

Too long, too short, or too variable? Sleep intraindividual variability and its associations with perceived sleep quality and mood in adolescents during naturalistically unconstrained sleep

Running title: Sleep variability and mood in adolescents

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ABSTRACT

Study Objectives. Research has extensively examined the relationship between adolescents' mental health and average sleep duration/quality. Using rigorous methodology, this study characterized adolescents' objective sleep intraindividual variability (IIV), and examined its role on mood beyond the effects of mean sleep parameters.

Methods. 146 community-dwelling adolescents (47.3% male) aged 16.2 ± 1.0 ($M \pm SD$) years wore an actigraph that assessed bedtime, risetime, time-in-bed (TIB), and sleep onset latency (SOL) throughout a 15-day vacation with relatively unconstrained sleep opportunity. Self-report sleep quality (SSQ), negative mood (MOOD), and other covariates were assessed using questionnaires. For each sleep variable, individuals' mean values and IIV were used to simultaneously predict MOOD with SSQ as a mediator. Models were estimated in a Bayesian IIV framework; both linear and quadratic effects of the mean and IIV were examined.

Results. Longer and more variable TIB, as well as more variable SOL (but not mean SOL), were associated with poorer SSQ ($ps < .01$), which in turn, was associated with more negative MOOD ($ps < .05$). The indirect effect of SOL IIV was curvilinear, such that as SOL became more variable, the deteriorating effect of high SOL IIV accelerated. Neither bedtime nor risetime IIV was significantly associated with SSQ or MOOD.

Conclusions. During relatively unconstrained sleep opportunity, more variable TIB and SOL were associated with more negative mood, mediated by poorer perceived sleep quality. Significant effects of IIV were over and above that of mean values, suggesting that unique aspects of sleep IIV are relevant to how adolescents perceive sleep quality and their mood.

Key Words: intraindividual variability, mood, depression, anxiety, sleep, adolescents, sleep restriction, vacation.

STATEMENT OF SIGNIFICANCE

This is the first study to examine adolescents' naturalistic sleep intraindividual variability (IIV) without the constraints of school schedules. We found that more variable sleep duration and sleep onset latency (SOL), independent of their mean values, were associated with more negative mood, mediated by poorer perceived sleep quality. Notably, the association between SOL IIV and mood was curvilinear, such that as SOL became more variable, its mood-worsening effect via perceived sleep quality, accelerated. These findings highlighted the importance of sleep IIV in relation to adolescents' perceived sleep quality and mood, and raised the possibility that reducing IIV of sleep duration and onset latency may reduce sleep complaints and improve mood in adolescents.

INTRODUCTION

Restricted mean sleep duration and/or poor mean sleep quality have been consistently linked to negative mood and mental health problems in adolescents¹⁻⁴. Less is known about the relationship between intraindividual variability (IIV; variations around the mean) of sleep and mood disturbance. In adolescents, sleep IIV can be decomposed into two distinct components. The first is major changes during the transition between school- and non-school days (e.g., weekday-weekend difference where sleep timing is typically earlier, and duration shorter on weekdays)^{1,5-7}. This type of change from one condition (i.e., school days) to another (i.e., non-school days), although sometimes referred to as “variability” or “irregularity”, are more consistent with disturbance to the *means* of sleep parameters, and have been well examined.

The second, and much less understood component, is the *daily* IIV of sleep that is *not* accounted for by school schedules. Variable daily sleep patterns may be associated with sleep restriction and/or circadian misalignment, both of which are known to be associated with negative mood^{8,9}. From a physiological perspective, both sleep restriction/deprivation and circadian misalignment have been associated with higher inflammatory biomarkers^{10,11}, and inflammatory responses have been suggested in the pathophysiology of depression^{12,13}. Further, sleep restriction and circadian misalignment related to variable *daily* sleep patterns may be more chronic and cumulative compared to the typically short-lasting weekday-weekend changes in sleep. In adults, where weekday-weekend differences are less pronounced, more variable sleep patterns have been associated with poorer health, mental health, and insomnia (see a systematic review¹⁴). The limited studies on sleep IIV in adolescents have linked more variable sleep duration to poorer mood¹⁵, higher BMI¹⁶ and abdominal obesity¹⁷, and possibly, based on a recent brain imaging study, altered brain development¹⁸. A recent systematic review of the

correlates of sleep IIV in children and adolescents¹⁹ further echoes the relevance of sleep IIV, and the need for further research.

Studying the relationship between daily sleep IIV and mood in adolescents in the absence of school-related sleep restriction (i.e., vacation) has the following advantages: (a) school start times result in sleep restriction and externally constrained, and often low, intra- *and* inter-individual variability in daily sleep⁵, (b) a typical school week contains only five daily sleep measures before a mean shift in sleep patterns is brought about by the weekend, which could lead to unreliable estimate of IIV due to an insufficient number of observations²⁰, and (c) as we have previously demonstrated, the strong influence of school schedules on adolescents' sleep/wake behaviors can mask potential associations between sleep, and both emotional²¹ and behavioral²² correlates.

