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REGULAR ARTICLE

Temporal Associations Between Daytime Napping and Nocturnal Sleep: An Exploration of Random Slopes

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Abstract

Background Restricting daytime naps is a common sleep hygiene recommendation to improve nocturnal sleep, but research on whether napping is related to sleep is mixed. The current literature is limited in that day level, bidirectional associations have not been tested in college students, and existing studies have not sufficiently examined the role of individual differences in these daily associations.

Purpose The current study addressed these limitations by assessing the temporal associations between self-reported daytime nap duration and objectively assessed nocturnal sleep, and whether these associations were moderated by chronotype or nap frequency, in college students.

Methods Participants (N = 384) self-reported nap duration and wore an actiwatch to measure nocturnal sleep for 14 consecutive days and nights. Mixed linear models were used to test the daily associations between daytime nap duration and total sleep time (TST), sleep onset latency (SOL), sleep efficiency (SE), and wake after sleep onset (WASO). In addition, random slope modeling was used to test whether these associations significantly varied between participants.

Results Longer nap duration was significantly associated with greater WASO, lower SE, and longer SOL. Shorter TST, shorter WASO, and greater SE were related to longer next-day nap duration.

Conclusions There were several significant associations between daytime napping and nocturnal sleep, and nap frequency significantly moderated the association between TST and next-day nap duration. Future research should test daily and contextual moderators of daytime napping and nocturnal sleep, which could refine sleep hygiene efforts by identifying individuals for whom recommendations would be most helpful.

Keywords Sleep · Napping · Multilevel modeling · Individual differences

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Introduction

Sleep hygiene recommendations are a commonly used set of behavioral and environmental recommendations to improve sleep among the general population. However, empirical support for many sleep hygiene recommendations is presently lacking or incomplete [1]. One such recommendation is the avoidance of daytime naps, particularly naps of longer duration or later in the day [2]. However, it is not entirely clear how daytime napping and nocturnal sleep relate to one another, particularly in college students, who may be more susceptible to restricted sleep and have more opportunities for daytime napping [3].

Several cross-sectional [4–7] and experimental [8–11] studies have demonstrated no relationship between napping and nocturnal sleep. In contrast, other studies have found that napping is related to worse self-reported sleep quality [12, 13], increases in sleep onset latency (SOL) [10, 14], reduced sleep efficiency (SE) and sleep duration [15], and short or long sleep duration [16]. These discrepant findings may be due to the inability of these study designs to examine the temporal associations in a naturalistic environment; they cannot test whether daytime napping influences nocturnal sleep, whether nocturnal

sleep influences next-day napping or both. These designs may also not examine the role of contextual factors and individual differences. Aspects of the nap (e.g., duration and timing) and individual differences (e.g., frequent nappers vs. non-frequent nappers) may influence the associations between daytime napping and nocturnal sleep. Studies that collect daily data over an extended period of time allow for the testing of temporal associations between napping and sleep [17] and possible moderators of these relationships.

To date, several studies have tested the daily, temporal associations between daytime napping and nocturnal sleep. Four studies have found bidirectional relationships between daytime napping and nocturnal sleep. In a study of middle-aged adults, daytime napping was associated with lower actigraphy assessed SE but did not influence SOL or sleep duration [18], and duration of the nap had no effect on any sleep outcome. In contrast, a shorter sleep duration predicted more time spent napping the next day. In another study of middle-aged adults, Häusler et al. [19] found that self-reported shorter sleep duration and lower sleep quality increased nap likelihood and duration the next day, while daytime napping had no effect on subsequent night sleep. Jakubowski et al. [20] found that in adolescents between 14 and 19 years old, shorter objective sleep duration predicted longer actigraphy assessed nap duration the following day, and longer daytime naps predicted shorter subsequent night sleep. Sleep continuity was not related to napping in this study. Lastly, Goldman et al. [21] demonstrated in a sample of older adults that actigraphy assessed nocturnal sleep duration and continuity did not predict next-day nap duration, but longer daytime naps were associated with shorter sleep duration that night.

