performance. Longer sleep durations and earlier bedtimes predicted better test performance primarily in females, younger students, and morning-types. Interestingly, students with above-median fluid intelligence scores were resilient to the expected effects of short sleep and late bedtimes. Our findings indicate that both sleep and circadian factors should be addressed to optimize educational learning, particularly in the students who are most susceptible to sleep loss.

Keywords

circadian rhythms; evening classes; gender; education; naturalistic learning; individual vulnerability; actigraphy; metacognition; chronotype

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Declaration of Interest Statement

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A common belief amongst college students is that they only have time for two of the following three: social life, studying, or sleep (Evans 2016; Wisniewski 2016). Whether or not a student subscribes to this “two-out-of-three myth,” many students regularly sacrifice sleep (Thacher 2008;). For example, in a study of 1,125 college students, Lund and colleagues (2010) found that more than 60% of students met criteria for poor sleep quality on the Pittsburgh Sleep Quality Index (PSQI; Buysse et al. 1989).

Sacrificing sleep to study may be considered normal behavior in many universities, but research has shown that shorter sleep durations are associated with achieving worse grade point averages (Hartmann and Prichard 2018; Kelly et al. 2001). Though most sleep and education studies measure sleep subjectively (PSQI, sleep diary), when sleep is monitored objectively using wristband actigraphy, students with shorter and more irregular/variable sleep durations show lower levels of attention, creativity, and grade point averages (King et al. 2017; Phillips et al. 2017). Furthermore, a large literature of acute, total sleep deprivation studies in college-aged adults have demonstrated that sleep loss impairs performance on various laboratory measures of cognitive functioning (e.g., sustained attention, memory; Scullin and Bliwise 2015).

While maintaining at least 7 hours of sleep per night is important (Watson et al. 2015), it may be equally important to academic performance for students to go to bed early (Curcio et al. 2006; Eliasson et al. 2010). Not only do early bedtimes relate to grade point averages, but maintaining *consistent* bedtimes have been linked to lower reading and math scores, at least in childhood (Kelly et al. 2013). However, the relative importance of sleep duration compared with early and consistent bedtimes to academic learning has not been thoroughly investigated.

Individual Susceptibility Factors

Little is known regarding whether some students are more susceptible to the cognitive consequences of sleep loss or late bedtimes than others (Friedman et al. 2009; Lowe et al. 2017; Van Dongen et al. 2004). Suspected moderators of vulnerability to altered sleep/bedtimes include chronological age (Philip et al. 2004), intelligence (Erath et al. 2015) and chronotype (Selvi et al. 2007). Gender is also suspected to moderate vulnerability to sleep loss, however, the existing literature has produced conflicting findings. On the one hand, following sleep loss, females performed better on measures of sustained attention (Lowe et al. 2017) and showed less delta electroencephalographic (EEG) rebound activity than males (Corsi-Cabrera et al. 2003). According to these studies, females are more resilient to sleep loss, a finding that has spurred some authors to apply the evolutionary interpretation that females need to be resilient to sleep loss to meet the functional demands of rearing children after long periods of wakefulness.

On the other hand, some recent studies suggested that females are more detrimentally impacted by sleep loss than males. Smarr (2015) examined self-reported sleep data in 1,109 students enrolled in a biology lab course, and he found a stronger negative correlation between self-reported sleep duration and class performance in female students than in male students. Furthermore, Rångtell et al. (2018) observed that experimental sleep loss

significantly impaired working memory performance in females, but not in males. According to some recent studies, females are more vulnerable to sleep loss, potentially due to gender differences in susceptibility to stressors (Bale and Epperson 2015; Goldstein-Piekarski et al. 2018) and/or gender differences in sex hormones (Alhola et al. 2008; Sattari et al. 2017; Vidafar et al. 2018).