To the best of our knowledge, no study has examined sleep IIV in the absence of changes in school schedule constraints. Further, existing studies have several limitations. For example, many studies have not controlled for individual means when the effects of IIV were examined. The mean and IIV are often correlated, especially for variables with skewed distribution²³ (e.g., SOL), thus the unique effects of one is best established while controlling for the other. Also, most studies quantified IIV using methods (e.g., standard deviation) with significant limitations, such as low reliability and inadequately treatment of missing data²⁰. Finally, there is a lack of understanding as to whether greater variability is always associated with deleterious outcomes, or whether such associations are linear or nonlinear. Depending on contexts, high IIV can be theorized as being either adaptive or nonadaptive²⁴. Therefore, both linear and nonlinear associations between sleep IIV and outcomes of interest should be considered.

This study examined IIV in objectively assessed sleep in relation to adolescents' mood and subjective sleep during school vacations, a time during which sleep opportunities have been shown to be relatively unconstrained⁵. Objectively and subjectively assessed sleep were examined simultaneously, because perceived sleep quality has been demonstrated in this population to be a key mechanism through which objective sleep is associated with negative mood²¹. It was hypothesized that (1) after adjusting for potential confounds and mean sleep parameters, more variable sleep patterns would be associated with poorer perceived sleep quality and more negative mood, and that (2) subjective perception of sleep quality would mediate the relationship between sleep IIV and negative mood. The conceptual model is shown in Figure 1. These hypotheses were formulated based on our published model linking mean sleep characteristics and negative mood in the same manner²¹. In this study, both linear and quadratic effects of sleep IIV were examined simultaneously, with the latter being an exploratory aim.

[INSERT FIGURE 1 HERE]

METHODS

The study was approved by the Human Research Ethics Committee of the University of Melbourne, and informed consent was obtained from participants and their parents/guardians. Adolescents enrolled in Years 10-12 of Australian secondary colleges were recruited via flyers and school e-newsletters from the community, with two movie vouchers per person as incentives. Data for the study were collected over five two-week vacations, excluding summer vacations, with each participant contributing a single vacation. Participants were asked to register bedtimes and risetimes using the actigraph's Event Marker and to wear the actigraph on the non-

dominant hand continuously throughout the two-week period. Self-report measures were conducted via online survey within the second week of the vacation.

Equipment and Materials

Actigraphy. Data were collected at one-minute epochs using Mini Mitter Actiwatch 2 or Actiwatch-64 (Bend, OR, USA) with comparable statistics²⁵, and analysed based on “medium” threshold for sleep/wake detection in Actiware 5.5. The following variables were generated: bedtime (BT), risetime (RT), time-in-bed (TIB), and sleep onset latency (SOL; see previous publication⁵ for details on data processing). They were examined because of their direct relevance to behavioral aspects of sleep. Data between the Saturdays at the start and the end of the vacation (15 days) were included in analyses.

Subjective sleep. The Pittsburgh Sleep Quality Index²⁶ was used to assess subjective sleep quality. Raw values for self-report SOL (minutes), sleep efficiency (%), sleep disturbance (sum of items 5b-5j), sleep quality (item 9), and sleep-related daytime dysfunction (item 7) were standardized and summed to represent subjective sleep quality (SSQ). Item 8 on motivation was not included to reduce overlap with mood.

Negative mood. A negative mood composite score (MOOD) was created by standardizing and summing two scales that are well validated in adolescent populations: the Centre for Epidemiological Studies Depression Scale²⁷ (excluding the sleep item to reduce overlap with sleep) and Spence Children’s Anxiety Scale²⁸. The two scales correlated highly at .68, and both scales had excellent reliability in this study ($\alpha > .90$ for both).

Covariates. Frequency of experiencing adolescent-relevant everyday hassles was measured using the total score from the 41-item Inventory of High-School Students’ Recent Life Experiences²⁹ (e.g., “disagreements with friends”, $\alpha = .95$). Chronotype was assessed using the

Morningness–Eveningness Questionnaire ($\alpha=.80$)³⁰. Other covariates were age, sex, race (white/non-white), and self-reported presence of current psychiatric or sleep condition (labelled as “comorbidity” in subsequent text). Selection of these covariates was based on findings from our recent systematic review on the correlates of sleep IIV¹⁴.