Taken together, results from these day-level studies suggest that there are significant, bidirectional associations between daytime napping and nocturnal sleep. However, results across studies are inconsistent, which may be attributed to several limitations. First, a majority of this research has been conducted in middle-aged and older adults, with the one exception being a study in high school students [20]. To our knowledge, temporal associations between daytime napping and nocturnal sleep have not been tested in college students. It is likely that the relationships between napping and nocturnal sleep differ throughout the lifespan [22]. For instance, it is possible that college students may be more likely to compensate for a night of poor sleep by daytime napping than high school students or older adults, given more flexible schedule demands in college students (e.g., taking a nap in between classes). Second, these studies have tested the temporal relationships across a period of 7–9 days. While seven nights is considered an acceptable time frame to observe naturalistic sleep behavior, longer assessment periods may be more effective in characterizing the associations between daytime napping and nocturnal sleep by providing a more reliable estimate of sleep behavior [23]. This is particularly true when studying a behavior like napping, which may occur in a low frequency [13, 24]. Lastly, the analyses used in these papers tested aggregate effects of the associations between daytime napping and nocturnal sleep. This analytic approach increases the possibility that associations appear to be null, though in reality there may be significant variability of these relationships across the sample. For example, daytime napping may be associated with poor sleep for some individuals, healthier sleep for others, and no relationship for a third group.

Identifying individuals for whom napping impairs nocturnal sleep would help inform the development of individually tailored sleep health promotion efforts. Current sleep health promotion efforts have shown inconsistent results [25, 26] which may be in part due to the use of a "one size fits all" approach [1]. In fact, individually tailored approaches to health behavior promotion may be more effective than non-tailored [27]. Tailored approaches may improve sleep health interventions by effectively targeting at risk individuals or populations and reducing intervention burden on patients with irrelevant information [28]. It is not yet clear which individual differences may moderate these associations, but a recent study that characterized reasons for napping suggested that chronotype (preference for early or late sleep timing) may be an important individual-level factor to consider in the investigation of sleep and napping [29]. Moreover, evening types have been shown to nap more frequently, and for longer durations, than morning types [30], and thus may benefit more from sleep hygiene efforts targeting napping than morning types. Relatedly, it is possible that frequent nappers "habituate" to daytime napping and napping does not impact their nocturnal sleep [1]. However, it is not yet clear whether individual factors like chronotype or nap frequency influence the associations between daytime napping and nocturnal sleep.

The current study aimed to address these limitations by assessing the temporal associations between self-reported daytime napping and objectively assessed nocturnal sleep in college students across a 2-week period. There were two study hypotheses: (a) More time spent napping during the day would be associated with a shorter nocturnal sleep duration, greater wake after sleep onset (WASO), poorer SE, and longer SOL that night. (b) Shorter nocturnal sleep duration, greater WASO, poorer SE, and longer SOL would be associated with more time spent napping the next day. In addition, it is likely that the relationships between daytime napping and nocturnal sleep vary between participants. Thus, random slope models were used to examine whether the intercepts and slopes for each tested association varied between participants, which would indicate that distinct patterns of associations between daytime napping and nocturnal sleep were present across participants. Exploratory analyses testing the impact of chronotype and nap frequency were conducted in models showing

significant slope variability. There were no specific hypotheses for these exploratory analyses.

Methods

Participants

Participants were recruited from a Midwestern university through a subject pool and were eligible to participate if they were non-smokers, were not binge drinkers, were not currently being treated for a sleep disorder, did not have any medical conditions (e.g., migraines, pain) that could affect sleep, and were not shift workers. A sample of 407 participants was recruited for the study. Of these, 23 participants were removed for missing at least half of study nights or invalid actigraphy data (e.g., watch malfunction, withdrew from study early). Participants who were not included in the final analyses were not different from the rest of the sample on any study variables. In the final sample for analyses (N = 384), seven participants had less than 14 days of actigraphy (e.g., withdrew early, protocol nonadherence) but remained in analyses: one participant had nine nights, one participant had 11 nights, two participants had 12 nights, and three participants had 13 nights; 98.2% of participants in the final sample had 14 nights.