Morning, Afternoon, and Evening Classes

One remaining question that is pertinent to the current work is whether time of learning and testing affects performance (Evans et al. 2017). Early morning classes are clearly detrimental to learning (e.g., before 8:30; Kelley et al. 2017), but there has been minimal empirical work on the educational impact of evening classes (i.e., classes taught between 18:00 and 21:00). In cross-sectional studies, students who enrolled in evening classes showed worse academic performance than students enrolled in daytime classes (Andreoli and Martino 2012; Lazari 2009). By contrast, other research shows that young adults have phase-delayed chronotypes, and possibly even a “wake maintenance zone” that allows for strong cognitive functioning in the evening (Roenneberg et al. 2003; Shekleton et al. 2013). To test whether evening classes are detrimental to educational learning, we randomly assigned participants to take a virtual lecture on microeconomics at 12:00 (noon class) versus at 19:30 (evening class), and then return one week later to test on the material at the same time of day.

The Current Study

In the current study, participants performed an educational learning task that was developed to maintain ecological validity, while still being performed in a controlled laboratory setting. Participants wore wristband actigraphy during the week between learning and testing. We aimed to address three questions. First, we hypothesized that shorter total sleep time and later bedtimes would be detrimentally associated with worse test performance. Second, we hypothesized that gender and other factors (e.g., intelligence) would confer greater susceptibility to short sleep/late bedtimes (given the variability in the literature, we were agnostic to whether females or males would show stronger associations). Third, given recent theorizing that noon is an optimal time for class (Evans et al. 2017), we hypothesized that participants who learned in the evening would perform significantly worse than those who learned at noon.

Materials and Methods

Design Overview

The study took place over two sessions in a cognitive-testing laboratory. We randomly assigned university students to participate at 12:00 to 13:00 (hereafter, “noon” condition) versus 19:30 to 20:30 (hereafter, “evening” condition). They participated at the same time for both sessions, with sleep duration and bedtime being monitored objectively using wristband actigraphy for one week between sessions. During Session 1, participants took a single 30-minute virtual lecture on microeconomics. During Session 2, participants

completed a test that included both trained concepts and novel concepts (knowledge transfer).

Participants

Ninety-one adult student participants were initially contacted for willingness to be randomly assigned to noon and evening conditions, with 85 of these participants being enrolled. Seven participants did not return for Session 2 due to scheduling conflicts. The final sample of 78 participants ($M_{\text{age}} = 20.14$, age range: 18–27) was relatively diverse in race/ethnicity composition with a mixture of Caucasian (44.87%), Asian/Pacific Islander (23.08%), Hispanic (14.10%), and African American (14.10%) students. Additional demographic data are presented in Tables 1 and 2. We enrolled participants regardless of whether they had taken a prior economics course, but none of the primary findings were altered by statistically adjusting for prior economics course history.

The study was approved by the Baylor University Institutional Review Board and all participants provided written consent.

Actigraphy and Sleep Diary Measurements

To objectively estimate sleep/wake state, we used wristband actigraphy (Phillips Respironics – Actiwatch 2 Spectrum Plus). The actiwatch device was worn on the non-dominant wrist for the duration of the study. We used an epoch length of 15 seconds and a medium-threshold sensitivity (40 activity counts for defining wake onset and 10 minutes of immobility for defining periods of rest as sleep). Participants also maintained a sleep diary (Carney et al. 2012).

Educational Learning Task

The educational learning task was developed by Howard and colleagues (Scullin 2011) using materials from an undergraduate microeconomics textbook (Baumol and Blinder 2007). We selected microeconomics content for our virtual educational learning task because 1) the virtual lecture is more ecological than traditional laboratory learning tasks (e.g., learning word lists), 2) the content can still be completed in a controlled, laboratory environment (minimizing the influence of differential re-studying across male and female students), 3) most college students have minimal classroom experience with economics, and 4) the microeconomics test separately assesses participants' abilities to solve trained problems versus knowledge transfer problems (i.e., integrating trained concepts to solve an untrained problem), which is common in college-level classroom testing.

At their assigned time, participants engaged in a computer-based interactive lecture on microeconomics for approximately 30 minutes. Though 30 minutes is shorter than a typical college-level course, the lecture covered an amount of content that was similar to what would be covered during a traditional 50-minute period (but without extra time dedicated to previous class material, question and answer, or upcoming assignments). In one section of the lecture, participants learned about the principles of supply, and in another section, they learned about the principles of demand (order counterbalanced). In each section, participants were guided in how to identify and calculate market-based changes in supply or demand by

shifting the supply or demand curve. An example is shown in Figure 1a. The virtual lecture included practice problems with immediate feedback as well as a 12-item test of supply and demand questions immediately following the lecture (see literature on how immediate testing improves later performance; e.g., Roediger and Karpicke 2006).