Statistical Analyses

Estimating IIV. Indexes of IIV (e.g., individual standard deviations³¹) tend to have poor reliability, which, unless accounted for, reduces power and results in biased estimates. To account for unreliability in estimating IIV, analyses were conducted using a purpose-built Bayesian framework²⁰. First, a multilevel Bayesian model was fit to each sleep variable with a random intercept (capturing individual means) and a random residual variability (capturing IIV). The dependent variable (i.e., each sleep variable) and the random intercept were assumed to come from a Gaussian (normal) distribution. Random residual IIVs were modeled using a Gamma distribution, as IIV is bounded by zero and often has a long right tail. Second, the random intercepts and random residual IIVs were entered with covariates to predict outcomes. The entire model was estimated simultaneously, allowing the unreliability of IIV estimates to be accounted for. Missing data are handled in the multilevel Bayesian IIV models, which use all available data, such that individuals missing one or more days were not excluded from analyses. Analyses were conducted using R v3.3.0³² and Stan³³ v2.10.0 via the R packages *varian* v0.3.0 and *rstan* v2.10.1. For technical details please refer to our previous technical report²⁰ and the *varian* package.

Analytic plan. The conceptual model in Figure 1 was tested for each sleep variable. Individual means (denoted with the suffix “m”, e.g., TIBm) and IIV (denoted with the suffix “v”, e.g., TIBv) were estimated using methods described above; their linear and quadratic terms were

simultaneously entered along with covariates in regressions on SSQ and MOOD. Quadratic terms that were not statistically significant were dropped in the final models, and the linear term was interpreted. Mediated relationships were assessed using indirect effects. In the case of statistically significant quadratic terms for IIV, simple indirect effects across the range of IIV values were estimated and plotted. Results were considered statistically significant at $p < .05$.

RESULTS

Sample characteristics. 146 adolescents (47.3% males) with an average age of 16.18 ($SD = 1.00$) years were recruited. They were primarily of Australian (59.6%) or Asian (26.7%) descent. Overall, the sample was healthy, with 90.4% scoring under the clinical cutoff for depressive symptoms³⁴, and 91.8% within the normal range for anxiety symptoms²⁸. One female was excluded due to the presence of multiple sleep disorders and daily naps. A small number of participants reported having a depressive, anxiety, or attention deficit hyperactivity disorder (6.2%), or insomnia/hypersomnia (5.5%) at the time of recruitment. To retain the representativeness of a community sample, these conditions were not excluded, but their presence was controlled for.

Fifteen (10.3%) participants reported activities affecting their vacation sleep timing on some days, and in total, this occurred for 0.6% of all BT and 1.9% of all RT. This is in contrast to school terms, during which the majority of participants reported having school and extra-curricular activities starting 08:30-09:00 (84.3%) and finishing 15:00-16:00 (82.9%).

The rate of missing data was low for both questionnaires (<1.5% for all scales) and total actigraphy daily records (7.1%). Table 1 summarizes descriptive statistics of all variables used.

[INSERT TABLE 1 HERE]

Visual representations of IIV. The panels in the left column of Figure 2 provide graphic description of raw data obtained from two individuals that fell in the high (80th) and low (20th) percentiles of sleep IIV. The panels in the right column of Figure 2 show the sample distribution across different levels of IIV.

[INSERT FIGURE 2 HERE]

Sleep timing. For sleep timing (BT and RT), none of the quadratic terms were statistically significant (all $p > .20$), and therefore only linear terms were considered. Neither BTm nor BTv were related to SSQ or MOOD (all $p > .15$). The mean ($b = .41, p = .020$) but not IIV ($p = .352$) of RT was related to poorer SSQ. Neither RTm nor RTv were directly associated with MOOD (both $p > .40$), but later RTm (but not RTv) was indirectly related to poorer MOOD via SSQ ($b = .03, p = .023$).

[INSERT TABLE 2 HERE] [INSERT FIGURE 3 HERE]

Sleep duration. Findings for sleep duration are summarized in Table 2 and displayed in Figure 3 (top panel). All quadratic terms for TIB (mean or IIV) were non-significant (all $p > .05$), and were therefore dropped from the final model. Both longer TIBm and more variable TIBv were associated with poorer SSQ ($p < .05$). Poorer SSQ was associated with poorer MOOD ($p = .001$). There was a significant indirect relationship between TIBm and MOOD via SSQ (b

[95% CI] = .13 [.04, .24], $p = .001$). There was also a significant indirect relationship between TIBv and MOOD via SSQ (b [95% CI] = .15 [.02, .34] $p = .014$). These results showed that poorer perceived sleep quality mediated the relationship between sleep duration (for both mean and IIV) and MOOD. Controlling for SSQ and TIBm, greater TIBv was directly associated with *better* MOOD ($p = .036$); the direct effect of TIBm on MOOD was not significant ($p = .74$).

Sleep onset latency. Findings for SOL are summarized in Table 2 and displayed in Figure 3 (bottom panel). The quadratic terms for SOLm were non-significant (both $p > .70$) and were dropped. The quadratic term for SOLv was significantly associated with SSQ ($p = .006$), but not with MOOD ($p = .509$). The average indirect effect of SOLv on MOOD via SSQ was significant ($b = .28$, 95% CI [.00, 1.31]). However, the quadratic relationship between SOLv and SSQ indicated a curvilinear (rather than linear) relationship, such that the indirect effect was higher for those with greater SOLv (see Figure 4). The indirect relation between SOLv and MOOD was statistically significant for those with a SOLv of 5.89 or greater (shaded areas in Figure 4).

