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Sleepless nights, sour moods: daily sleep-irritability links in a pediatric clinical sample

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Background: Sleep, or a lack thereof, is strongly related to mood dysregulation. Although considerable research uses symptom scales to examine this relation, few studies use longitudinal, real-time methods focused on pediatric irritability. This study leveraged an ecological momentary assessment (EMA) protocol, assessing bidirectional associations between momentary irritability symptoms and daily sleep duration in a transdiagnostic pediatric sample enriched for irritability. **Methods:** A total of $N = 125$ youth ($M_{age} = 12.58$ years, $SD = 2.56$ years; 74% male; 68.8% White) completed digital, in vivo surveys three times a day for 7 days. For a subset of youth, their parents also completed the EMA protocol. Trait irritability was measured using youth-, parent-, and clinician-report to test its potential moderating effect on the association between sleep duration and momentary irritability. **Results:** Results from multilevel modeling dynamically linked sleep to irritability. Specifically, according to youth- and parent-report, decreased sleep duration was associated with increased morning irritability ($bs \leq -.09$, $ps < .049$). A bidirectional association between parent-reported nightly sleep duration and anger was found—increased evening anger related to decreased nightly sleep duration, and decreased sleep duration related to increased morning anger ($bs \leq -.17$, $ps < .019$). Trait irritability moderated this association, which was stronger for more irritable youth ($b = -.03$, $p < .027$). **Conclusions:** This study adds to the literature and suggests sleep-irritability dynamics as a potential treatment target. **Keywords:** Irritability; sleep; temporal links; anger; ecological momentary assessment.

Introduction

Adequate sleep supports optimal psychological functioning in youth (Goldstein & Walker,2014; Wheaton & Claussen, 2021). Yet, many youth fail to obtain sufficient sleep (Crowley, Wolfson, Tarokh, & Carskadon, 2018; Wheaton & Claussen, 2021). Sleep impacts emotion regulation and affective processes, including negative mood and anger (Baum et al., 2014; Konjarski, Murray, Lee, & Jackson, 2018; Kouros, Keller, Martín-Piñón, & El-Sheikh, 2022; Palmer & Alfano, 2017; Short, Booth, Omar, Ostlundh, & Arora, 2020; Short & Louca, 2015; Tomaso, Johnson, & Nelson, 2021). Inadequate sleep duration relates specifically to mood dysregulation (Asarnow & Mirchandaney, 2021; Short et al., 2020) and a range of psychiatric diagnoses (Craig, Weiss, Hudec, & Gibbins, 2020; Gregory & Sadeh, 2012). However, at this time, much of the research on youth focuses on unidirectional, retrospective relations between sleep and mood dysregulation (Asarnow & Mirchandaney, 2021; Short et al., 2020). Furthermore, there is a lack of work investigating reciprocal, prospective associations between sleep and pediatric irritability, a phenotype of mood dysregulation.

Irritability, an increased proneness to anger relative to peers, is a common transdiagnostic symptom (Brotman, Kircanski, Stringaris, Pine, & Leibenluft, 2017; Evans, Corteselli, Edelman, Scott, & Weisz, 2023). Children and adolescents with high levels of irritability tend to be easily angered and annoyed, have decreased thresholds for frustration, and exhibit grouchy mood. Understanding the role of sleep in irritability has clinical implications, as it is an easily targeted and modifiable behavior (Short et al., 2020; Whiting, Bellaert, Deveney, & Tseng, 2023). Limited previous work has studied sleep problems (e.g., insufficient duration, daytime sleepiness, delayed onset) and irritability in typically developing youth (Baum et al., 2014; Beebe et al., 2008; Rubens, Evans, Becker, Fite, & Tountas, 2017; Tamura, Komada, Inoue, & Tanaka, 2022) or in the context of one specific clinical diagnosis (e.g., anxiety disorders or depression or attention-deficit/hyperactivity disorder [ADHD] or autism spectrum disorder; Loram et al., 2021; Mazurek & Sohl, 2016; Mulraney, Zendarski, Mensah, Hiscock, & Sciberras, 2017; Poznanski et al., 2018). Two studies have investigated sleep behaviors in the context of youth with disruptive mood dysregulation disorder (DMDD; Delaplace et al., 2018; Estrada-Prat et al., 2017), a diagnosis characterized by severe and chronic irritability. Results indicated fragmented sleep (i.e., nighttime awakenings, increased motor activity) in this clinical sample (Delaplace et al., 2018; Estrada-Prat et al., 2017). Few of the studies that investigated sleep and irritability

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implemented a validated irritability-specific measure (Loram et al., 2021; Rubens et al., 2017; Whiting et al., 2023). Additionally, much of the prior research on sleep and irritability used retrospective methods, while including one specific clinical group (Loram et al., 2021; Mazurek & Sohl, 2016; Mulraney et al., 2017; Poznanski et al., 2018), representing a critical gap in the literature.