One week later, participants were asked to solve 27 different microeconomics problems with 18 “trained-item” questions and nine “knowledge-transfer” questions. The “trained-item” questions were similar to the examples given in the lecture (similar to Figure 1a), where participants need to shift *either* the supply or the demand curve. Of the trained items, half were supply-only, and half were demand-only. The remaining problems were “knowledge-transfer” questions, in which participants need to shift *both* supply and demand curves and realize that the solution (without being instructed) was the intersection of the two new curves. An example of a knowledge transfer question is shown in Figure 1b. As an exploratory measure, we examined meta-cognition by having participants estimate from 0 to 100 how well they expected to perform before taking the test (prediction), as well as estimate how well they thought they performed after taking the test (postdiction; Dunlosky and Metcalfe 2008).

Procedure

During the first session, participants read and signed an informed consent. Then they completed a demographics questionnaire, the microeconomics lecture, and the microeconomics immediate test. Participants were instructed on how to fill out the sleep diary and wear the actiwatch before departing.

During the second session, participants completed the full microeconomics test. To estimate chronotype/circadian preference, participants completed the 19-item Morningness-Eveningness Questionnaire (MEQ; Horne and Östberg 1976). To estimate fluid intelligence, participants completed a 10-minute Raven’s Progressive Matrices Test (RPMT; Raven 1938) of 18 complex figures. Finally, participants completed a questionnaire that queried their academics including self-reported grade point average. Participants were debriefed and provided monetary compensation or class credit for their participation.

Statistical Analysis

We used independent samples t-tests to compare sample characteristics across gender groups and time-of-day conditions, as well as 2×2 Analyses of Variance (ANOVA) to determine whether these groups interacted to impact microeconomics test performance. We complemented this approach by using JASP software to conduct Bayesian analyses to test for critical null effects (Love et al. 2015). Furthermore, we conducted hierarchical linear regressions to test whether grouping variables (i.e., gender, age, fluid intelligence, chronotype) interacted with sleep to influence test performance.

Based upon the education literature, we focused our actigraphy hypotheses on calculating the mean and standard deviation (consistency) of total sleep times (King et al. 2017) and bedtimes. We supplemented these sleep duration and bedtime analyses with an emerging actigraphy measure for circadian timing, the midpoint of sleep (Patel et al. 2014; Bei et al. 2016). We used Pearson correlation to test whether these actigraphy variables were

associated with performance on trained and knowledge-transfer tests problems; if more than one actigraphy measure correlated with test performance, then we planned to use linear regression to determine whether the sleep/circadian variables explained unique variance in test performance.

Results

Sample Characteristics Across Groups and Conditions

Table 1 shows that males and females were similar in mean grade point average, fluid intelligence, chronotype, and actigraphy characteristics. The male participants were slightly older (<1 year) than the female participants. Therefore, when we analyzed gender differences on microeconomics test performance we controlled for age. Table 2 shows that participants in the time-of-day conditions were also similar on educational, intelligence, chronotype and actigraphy characteristics, except that, despite random assignment of participants to conditions, the noon condition showed longer sleep durations than the evening condition. Therefore, when we analyzed time-of-day effects on microeconomics test performance we also controlled for mean sleep duration.

Time of Day Effects on Microeconomics Test Scores

There are competing hypotheses as to whether evening classes impair educational outcomes (e.g., Shekleton et al. 2013; Carrier and Monk 2000). Table 2 presents performance data for the microeconomics immediate and one-week-delay tests. There was no statistical evidence for a significant time of day effect or interaction with gender, regardless of whether we controlled for total sleep time or excluded participants who had previously taken an economics course (all p s $> .05$). To reinforce this null effect, we conducted a Bayesian analysis. As illustrated in Figure 2, the Bayesian analysis indicated that learning/testing at noon was equivalent to learning/testing in the evening, $BF_{10} = 0.25$. These null effects have practical implications (to be elaborated in the discussion section), but for present purposes, in subsequent analyses we will collapse across time-of-participation conditions.