[INSERT FIGURE 4 HERE]

DISCUSSION

During a period of relatively unconstrained sleep opportunity, more variable actigraphy TIB and SOL were associated with more negative mood, a relationship that was mediated by poorer perceived sleep quality. Notably, significant effects of IIV in this study were over and above the effect of means. This suggests that unique aspects of sleep IIV are relevant not only to how adolescents perceive sleep quality, but also sleep-related mood disturbances.

Our findings of associations between TIBv, SOLv, and negative mood among adolescents during vacation are consistent with similar findings in adults¹⁴, and in adolescents during

periods when sleep is constrained by school schedules¹⁵. Although we found that later RTm was associated with worse perceived sleep and indirectly, worse mood, we did not find a significant association between sleep timing IIV and MOOD. This is consistent with mixed findings in adults, where more variable sleep timing was associated with greater depressive symptomatology in an older³⁵ but not younger³⁶ cohort. Considering the developmental context of adolescence, sleep restriction and circadian misalignment, two prominent features of sleep on school days, are not likely to be common during the sampling period. Relatively unconstrained sleep opportunities and potentially well aligned sleep timing against circadian phase may be protective of mood, and contributed to the weak associations between sleep timing IIV and mood observed in this study.

A novel finding of the current study was that the associations between negative mood and actigraphy-measured TIBv and SOLv were *fully* mediated by perceived poor sleep. Although our design did not allow us to explore potential physiological mechanisms, it did allow us to explore explanatory psychological factors that were found to play an important role in the sleep-mood relationship. That is, both the mean²¹ *and* the daily variability of sleep are associated with adolescents' perceived sleep quality. From a clinical perspective, this raises the possibility that targeting sleep-related behaviors may reduce sleep complaints and improve mood. For example, adolescents can be encouraged to prioritize sleep, dedicate time to unwind before bedtime to facilitate consistent sleep onset and reduce day-to-day variability in time to fall asleep.

Further, the indirect effect of SOL was curvilinear (see Figure 4): when SOL IIV was relatively low (individual standard deviation < 5.89 minutes), it did not have a significant effect on perceived sleep quality or mood; however, as SOL became more variable, the deteriorating effect of high SOL IIV accelerated. This finding suggests that for the small number of

adolescents (unshaded area in Figure 4) whose SOL IIV was low, daily variation in SOL may be a natural part of sleep/wake patterns and be of little concern. However, for the majority of adolescents (shaded area in Figure 4), variable SOL may be associated with sleep complaints and mood disturbance.

It is worth noting that although more variable daily behavioral patterns have been associated with better outcomes in other contexts³⁷, we did *not* find a “J” or “U” shaped association between the IIV of sleep variables and the outcomes examined. Without controlling for SSQ, either the association was nonsignificant, or greater IIV was associated with worse perceived sleep quality and indirectly, mood. However, when SSQ was controlled for, more variable TIB was associated with *less* negative mood. This counter-intuitive finding suggest that variable sleep duration, when not associated with sleep complaints, might be associated with behaviors that are protective of mood (e.g., evening social events) or reflect higher functioning (e.g., part-time work). There seems to be a complex etiology in the relationship between sleep IIV and its consequences in different contexts.

There are several limitations to this study. First, IIV was sampled in only one condition (i.e., vacation), and it is not possible to ascertain causal directions. Second, this naturalistic, observational study, measured sleep IIV during a period when adolescents have relatively high control over their own sleep/wake patterns. Although this makes findings highly relevant to how adolescents regulate their own behaviors in the real world, in order to understand how adolescents respond to externally imposed sleep IIV (e.g., how variable sleep patterns affect an individual whose sleep is usually stable), experimental studies that manipulate the degree of sleep IIV would be required. Third, data were collected at different times of the year. Sensitivity analyses, whereby season was included as an additional covariate, yielded the same findings.

However, results may not generalize to summer, as only non-summer seasons were included in this study. Finally, participants were mostly older adolescents, limiting generalizability of findings to other conditions/contexts or younger cohorts.

Using longitudinal repeated measures design and advanced analytics, we demonstrated that daily IIV of sleep duration and onset latency, in the absence of school-related sleep restriction, are relevant to adolescents' perceived sleep quality, and indirectly, mood. Effective interventions that improve sleep behaviors could improve sleep and promote wellbeing in adolescents. Intervention studies that incorporated measures of sleep IIV showed that treatment protocols that aimed to improve sleep in adolescents also tended to reduce sleep IIV^{38,39}. Findings in this study underscore the importance of interventions that directly target reduction of variable sleep/wake patterns in adolescents, and further research on the nature and consequences of daily IIV in adolescents. To that end, it will be important to incorporate IIV as a second dimension, in addition to the mean, when studying sleep/wake behaviors and their consequences in adolescents.