Procedure

Data for analyses were from the baseline of a larger parent study that tested the impact of behavioral recommendations (i.e., caffeine restriction, napping restriction, consistent sleep schedule) on sleep health. Data were collected between 2013 and 2017. Participants came to the lab for an initial session in which they provided written informed consent and completed questionnaires assessing chronotype. Participants were then given an actiwatch and received instructions for its care and use. Participants then completed a 2-week baseline assessment in which they wore the actiwatch each night of the study and completed daily bedtime diaries to self-report their nap duration for each day. At the end of the 2 weeks, participants returned to the lab and received course credit for completing the 2-week baseline assessment and continued with the parent study.

Measures

Demographics

Age, gender, and race were self-reported by participants. Age was used as a continuous variable, while gender (0 = male, 1 = female) and race (0= white, 1 = non-white) were dichotomized.

Daytime napping

Each night of the study, participants completed a modified form of the Pittsburgh Sleep Diary [31], in which they self-reported how many minutes they spent napping that day. Days in which participants did not self-report a nap were given a value of 0. Nap frequency was assessed by categorizing participants into one of two groups: frequent nappers (six or more naps during the 2-week study period) and non-frequent nappers (five or less naps during the 2-week study period).

Nocturnal sleep

Objective sleep parameters were measured using actigraphy (Phillips, Bend, OR), a wrist worn accelerometer that uses movement to detect wake vs. sleep states. Actigraphy is an effective tool for objective sleep measurement, particularly for naturalistic sleep assessment in nonclinical samples [32]. Prior to analyses, total sleep time (TST; the number of minutes spent sleeping during the nocturnal rest interval) WASO (number of minutes spent awake during the sleep interval), SE (the percent of time spent asleep between initial sleep onset and final awakening), and SOL (number of minutes taken to fall asleep) were selected as the sleep variables for analyses. Actiwatch devices for this study used 60 epochs with 10 immobile minutes and a medium wake threshold to identify wake versus sleep states. In addition to actiware's algorithms, two steps were taken to ensure the validity of the data. First, participants pressed a marker button each night when they started trying to sleep, and each morning when they were done sleeping. Second, participants self-reported their bedtime and waketime each study day via a morning sleep diary. The marker button, scoring algorithms, and self-report data were used in conjunction with one another to score the rest and sleep intervals.

Chronotype

The 13-item Composite Scale of Morningness [33] is a self-report questionnaire assessing preference for morning versus evening. This scale demonstrated good internal reliability in the present sample ($\alpha = 0.87$). Responses range from 1 to 4 and possible total scores fall between 13 and 55, with higher scores indicating preference for morning chronotype.

Data Analysis

Data Preparation

SPSS version 25 was used for all analyses. Before conducting analyses, outliers for each predictor were identified. Intervals with nap durations of 6 hr or more were excluded from all analyses (6 out of 5,361 data points

had nap durations of this length). The distributions for nap duration, TST, WASO, SE, and SOL were tested for normality. TST was normally distributed (skewness = −0.05(0.03), kurtosis = 1.22(0.07)). Nap duration (skewness = 3.87(0.03), kurtosis = 20.69(0.07)), SOL (skewness = 3.38(0.03), kurtosis = 18.44(0.07)), WASO (skewness = 2.08(0.03), kurtosis= 10.57(0.07)), and SE (skewness = −1.58(0.03), kurtosis= 5.86(0.07)) were not normally distributed. Nap duration, WASO, and SOL were Log10 transformed. SE was square root transformed to make the data conform to normality. The transformed values for nap duration, WASO, SOL, and SE were used in all models in which these variables were a predictor or outcome variable.

Mixed Linear Models

Mixed linear modeling was used to test the temporal associations between daytime nap duration and nocturnal sleep. First, it was tested whether daytime nap duration predicted sleep duration and continuity that night. Four separate linear models were used to test whether daytime napping was associated with same night TST, WASO, SE, and SOL. It was then tested whether sleep duration and continuity predicted next-day nap duration. Four separate linear models were used to test whether TST, WASO, SE, and SOL were associated with next-day nap duration. The lagged variables of TST, WASO, SE, and SOL were entered as fixed effects in each model. Autoregressive heterogeneous covariance structures were used in each model to allow variances to covary at each time point, and random intercepts were used to allow for differences in mean levels for outcome variable across participants.