Sleep and Circadian Timing in Relation to Microeconomics Test Performance

Table 3 demonstrates that, as hypothesized, better performance on trained items on the microeconomics test was associated with greater mean sleep duration, $r(74) = .30$, $p = .01$, and earlier bedtimes, $r(74) = -.32$, $p = .01$. Linear regression analyses showed that sleep duration ($\beta = .30$, $p = .01$) and bedtime ($\beta = -.23$, $p = .07$) accounted for 13% of the variance in performance on trained items, $R^2 = .13$, $F(2,73) = 5.50$, $p = .01$.

A related idea is that consistency in sleep duration and bedtime patterns should promote better learning and retention (e.g., Phillips et al. 2017; King et al. 2017). However, intraindividual variability in bedtimes, sleep duration, and midpoint of sleep were not significantly related to performance on trained items or knowledge-transfer items (all p s $> .20$). Actigraphy variables were not significantly related to metacognitive measures (all p s $> .10$).

Individual Differences in Susceptibility to Short Sleep and Late Bedtimes

Gender is perhaps the most controversial proposed moderator of altered sleep/bedtimes. Early studies suggested that females are resilient to sleep loss (e.g., Corsi-Cabrera et al. 2003), whereas more recent studies suggest the opposite pattern (Rångtell et al. 2018; Smarr 2015). Figures 3 and 4 present scatterplots of sleep duration and bedtime in relation to microeconomics scores in female and male students. In female students, better performance on trained items was related to longer sleep durations and earlier bedtimes. In male students, these associations were nonsignificant. Earlier bedtimes also predicted better performance on knowledge transfer items in female students ($r(46) = -.40, p = .01$), but not in male students ($r(26) = .17, p = .38$; all other $ps > .05$).

To mirror how the gender analyses were dichotomized (male/female), we used median splits to dichotomize chronological age and fluid intelligence. We also dichotomized morningness-eveningness chronotype by using item #19 on the morningness-eveningness questionnaire in which participants are forced to choose whether they consider themselves to be morning-types or evening-types. The subgroup analyses are shown in Table 4. Test performance was significantly associated with shorter sleep and later bedtimes in younger students and students with below-median fluid intelligence scores. Later bedtimes were detrimentally associated with test performance for both morning- and evening-type individuals, but only the morning-type individuals showed strong negative associations between test performance and shorter total sleep times. We supplemented the subgroup analyses with hierarchical linear regression analyses. For each analysis, the sleep/bedtime variable and the susceptibility factor (gender, age, intelligence, or chronotype) were entered at the first step and the interaction term was entered at the second step. Table 5 illustrates that gender was the strongest factor in conferring susceptibility to later bedtimes.

Discussion

Evening classes may not harm educational learning, but shorter sleep durations and later bedtimes seem to. Our experimental and actigraphy-based findings build upon survey studies conducted in the classroom that connected self-reported sleep duration and bedtimes to grade point averages (Eliasson et al. 2010; Kelly et al. 2001; Smarr 2015). Interestingly, we found that some individuals were more susceptible to the negative effects of sleep loss and later bedtimes than others: Educational learning was most vulnerable to sleep loss and later bedtimes in individuals who were female, younger, morning-types, and lower on a fluid intelligence test.

Individual Susceptibility Factors

Gender differences in susceptibility to altered sleep has received increasing attention (Lowe et al. 2017; Rångtell et al. 2018). Some research indicated that females might be more resilient to sleep loss than males (e.g., Corsi-Cabrera et al. 2003). In Kabrita and Hajjar-Muça's study (2016), later bedtimes on weekends predicted lower grade point averages in males but not in females. However, other studies argue for the opposite result. For example, using a website-based diary to record sleep, Smarr (2015) found that greater variance in sleep duration and later mean bedtime more strongly predicted class performance in females

than in males. Using actigraphy measurements, the current study provides converging evidence that females are more susceptible. One possible explanation for the gender dissociation arises from sex differences in the hypothalamic–pituitary–adrenal axis, which shows greater stress reactivity in women (Oldehinkel and Bouma 2011). Elevated stress levels, in turn, might impair memory processes that depend on hippocampal or prefrontal cortex activity, causing lower learning, retention, and knowledge transfer (Lupien et al. 1997; Qin et al. 2009). Future research should utilize emotional reactivity and other stress measures at multiple points throughout the learning process to test whether sleep exacerbates test anxiety more so in females than in males.