ABBREVIATIONS

BT, bedtime

IIV, intraindividual variability

Suffix "m" denotes the individual means of a sleep variable

MOOD, negative mood

RT, risetime

SOL, sleep onset latency

SSQ, self-report sleep quality

TIB, time-in-bed

Suffix “v” denotes intraindividual variability of a sleep variable

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Table 1
Descriptive Statistics of Variables Used

	Descriptive Statistics		
Sex	52.7% female		
Age	16.18 ± 1.00 years		
Race/Ethnicity	Australian/New Zealand: 59.6%		
	Asian: 26.7%	European: 5.5%	Middle Eastern: 2.1%
	African: 2.1%	Other: 4.1%	
Actigraphy sleep variables	BT = 00:38 ± (1:21) am	RT = 09:37 ± (1:20) am	
	TIB = 8.98 ± 0.83 hours	SOL = 20.84 ± 13.39 minutes	
PSQI Global	5.62 ± 2.94		
MEQ (chronotype)	48.25 ± 8.51		
CES-D (depressive symptoms)	11.23 ± 8.40		
SCAS (anxiety symptoms)	19.08 ± 13.56		
IHSSRLE (everyday hassles)	68.55 ± 19.61		

Note. BT = bedtime, RT = risetime, TIB = time-in-bed, SOL = sleep onset latency, PSQI = Pittsburgh Sleep Quality Index, global PSQI scores were provided for reference only, and were not used for any analysis; MEQ = Morningness-Eveningness Questionnaire, CES-D = Centre for Epidemiologic Studies Depression Scale, SCAS = Spence Children's Anxiety Scale, IHSSRLE = Inventory of High School Students' Recent Life Experiences.

Table 2

Summary of Path Coefficients for Time-in-Bed and Sleep Onset Latency Primary Analysis Models

Outcome	Predictor	TIB Model	SOL Model
SSQ	IIV Linear	1.55 [0.33, 2.77], 0.013	-0.29 [-0.61, 0.03], 0.077
	IIV Quadratic	Nonsignificant, dropped.	0.01 [0.003, 0.02], 0.006
	Mean Linear	1.28 [0.63, 1.95], < .001	0.03 [-0.06, 0.11], 0.504
	Mean Quadratic	Nonsignificant, dropped.	Nonsignificant, dropped.
	Sex	0.55 [-0.21, 1.34], 0.158	0.80 [0.10, 1.52], 0.025
	Age	0.21 [-0.15, 0.58], 0.236	0.14 [-0.19, 0.48], 0.389
	Hassles	0.06 [0.04, 0.08], < .001	0.05 [0.03, 0.07], < .001
	MEQ	-0.03 [-0.08, 0.01], 0.167	-0.04 [-0.08, 0.01], 0.101
	Race	0.97 [0.20, 1.70], 0.016	1.15 [0.44, 1.88], 0.002
	Comorbidity	-0.14 [-1.30, 1.02], 0.825	-0.07 [-1.16, 1.03], 0.899
MOOD	IIV Linear	-0.39 [-0.75, -0.03], 0.036	0.04 [-0.06, 0.14], 0.399
	IIV Quadratic	Nonsignificant, dropped.	-0.001 [-0.004, 0.002], 0.509
	Mean Linear	-0.04 [-0.25, 0.17], 0.738	-0.02 [-0.05, 0.01], 0.157
	Mean Quadratic	Nonsignificant, dropped.	Nonsignificant, dropped.
	SSQ	0.10 [0.04, 0.15], 0.001	0.09 [0.02, 0.16], 0.013
	Sex	0.34 [0.12, 0.56], 0.002	0.34 [0.12, 0.56], 0.003
	Age	-0.05 [-0.16, 0.06], 0.364	-0.07 [-0.17, 0.04], 0.198
	Hassles	0.02 [0.02, 0.03], < .001	0.02 [0.02, 0.03], < .001
	MEQ	-0.003 [-0.02, 0.01], 0.661	0.002 [-0.01, 0.01], 0.795
	Race	-0.07 [-0.29, 0.16], 0.557	-0.09 [-0.33, 0.16], 0.491
	Comorbidity	0.04 [-0.29, 0.37], 0.803	0.07 [-0.27, 0.41], 0.679

Note. Unstandardized path coefficient [95% confidence interval], *p*-values are shown (statistically significant coefficients are in bold font). Indirect effects are described in the text and displayed in Figure 4 for the SOL model. SSQ = Subjective Sleep Quality, MOOD = Negative Mood composite score, TIB = time-in-bed, SOL = sleep onset latency, IIV = intraindividual variability of the sleep variable, Mean = individual mean of the sleep variable. “Linear” and “Quadratic” indicate the linear and quadratic terms that were tested. Quadratic terms that were not statistically significant were dropped in the final model, and the effects of the linear terms were then interpreted. Shaded rows are covariates controlled for; among these, dummy coded variables are: sex (0 = male, 1 = female), race (0 = non-white, 1 = white), and comorbidity (absence [0] or presence [1] of self-reported sleep/psychiatric disorder).