Random Effect Models

Mixed linear models that test only fixed effects are limited in interpretation, in that it allows only for the testing of the aggregate relationship between predictor and outcome variables. Thus, it does not identify participants for whom the relationships between these variables may differ. In contrast, random slope modeling estimates a slope for each participant, and the range of slopes can be calculated. Thus, random slope models were used to test whether the intercept variance, slope-intercept covariance, and slope variance were significant in each model. A significant intercept variance would indicate that mean levels in the outcome variable significantly differed between participants. A significant slope-intercept covariance would indicate that there is a significant association between the intercept and slope in the model. For example, a significant and negative slope-intercept covariance would indicate that lower values for the intercept are associated with steeper slopes. A significant slope variance would indicate that the relationship between daytime napping and nocturnal sleep significantly varies among participants. Autoregressive heterogeneous covariance structures were used, and participant intercepts and slopes were random. The napping/sleep predictor variable was added as a random effect. For the random slopes, unstructured covariance was used to identify the significance of the intercept, slope, and intercept-slope covariance. This was repeated for all models.

Exploratory Analyses

After demonstrating significant slope variability, an approach to reduce this variance is to add more predictors to the model as both a predictor and moderating variable. This would identify for whom the associations between daytime napping and nocturnal sleep may differ. Exploratory analyses were conducted in an attempt to reduce the slope variance in models that showed significant variability of slopes among participants. Significant moderators that reduce this sleep variance would illustrate for whom the associations between daytime napping and nocturnal sleep may differ. To reduce this slope variance, chronotype and nap frequency were tested in all models that identified significant variability of slopes among study participants. Given multiple comparisons, the p value indicating statistical significance was adjusted to $p < .01$.

Results

Demographics

Most participants were female (55.4%), white (88.5%), were generally short sleepers (on average, 6 hr and 45 minutes per night), and had mostly healthy sleep continuity (see Table 1). Seventy-five (19.5%) participants did not take any naps over the 2-week period and were included in analyses. Participants who did nap, napped on average 3.73 (SD = 2.62) times during the study period and 18.2% of participants were classified as frequent nappers. On days in which a nap occurred, the average duration was 75.88 (SD = 48.10) min, 95% of nappers typically napped for more than 20 min per day, and 20% of napped for more than 100 min per day.

Unconditional Models

Before testing the full models, empty models were run to determine the intraclass correlations at level

1 (within-person, between day) and level 2 (between-person). This identifies how much of the variance in the outcome variable is at each level. Intraclass correlations indicated that 71.27% of the variance in nap duration, 77% in TST, 54.97% in WASO, 58.68% in SE, and 84.27% in SOL existed within persons. Further, 28.73% in nap duration, 23% in TST, 41.32% in WASO, 41.32% in SE, and 15.74% in SOL existed between-persons.

Fixed Effect Models

Output from models of daytime napping predicting nocturnal sleep is displayed in Table 2, and models of nocturnal sleep predicting next-day napping in Table 3.

Table 1 Demographic, sleep, and napping characteristics (N = 384)

Gender, (%)	
Male	44.5
Female	55.2
Age, mean (*SD*), years	18.85 (1.49)
Race, *n*(%)	
White	88.5
Non-white	11.5
Total sleep time, mean (*SD*), minutes	405.29 (40.77)
Wake after sleep onset, mean (*SD*), minutes	47.10 (15.77)
Sleep efficiency, mean (*SD*), percent	83.15 (4.72)
Sleep onset latency, mean (*SD*), minutes	16.47 (10.36)
Percentage of participants who napped at least once	
No	19.5
Yes	80.5
Total naps taken in participants who napped at least once, mean (*SD*)	3.73 (2.62)
Nap duration, mean (*SD*), minutes	16.56 (19.41)
Nap duration on days in which nap took place, mean (*SD*), minutes	75.84 (48.10)
Chronotype, mean (*SD*)	33.34 (6.55)

Daytime nap duration was not significantly associated with TST (b = 1.89, p = .23) or SE (b = −0.03, p = .07) that same night. However, longer daytime nap duration was significantly associated with longer SOL (b = 0.03, p = .001) and greater WASO (b = 0.02, p = .003). SOL was not associated with next-day nap duration (b = 0.01, p = .82). However, longer TST (b = −0.002, p < .001), greater SE (b = −0.05, p = .001), and more WASO (b = −0.34, p < .001) were associated with shorter nap durations the following day.