Hence, in the current study, we used ecological momentary assessment (EMA) to investigate relations between sleep duration and irritability that are measured in real-time, in vivo, and prospectively in a transdiagnostic pediatric clinical sample. Variables were measured multiple times over a week, allowing us to test the reciprocity and directionality of daily sleep and momentary irritability associations. First, we hypothesized daily sleep duration and momentary irritability symptoms would manifest a bidirectional association. Specifically, we hypothesized that decreased nightly sleep duration would predict increased morning irritability, and vice versa, that increased evening irritability would predict decreased nightly sleep duration. Second, we hypothesized that these real-time associations would manifest more strongly among youth with higher levels of trait irritability.

Methods

Participants

Data for those who consented to share are publicly available at: https://doi.org/10.17605/OSF.IO/8NT32. Data were collected from a transdiagnostic sample of 125 youths 8–18 years old with varying levels of irritability (M_{age} = 12.58 years, SD = 2.56 years, 74% male, 68.8% White, 9.6% Black, 83.2% Not Hispanic/Latino; see Table 1 for additional demographic data). Recruitment posters were delivered via mail or online platforms. Participants had a primary diagnosis of either DMDD (n = 37), ADHD (n = 33), anxiety disorders (ANX; n = 28), or were categorized as typically developing youth (TD; n = 27). Diagnoses were determined based on a semi-structured clinical interview (Kiddie Schedule for Affective Disorders and Schizophrenia [K-SADs], Kaufman et al., 1997). Exclusion criteria broadly were an IQ <70 assessed with the Wechsler Abbreviated Intelligence Scale (Wechsler, 1999) and substance use during the past 3 months (See Naim et al., 2021 for all inclusion/exclusion criteria). Of note, the current sample overlaps with previously published data (Naim, Smith, et al., 2021). However, this study includes an additional 16 participants and the questions on sleep duration as a potential factor associated with momentary irritability symptoms were not examined before.

Ethical considerations. Informed assent and consent were obtained from all youth participants and their parents. This study was approved by the National Institute of Mental Health institutional review board.

Procedure

Using a previously validated EMA protocol (Naim, Smith, et al., 2021), youth completed surveys three times a day (morning, afternoon, evening) for 7 days (21 total surveys).

Table 1 Demographic information for the sample

N = 125	M (SD) or % (n)
Demographics	
Age	12.58 (2.56)
Sex (male)	74.4% (93)
IQ[a]	113.29 (12.77)
Race	
Black	9.6% (12)
White	68.8% (86)
Asian or Asian American	3.2% (4)
American Indian or Alaskan Native	2.4% (3)
Multiple races	12.0% (15)
Not reported	4.0% (5)
Ethnicity	
Not Hispanic or Latino	83.2% (104)
Latino or Hispanic	11.2% (14)
Not reported	5.6% (7)
Symptom measures	
Youth-reported ARI	3.44 (3.30)
Parent-reported ARI	3.93 (3.75)
CL-ARI[b]	27.98 (18.57)

ARI, Affective Reactivity Index; CL-ARI, Clinician Affective Reactivity Index.
[a]IQ data are missing for 20 participants.
[b]CL-ARI data are missing for 58 participants.

Youth were asked about their wake and bedtimes in the morning and momentary irritability symptoms during each time window. Parents of youth with DMDD and ADHD also completed this EMA protocol, providing information about their child's wake and bedtimes, and daily irritability symptoms. Youth's trait irritability was assessed within 2–3 days upon completing EMA, using validated metrics obtained from several informants (self-, parent-, and clinician-report; see below for more information), capturing multiple perspectives and mitigating self-report biases (Kircanski et al., 2018; Smith, 2007). Compensation was provided with a bonus for completing 75% or more of the surveys.