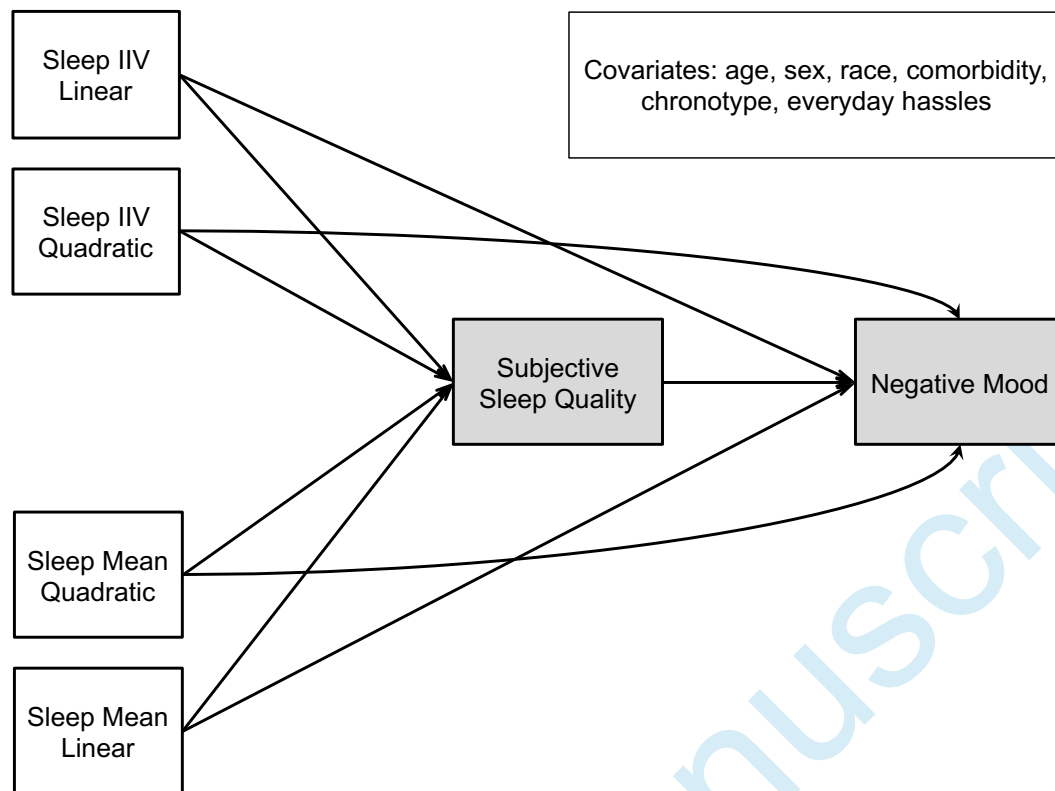


Figure 1. Mediation models tested for bedtime, risetime, time-in-bed, and sleep onset latency. For each sleep variable, both the linear and quadratic effects of both the individual mean and intraindividual variability (IIV) were entered as independent variables, with Negative Mood as the dependent variable, and Subjective Sleep Quality as a mediator.