Random Effect Models

Daytime napping predicting nocturnal sleep

All four models showed significant intercept variance (all ps < .001), demonstrating that mean levels of TST, WASO, SE, and SOL significantly varied between participants (see Table 2). All four models had nonsignificant slope-intercept covariance (all ps > .05). This demonstrates that the associations between the mean levels of sleep duration and continuity are not significantly related to the slope of daytime nap duration. Lastly, one model showed significant slope variance. The slope variance for napping, WASO, SE, and SOL (all ps > .05) was not significant. However, the slope variance for nap duration predicting subsequent TST was significant (p < .001), indicating that this relationship was significantly different between participants. The 95% range of slopes was calculated and showed that 95% of the nap duration slopes fell between bs of −31.90 to 37.80. This demonstrates that the impact of napping on subsequent TST is positive for some participants and negative for others.

Nocturnal sleep predicting next-day nap duration

There were no significant random effects for the associations between nocturnal SE (all ps > .05) or SOL (all ps > .05) and next-day nap duration (see Table 3). In the

Table 2 Fixed and Random Effects of Daytime Napping Predicting Nocturnal Sleep

	Total sleep time	Wake after sleep onset	Sleep efficiency	Sleep onset latency
Fixed effects	*b* (*SE*)	*b* (*SE*)	*b* (*SE*)	*b* (*SE*)
Nap duration	1.89 (1.57)	0.02 (0.00)*	−0.03 (0.01)	0.03 (0.01)*
Random effects	Estimate (*SE*)	Estimate (*SE*)	Estimate (*SE*)	Estimate (*SE*)
Intercept variance	1223.29 (123.83)*	0.02 (0.00)*	0.26 (0.02)*	0.07 (0.01)*
Slope-intercept covariance	−26.10 (83.55)	−0.00 (0.00)	−0.00 (0.01)	−0.00 (0.00)
Slope variance	316.17 (87.76)*	0.00 (00)	0.00 (0.00)	0.00 (0.00)

*p < .01.

All models included the following covariates: age, race, gender.

Table 3 Fixed and Random Effects of Nocturnal Sleep Predicting Daytime Napping

	Fixed effects	Random effects		
		Intercept variance	Slope-intercept variance	Slope variance
	b (*SE*)	Estimate (*SE*)	Estimate (*SE*)	Estimate (*SE*)
Total sleep time	−0.002 (0.00)*	0.64 (0.11)*	−0.00 (0.00)*	1.89 (5.15)*
Wake after sleep onset	−0.34 (0.05)*	1.41 (0.32)*	−0.74 (0.19)*	0.41 (0.11)*
Sleep efficiency	−0.05 (0.02)*	0.13 (0.11)	−0.02 (0.02)	0.01 (0.01)
Sleep onset latency	0.01 (0.02)	0.10 (0.02)	−0.00 (0.01)	n/a

*$p < .01$.

n/a covariance parameter is redundant and cannot be computed.

All models included the following covariates: age, race, gender.

model that tested the association between nocturnal TST and next-day nap duration, there were three significant random effects. First, there was significant intercept variance ($p < .001$), indicating that mean level nap duration differed among participants. There was significant slope-intercept covariance ($p < .001$), indicating that as mean levels of nap duration increased, the TST slope became more shallow. In other words, the more time an individual spends napping, the smaller the impact of TST on next-day nap duration. Lastly, there was a significant slope variance ($p < .001$), indicating that the associations between nocturnal TST and next-day napping significantly varied between participants. The 95% range of slopes was calculated and showed that 95% of the TST slopes fell between *b*s of −2.69 to 2.69. This demonstrates that greater TST predicted longer next-day nap duration for some participants and shorter next-day nap duration for others. The model testing the association between nocturnal WASO and next-day nap duration also had three significant random effects. Similar to the previous model, a significant intercept variance ($p < .001$) demonstrated that mean nap duration differed among participants. The slope-intercept variance was significant ($p < .001$), indicating that as mean levels of nap duration increased, the impact of WASO on next-day nap duration declined. Lastly, a significant slope variance ($p < .001$) demonstrated that the associations between WASO and next-day nap duration significantly varied among participants. The 95% range of slopes was calculated, and 95% of the WASO slopes fell between *b*s of −1.57 and 0.93. This demonstrates that for some participants, longer WASO predicted a longer next-day nap duration, and for others, a shorter next-day nap duration.