Another possible explanation for the gender differences arises from sex differences in circadian rhythmicity (Van Reen et al. 2013). For example, Fabbian and colleagues (2016) argued that progressive eveningness (i.e., increasingly later bedtimes) compromised academic performance, especially in women. Furthermore, Santhi and colleagues (2016) found that the circadian effects on cognitive functions differed across genders. Specifically, females presented a larger amplitude of circadian modulation in some mental health and cognitive domains, such that they experienced greater impairments in the morning. Thus, it is possible that testing participants in the morning would have produced stronger associations between actigraphy measures and educational learning, at least in females.

Evening Classes

The literature clearly shows that morning testing—before 08:30—is detrimental to educational learning (for review, see Evans et al. 2017). However, there is much less known about educational learning near the end of the day. This gap in the literature is particularly noticeable because of the proliferation of evening classes and any-time-of-day online courses (Seaman et al. 2018). Therefore, there has been some concern over whether later class times detrimentally affect learning (Andreoli and Martino 2012; Lazari 2009). Alternatively, some theories predict that evening class times might even improve learning because the timing coincides with the wake maintenance zone (Shekleton et al. 2013). To our knowledge, the current work was the first experimental study to test whether evening learning affects retention and knowledge transfer of educational content. Bayesian analyses supported the null hypothesis: Evening time per se did not hurt or benefit learning outcomes in university students.

Limitations and Conclusions

The limitations of the current work included a cross-sectional design (age, gender, and intelligence cannot be randomly assigned), use of actigraphy rather than polysomnography, short study duration (single lecture, one week of monitoring), treatment of gender as a binary variable, and a small sample size relative to survey studies. The above notwithstanding, the current study builds on our understanding of sleep and education by using a controlled laboratory setting while employing an ecologically-valid task, objective monitoring of sleep/wake state, and experimental design to inform whether evening learning impairs retention and knowledge transfer. Our results converged with the view that female students are more susceptible to sleep loss and late bedtimes than male students. Understanding the biopsychosocial mechanisms underlying individual susceptibility to sleep

loss and later bedtimes is a worthy goal for future research. Until such mechanisms are identified and used to promote resilience against sleep loss and circadian misalignment, the recommendation to college students is to recognize that the “two-out-of-three myth” is, indeed, a myth. Maintaining sufficient sleep with an early bedtime should facilitate, rather than compromise, studying and social life.

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(a)

Changes in the Supply Curve

Now imagine a change in demand, such that manufacturers will supply more of an item at **any** price. This is called a shift **of** the supply curve.

Before the shift in the supply curve, manufacturers will supply 39 units at price \$70

After the shift in the supply curve, manufacturers will supply 59 units at price \$70

(b)

Figure 1.

Examples of the microeconomics lecture (A) and knowledge transfer test (B). In the knowledge transfer question, Participants need to shift the supply and demand curves (black lines, present on the test) towards the correction direction (indicated by arrows, not present on the test) to the correct positions (gray lines, not present on the test). The intersection of shifted curves (circled) indicates that price equilibrium occurs at 83 units and \$80.

Figure 2.

Graphed is the prior and posterior distributions for effect size δ as a function of the impact of time of day on educational test performance. The data provide evidence in favor of the null hypothesis of no difference between noon and evening performance.

Figure 3. Scatterplots to illustrate that mean sleep duration was significantly associated with microeconomics trained-item test scores in females (A), but not males (B).

Figure 4.

Scatterplots to illustrate that earlier bedtimes were significantly associated with better microeconomics trained- and knowledge-transfer test scores in females (A), but not males (B).