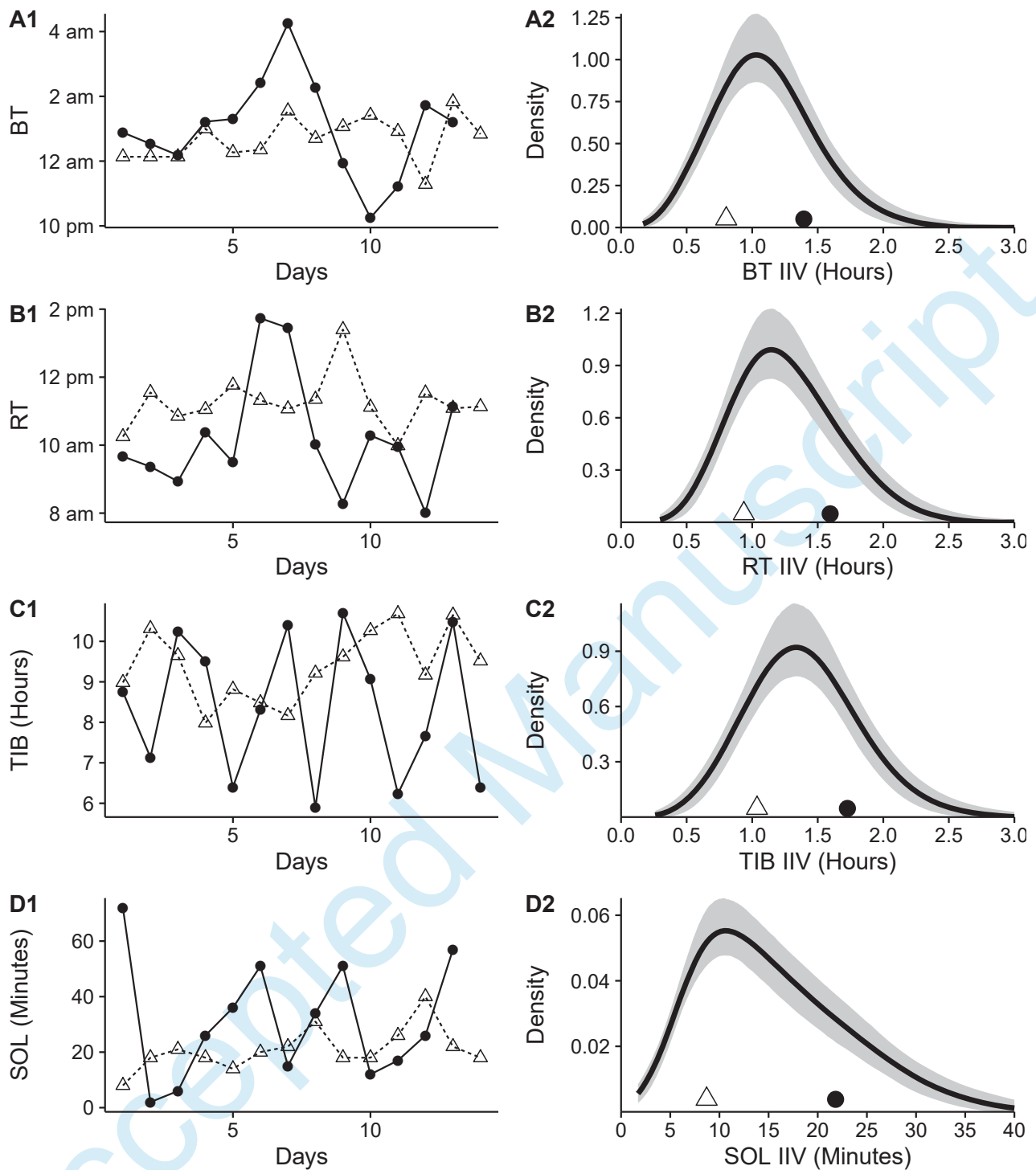


Figure 2. Daily data for bedtime (BT), risetime (RT), time-in-bed (TIB), and sleep onset latency (SOL) are plotted in rows A, B, C, D respectively. Left column: daily data for typical individuals with high (80th percentile, ●) and low (20th percentile, △) intraindividual variability (IIV). Right column: sample distributions across different levels of IIV; the sum of areas under the curve is 1 (100%); x-axis shows IIV (i.e., model estimated individual standard deviation), with the example high and low IIV individuals scores signified by ● and △ respectively for comparison.