Exploratory Analyses

There were three models with significant slope variance that were explored. It was first tested whether factors moderated the association between daytime napping and subsequent TST. Frequent nappers slept significantly less at night ($b = −21.85$, $p < .001$), but frequent napping was not a significant moderator ($b = −2.88$, $p = .60$) and did not reduce the slope variance. Chronotype was not related to sleep duration ($b = 0.14$, $p = .66$) and did not significantly moderate the association between nap duration and TST ($b = −0.27$, $p = .38$). It was then tested whether these factors would moderate the association between TST and next-day nap duration. Nap frequency was a significant predictor ($b = −1.34$, $p < .001$) of nap duration, and significantly interacted with TST ($b = 0.002$, $p < .001$). Specifically, nap durations were longer following nights of low TST in frequent nappers. This interaction did reduce slope variance, but slope variance was still significant in this model ($p = .004$). Chronotype was not related to nap duration ($b = −0.02$, $p = .03$) and did not significantly moderate the association between sleep duration and next-day napping ($b = 4.05$, $p = .07$). Lastly, it was tested whether these factors moderated the associations between WASO and next-day nap duration. Nap frequency was not related to nap duration ($b = −1.40$, $p = .03$) and did not significantly moderate the association between WASO and next-day nap duration ($b = 0.43$, $p = .14$). Chronotype was not related to nap duration ($b = −0.03$, $p = .07$) and did not significantly moderate the association between WASO and next-day nap duration ($b = 0.02$, $p = .12$).

Discussion

Avoidance of daytime naps is often included in sleep hygiene recommendations, although it is not yet clear how daytime napping and nocturnal sleep are bidirectionally associated in college students, and whether individual differences may moderate these associations. The purpose of the current study was to examine the bidirectional relationships between daytime napping and nocturnal

sleep, test whether these daily associations significantly varied between participants, and examine chronotype and nap frequency as moderators in the relationship between daytime napping and nocturnal sleep.

In line with study hypotheses, longer daytime nap duration was related to greater WASO and longer SOL. Contrary to hypotheses, daytime napping was not associated with subsequent TST or SE. The mixed results within the present study are consistent with other studies examining napping and sleep using micro-longitudinal designs, though the specific sleep parameters that are and are not significant vary across studies [18, 20, 21]. In the absence of any clear methodological or sample-based explanations for these different patterns of results, we posit that these discrepant findings may be due to the undetected variability of the effect of napping on sleep between participants. Indeed, the current study was the first to find that the influence of napping on TST significantly varied between participants, with longer daytime napping predicting longer TST for some and shorter TST for others, resulting in an aggregate null effect (i.e., the different slopes cancel each other out making it appear that there is no relationship). However, the extent to which this variability represents systematic differences between participants remains to be seen, as chronotype and nap frequency mostly did not moderate the relationship between daytime napping and nocturnal sleep.

Second, results indicated that longer TST, poorer SE, and greater WASO were all significantly related to shorter nap durations the following day, but SOL was not. This aligns with previous literature that has found longer TST [18–20] was associated with less time spent napping the next day. However, the current study contradicts previous research that did not find SE [20] and continuity [21] to be related to next-day napping. As with the effect of nap duration on subsequent TST, there was significant slope variability among participants in the relationship between nocturnal TST and next-day nap duration, although the overall effect was negative. Nap frequency was a significant moderator, in that nap duration was longest following nights of short sleep in frequent nappers. This may suggest that frequent nappers use naps to make up for a night of restricted sleep, whereas non-frequent nappers may be more likely to participate in other behaviors to compensate for sleep loss (e.g., caffeine consumption). Moreover, there was significant variability in the relationship between WASO and next-day nap duration, but still an overall negative effect. Chronotype and nap frequency were not significant moderators of this association.