Table 1

Demographic, Actigraphic, and Outcome Measures Across Gender Groups

Variable	Total N = 78	Male n = 29	Female n = 49	p-value
Age	20.14(1.88)	20.69(2.22)	19.82(1.59)	.047 [*]
Taken college-level economics course	27(35%)	10(34%)	17(35%)	.99
Self-reported grade point average	3.30(0.46)	3.27(0.44)	3.32(0.47)	.72
RAPM fluid intelligence	10.04(3.20)	10.34(3.20)	9.85(3.22)	.52
Lecture practice problems (%)	81.91(11.89)	86.61(10.96)	79.17(11.66)	.01 ^{**}
Immediate test total score (%)	65.92(25.56)	71.26(25.65)	62.76(25.24)	.16
Test – Trained (%)	66.59(27.48)	69.92(23.97)	64.58(29.46)	.39 ^a
Test – Knowledge transfer (%)	30.45(29.75)	38.31(30.94)	25.69(28.27)	.12 ^a
Test – Total (%)	54.55(25.38)	59.39(23.37)	51.62(26.32)	.22 ^a
Mean sleep duration (h/day)	6.85(0.75)	6.91(0.78)	6.81(0.73)	.58
Mean bedtime	00:18 a.m. (71.43 min)	00:20 a.m. (60.07 min)	00:17 am (77.88 min)	.87
Mean midpoint of sleep	04:19 a.m. (40.31 min)	04:27 a.m. (42.06 min)	04:14 a.m. (38.85 min)	.17
Variability of sleep duration (h)	1.63(0.975)	1.72(1.27)	1.58(0.76)	.59
Variability of bedtime (h)	1.75(1.40)	1.70(1.37)	1.78(1.44)	.81
Variability of midpoint of sleep (h)	0.99(0.71)	1.08(0.88)	0.93(0.60)	.41
MEQ raw score (higher = morning)	46.24(7.65)	44.83(6.45)	47.08(8.22)	.21
Time of participation (noon)	37(47%)	14(48%)	23(47%)	.91

Note. Data presented as Mean (Standard deviation) or frequency (%).

MEQ = Morningness-Eveningness Questionnaire; RAPM = Raven's Advanced Progressive Matrices.

^a Adjusted for age

^{*} *p* .05

^{**} *p* .01

Table 2

Demographic, Actigraphic, and Outcome Measures Across Time-of-the-Day Conditions

Variable	Total <i>N</i> = 78	Noon <i>n</i> = 37	Evening <i>n</i> = 41	<i>p</i> -value
Age	20.14(1.88)	20.46(1.85)	19.78(1.89)	.11
Taken college-level economics course	27(35%)	10 (27%)	17(41%)	.18
Self-reported grade point average	3.30(0.46)	3.41(0.46)	3.21(0.44)	.07
RAPM fluid intelligence	10.04(3.20)	9.70(2.83)	10.35(3.52)	.38
Lecture practice problems (%)	81.91(11.89)	80.63(12.84)	83.12(11.06)	.37
Immediate test total score (%)	65.92(25.56)	67.79(24.63)	64.23(26.57)	.54
Test – Trained (%)	66.59(27.48)	69.52(27.02)	63.89(27.96)	.89 ^a
Test – Knowledge transfer (%)	30.45(29.75)	27.63(29.70)	33.06(29.93)	.24 ^a
Test – Total (%)	54.55(25.38)	55.56(24.94)	53.61(26.05)	.72 ^a
Mean sleep duration (h/day)	6.85(0.75)	7.05(0.73)	6.66(0.72)	.02 [*]
Mean bedtime	00:18 a.m. (71.43 min)	00:10 a.m. (75.51 min)	00:25 a.m. (67.69 min)	.36
Mean midpoint of sleep	04:19 a.m. (40.31 min)	04:24 a.m. (36.50 min)	04:13 a.m. (43.26 min)	.24
Variability of sleep duration (h)	1.63(0.975)	1.55(0.98)	1.71(0.98)	.48
Variability of bedtime (h)	1.75(1.40)	1.66(1.46)	1.84(1.36)	.58
Variability of midpoint of sleep (h)	0.99(0.71)	0.96(0.69)	1.01(0.75)	.73
MEQ raw score (higher = morning)	46.24(7.65)	47.16(8.72)	45.41(6.53)	.32

Note. Data presented as Mean (Standard deviation) or frequency (%).