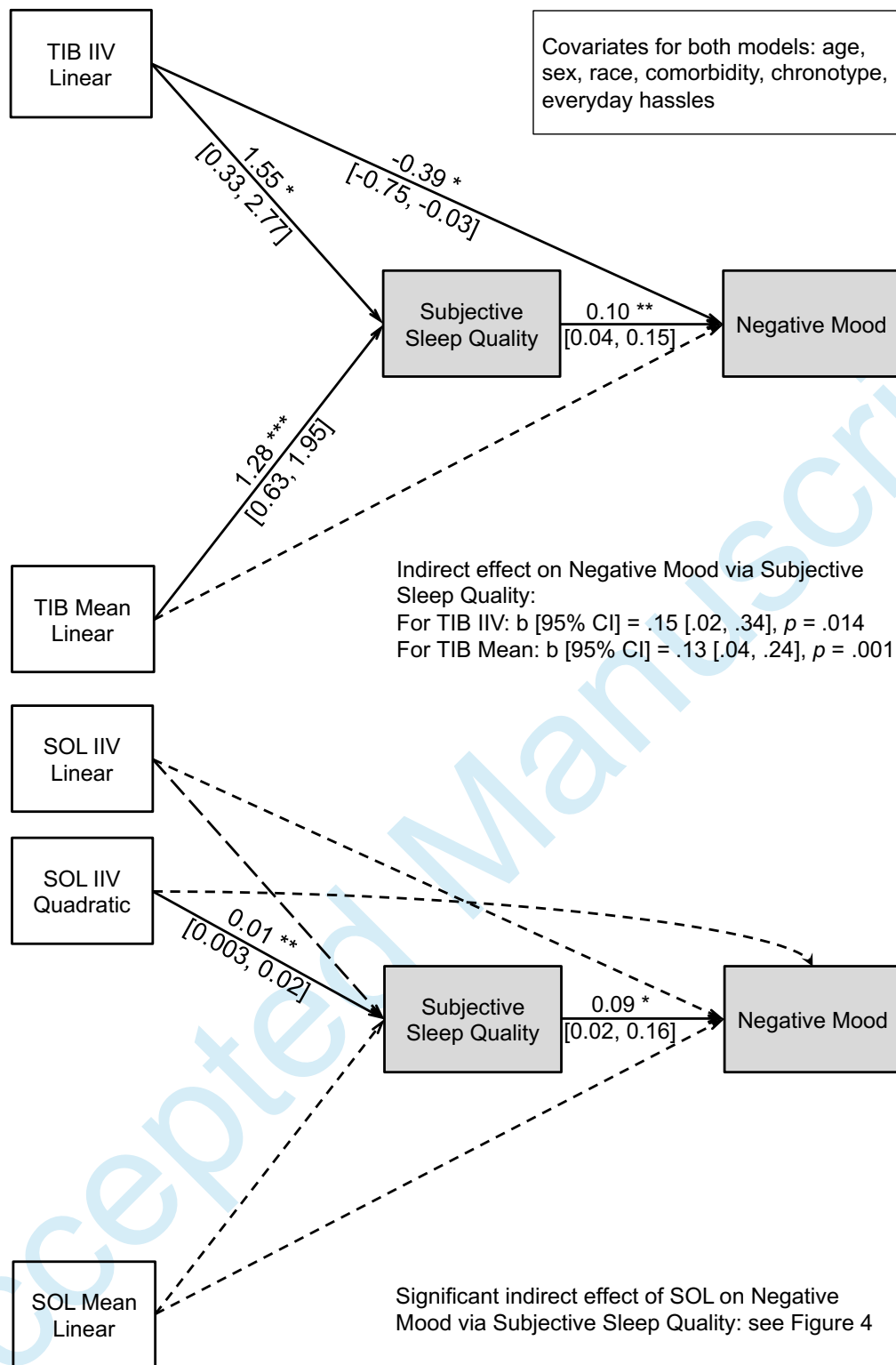


Figure 3. Mediation models showing the effects of the intraindividual variability (IIV) and individual mean of actigraphy assessed time-in-bed (TIB) and sleep onset latency (SOL) on negative mood via Subjective Sleep Quality. Unstandardized coefficients [95% confidence interval] are shown. Solid lines indicate statistically significant paths, dotted lines indicate non-significant paths, long dashed line from SOL IIV Linear to Subjective Sleep Quality indicates conditional effect of SOL IIV Linear when SOL IIV is held at zero (for more details see Figure 4); * p < .05, ** p < .01, *** p < .001.

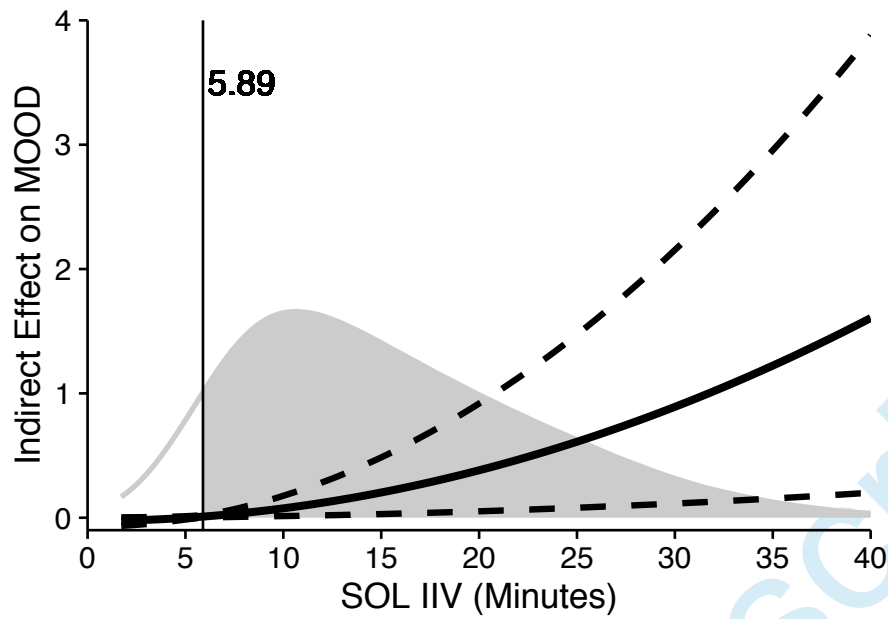


Figure 4. The indirect effect of sleep onset latency (SOL) on negative mood (MOOD) via subjective sleep quality. Solid black line indicates the indirect effect when SOL intraindividual variability (IIV; i.e., model estimated individual standard deviation) is at different levels. Dotted lines are 95% confidence intervals of the indirect effect. Population distribution of SOL IIV was plotted in grey shades for reference. When estimated standard deviation of SOL was above 5.89 (the shaded area of the population), the indirect effect was statistically significant, and subjective sleep quality mediated the relationship between SOL IIV and MOOD.