Results from this study highlight important considerations in the study of daytime napping and nocturnal sleep. Inconsistent findings across day-level studies may be due to some null associations attributable to significant variability of slopes across study participants. For example, one finding in this study was that there was no relationship between daytime nap duration and subsequent TST. However, further examination of individual slopes suggested that nap duration *was* related to TST, but the direction of this relationship was positive for some participants and negative for others. When all the individual slopes are aggregated into one fixed effect, this can lead to the conclusion that there is no relationship between the two. Thus, accounting for intra-individual variability in these associations can help identify more nuanced relationships between daytime napping and nocturnal sleep.

After identifying significant variability in several relationships, the next step is to identify whether this variability is due to systematic variability or random error. Overall, the moderators tested in the current study (chronotype and nap frequency) did not account for such systematic variability, with just one exception. However, results of random effect models may shed light on some individual differences. For example, among individuals who had higher mean levels of nap duration, previous night's TST and WASO were less predictive of their napping behavior. It may be that napping behavior can become ingrained, and a habitual napper may nap regardless of their previous night's sleep and are instead cued by environmental factors (e.g., coming home in between classes). Indeed, habit theory [34] has received more recent attention in the study of health behaviors but has not yet been applied to sleep [35, 36] or napping. Relatedly, there is not yet consensus on what defines a "frequent" or habitual" napper, and future work could establish this definition across age groups.

Taken together, results from this study should encourage future research to test other factors that may moderate associations between daytime napping and nocturnal sleep. For example, the current study exclusively explored trait moderators, such as chronotype and frequent napping behavior. It is possible that daily factors are more likely to influence the associations between daytime napping and nocturnal sleep. In fact, the intraclass correlations demonstrated that daytime napping and nocturnal sleep may be best predicted by daily (e.g., fatigue, nap timing), and not trait (e.g., chronotype, nap frequency), factors. Identifying individuals for whom napping is detrimental to sleep, or contextual factors that impair sleep, can help refine sleep health promotion and intervention efforts. Future work could examine more contextual factors and individual differences (e.g., insomnia symptoms) that might moderate these associations and create personalized sleep health interventions that recommended nap restriction for whom, or when, it would be most beneficial. In addition, future work could use innovative new approaches to the study of health behavior [37], such as an idiographic approach, to identify

study associations between napping and sleep at the individual level.

There were several strengths to this study. First, this study used actigraphy to measure nocturnal sleep characteristics over 14 consecutive nights. Previous studies have used actigraphy to assess sleep but for only seven [20, 22] or night [19] consecutive nights. While 7–9 nights may be sufficient to adequately capture frequent napping and sleep characteristics [23], 2 weeks provides more reliable estimates of these behaviors. This may be particularly true for daytime napping, which might occur in low frequency [13, 24]. Another strength of the study was the statistical analyses used to demonstrate significant variability in the associations between daytime napping and nocturnal sleep. However, these analyses are limited because the parent study for these data was not conducted to test these questions. An additional limitation is participants' self-reporting of their nap duration, which is subject to recall bias. Only one study has assessed daytime napping with actigraphy [19]. In addition to improving the accuracy of nap duration measurement, objective data collection may allow for more nuanced study of the associations between daytime napping and sleep. For example, future research could examine whether daytime nap architecture is related to subsequent night sleep [6]. Relatedly, nap timing could be examined in future research. It is possible that naps later in the day can have a more negative impact on subsequent sleep by disrupting an individual's late-night sleep drive. Moreover, future work could explore how the associations between daytime napping and nocturnal sleep differ between free days and non-free days in college students. While a strength of our study is its focus on college students, our participants were a healthy, nondiverse sample and these results may not replicate to other college populations. Lastly, given the role of both napping and sleep in public health [1, 38], future research could examine how the interplay between them relates to health.

In conclusion, results from this study add more evidence that daytime napping and nocturnal sleep have reciprocal influence on one another. Moreover, the analyses used in this study suggest that future research ought to consider individual differences when studying these relationships. Identifying individual differences in these relationships can enhance sleep health promotion and intervention efforts by identifying individuals for whom the reduction of daytime napping may be a beneficial target behavior.

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Compliance With Ethical Standards

Authors' Statement of Conflict of Interest and Adherence to Ethical Standards Authors Michael P. Mead, Phat Huynh, Trung Le, and Leah A. Irish declare that they have no conflict of interest. All procedures, including the informed consent process, were conducted in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2000.

Ethical Approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent: Informed consent was obtained from all individual participants included in the study.

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