MEQ = Morningness-Eveningness Questionnaire; RAPM = Raven's Advanced Progressive Matrices.

^a Adjusted for mean sleep duration

^{*} *p* < .05

Table 3

Correlations between Actigraphy Variables and Educational Test Outcomes

	Trained items	Knowledge transfer items	Trained items ^a	Knowledge transfer items ^a
Mean sleep duration	.30 ^{**}	.04	.28 [*]	.01
Mean bedtime	-.32 ^{**}	-.21	-.28 [*]	-.17
Mean midpoint of sleep	.16	.16	.13	.12
Variability of sleep duration	-.02	.15	-.05	.12
Variability of bedtime	-.13	.02	-.15	-.001
Variability of midpoint of sleep	-.07	.13	-.10	.11

^a adjusted for economics course history^{*}
p .05^{**}
p .01

Table 4

Subgroup Analyses on Factors That Influenced Susceptibility to Sleep Loss and Later Bedtimes

Grouping variable	Sleep duration – trained items correlations	Bedtime – trained items correlations	Bedtime – knowledge transfer correlations
Female	$r(46) = .39, p = .01^{**}$	$r(46) = -.43, p = .002^{**}$	$r(46) = -.40, p = .01^*$
Male	$r(26) = .11, p = .57$	$r(26) = -.02, p = .93$	$r(26) = .17, p = .38$
Age 18–19	$r(33) = .40, p = .02^*$	$r(33) = -.57, p < .001^{**}$	$r(33) = -.26, p = .13$
Age 20–27	$r(39) = .16, p = .31$	$r(39) = -.14, p = .38$	$r(39) = -.16, p = .31$
RAPM fluid intelligence below median	$r(39) = .41, p = .01^{**}$	$r(39) = -.34, p = .03^*$	$r(39) = -.28, p = .08$
RAPM fluid intelligence above median	$r(32) = -.024, p = .93$	$r(32) = -.03, p = .89$	$r(32) = .08, p = .66$
MEQ self-report morning	$r(24) = .59, p = .002^{**}$	$r(24) = -.43, p = .03^*$	$r(24) = -.30, p = .13$
MEQ self-report evening	$r(48) = .18, p = .21$	$r(48) = -.28, p = .05^*$	$r(489) = -.22, p = .12$

MEQ = Morningness-Eveningness Questionnaire; RAPM = Raven's Advanced Progressive Matrices.

*
 $p < .05$ **
 $p < .01$

Table 5

Interaction Between Moderators and Sleep on Test Performance

Moderator	Sleep duration – trained items relationship	Bedtime – trained items relationship	Bedtime – knowledge transfer relationship
Gender	$R^2 = .03$, $F(1,72) = 2.18$, $p = .15$	$R^2 = .03$, $F(1,72) = 2.54$, $p = .12$	$R^2 = .06$, $F(1,72) = 5.02$, $p = .03^*$
Age	$R^2 = .002$, $F(1,72) = 0.13$, $p = .73$	$R^2 = .01$, $F(1,72) = 0.97$, $p = .33$	$R^2 = .02$, $F(1,72) = 1.33$, $p = .25$
RAPM fluid intelligence	$R^2 = .01$, $F(1,71) = 0.71$, $p = .40$	$R^2 = .01$, $F(1,71) = 0.50$, $p = .48$	$R^2 = .01$, $F(1,71) = 0.96$, $p = .33$
MEQ self-report	$R^2 = .03$, $F(1,72) = 2.26$, $p = .14$	$R^2 = .001$, $F(1,72) = 0.10$, $p = .75$	$R^2 = .001$, $F(1,72) = 0.07$, $p = .80$

MEQ = Morningness-Eveningness Questionnaire; RAPM = Raven's Advanced Progressive Matrices.

*
 $p < .05$