Measures

EMA ratings for sleep duration. Each morning survey included the following items: "Last night, I fell asleep at/This morning, I woke up at" or "Last night, my child fell asleep at/This morning, my child woke up at." Participants selected a time from a dropdown menu, rounding to the nearest hour and selecting whether it was "AM" or "PM". Daily sleep duration was calculated as the difference between each day's reported bed and wake times. To control for outliers, we only included sleep duration times that fell within three standard deviations of the sample's mean (less than 2% of reported timepoints were removed from the dataset).

EMA ratings for momentary irritability symptoms. Momentary irritability symptoms were assessed through four items including questions on anger, frustration, grouchiness, and mood change (Naim et al., 2022; Naim, Smith, et al., 2021; Tseng et al., 2023). All items were assessed using 5-point Likert scales. Participants were presented with the following items: anger: "At the time of the beep, I felt annoyed or angry" (1 = not at all; 5 = extremely), frustration: "Since the last beep, I felt frustrated" (1 = not at all; 5 = extremely), grouchiness: "Since the last beep, aside from being really, really angry and out of control, I was feeling generally grouchy or cranky" (1 = none of the time, 5 = the whole time), and mood change: "Since the last beep, my mood

changed a lot" (1 = not at all; 5 = extremely; Naim, Smith, et al., 2021).

Self- and parent-reported trait irritability. The Affective Reactivity Index (ARI) was obtained from each parent-youth dyad (Stringaris et al., 2012). The ARI is a well-validated six-item scale that assesses youth trait irritability based on the prior 6 months. Respondents report irritability symptoms based on 3-point Likert scales (0–2), with higher total scores indicating higher levels of irritability (Range: 0–12). The ARI has well-established reliability and construct validity (Stringaris et al., 2012).

Clinician-reported trait irritability. The Clinician Affective Reactivity Index (CL-ARI) is a 12-item semi-structured interview that assesses trait irritability in several domains (home, school, with peers; Haller et al., 2020). Each item is scored on four-to-six-point Likert scales and combined to create three subscales: temper outbursts, irritable mood, and impairment. The frequency of temper outbursts is scored on a 5-point Likert scale (0 = "none," 4= "more than one outburst everyday") and the duration on a 6-point Likert scale (0 = "none," 5 = "60 min"). The frequency of irritable mood is scored on a 4-point Likert scale (0 = "none," 3= "four or more days") and the severity is scored on a 6-point Likert scale (0 = "not present," 5 = "severe"). The duration item for irritable mood is only completed if the frequency is reported as "four or more days" and is a binary (yes/no) outcome, probing whether irritable mood was present for at least half of the day. Lastly, the impairment subscale assesses irritability in three different domains (home, school, with peers) using 6-point Likert scales (0 = "none," 5 = "severe"). The measure's three subscales are weighted to create a total score (range: 0–100). The CL-ARI has established psychometric properties, demonstrating good test–retest reliability and convergent validity (Haller et al., 2020).

Data analysis

We conducted multilevel modeling (MLM; Goldstein, 1995) using HLM software (Version 8; Raudenbush, Bryk, Cheong, & Congdon, 2019) to examine daily in vivo associations between sleep duration and momentary irritability symptoms. Within-person continuous EMA variables of irritability symptoms (morning and evening) and nightly sleep duration for each of the seven EMA weekdays were included at level 1, person-centered. To model trait irritability and to account for age differences, ARI scores and age were entered as between-person variables at level 2, grand-mean centered. Age was included in all models. ARI scores were included in three separate models for each informant (see model below for details). Evening irritability symptoms (T-1) were cross-day lagged to analyze with that night's reported sleep duration (T). Missing data were removed via HLM using listwise deletion at Level 1, meaning removed per each analysis, maximizing available data points for each participant across the models. Of note, compliance rates were relatively high with 80.2% for youth-report and 84.4% for parent-report, consistent with previous EMA studies (Heron, Everhart, McHale, & Smyth, 2017; Wen, Schneider, Stone, & Spruijt-Metz, 2017; Wrzus & Neubauer, 2023). A Missing Completely at Random (Little's MCAR; Little, 1988) test was conducted including all EMA items of interest showing no significant effect, indicating that the missing data were observed at random.

For our primary question on whether nightly sleep duration would predict morning irritability symptoms, models included each of the irritability items measured in the morning (i.e., anger, frustration, grouchiness, mood change) as the outcome, and nightly sleep duration as the predictor (see below for a sample equation of sleep duration predicting morning anger). Level 1 continuous variables were standardized to enable coefficients comparison (Snijders & Bosker, 2012).

Level-1 model

$$\text{Morning Anger}_{ij} = \beta_{0j} + \beta_{1j}{}^{*}\left(\text{Nightly Sleep Duration}_{ij}\right) + r_{ij}$$

Level-2 model

$\beta_{0j} = y_{00} + y_{01}{}^{*}\,(\text{Age}_i) + r_{0j}$

$\beta_{1j} = y_{10} + y_{11}{}^{*}\,(\text{Age}_i) + r_{1j}\beta_{1j}$ denotes the association between sleep duration at the night prior and the morning anger in following day at prompt *i*, for participant *j*. At level 2, y_{10} denotes the association between these variables across the age range.

For the reverse question on evening irritability predicting nightly sleep duration, MLMs were similar, but nightly sleep duration was entered as the outcome variable and evening irritability symptoms were entered as the predictors (see below for a sample equation of evening anger predicting sleep duration).

Level-1 model

$$\text{Nightly Sleep Duration}_{ij} = \beta_{0j} + \beta_{1j}{}^{*}\left(\text{Evening Anger}_{ji-1}\right) + r_{ij}$$

Level-2 model

$\beta_{0i} = y_{00} + y_{01}{}^{*}\,(\text{Age}_i) + r_{0j}$

$\beta_{1i} = y_{10} + y_{11}{}^{*}\,(\text{Age}_i) + r_{1j}\beta_{1j}$ denotes the association between evening anger for participant *j*, at prompt *i*−1 (i.e., at the evening) and that following night's sleep duration, for participant *j*, as reported at prompt *i* (i.e., the morning after). At level 2, y_{10} denotes the association between these variables across the age range.

To examine the potential moderating effect of trait irritability, youth-, parent-, and clinician-ARI were each entered separately at level 2 and were grand centered. Youth-ARI was entered for youth-report models, parent-ARI was included for parent-report models, and clinician-ARI was run for both youth and parent-reported models.

Level-2 model

$\beta_{0i} = y_{00} + y_{01}{}^{*}\,(\text{Age}_i) + y_{02}\,(\text{ARI}_i) + r_{0j}$

$\beta_{1i} = y_{10} + y_{11}{}^{*}\,(\text{Age}_i) + y_{12}\,(\text{ARI}_i) + r_{1j}$

Notably, models based on youth-report included the full sample. However, since parent-reported EMA data were collected only for DMDD and ADHD groups, models based on parent-report included a subsample of DMDD/ADHD participants. Findings are reported accordingly.

Supplementary analyses. Our supplementary analyses included three additional models. First, we tested the specificity of our results by assessing whether nightly sleep duration predicted other negative (e.g., sadness) and positive (e.g., happiness) emotional states. More information on the analyses and findings is reported in the Supporting Information; findings overall indicated specificity for sleep-irritability associations (see Appendix S1). Second, in an exploratory manner, we tested bidirectional associations between sleep duration and daily lability of irritability symptoms (i.e., we used all three data points of daily EMA to calculate symptom variability). No significant findings emerged. More information on these models and findings are reported in the Supporting Information (see Appendix S1). Lastly, we examined the effect of sex and ethnicity on sleep duration, as well as the impact of sex and ethnicity on the associations between sleep duration and irritability (See Appendix S1). No significant findings emerged.

Results

Sample characteristics

Sleep duration. Average nightly sleep duration in the current sample was 8.74 hr (*SD* = 1.64) according

to youth-report. Similar sleep duration was found according to parent-report in the DMDD/ADHD subsample ($M = 9.22$ hr; $SD = 1.34$). Overall, participants obtained adequate sleep as recommended for their respective age groups (Paruthi et al., 2016; See Table 2). Sleep duration did not significantly differ between diagnostic groups for child-report (DMDD: $M = 8.94$, $SD = 2.24$; ADHD: $M = 8.66$, $SD = 2.52$; ANX: $M = 8.56$, $SD = 2.02$; TD: $M = 8.58$, $SD = 2.81$) or parent-report (DMDD: $M = 9.40$ $SD = 1.59$; ADHD: $M = 9.02$, $SD = 1.86$). Moderate parent-youth agreement was found for nightly sleep duration (ICC = 0.43; see Table 2 for all EMA variable statistics).

Trait irritability. Average youth-reported ARI was 3.44 ($SD = 3.30$), with higher scores, as expected, in the DMDD group ($M = 5.84$, $SD = 3.33$) compared to the other diagnostic groups (ADHD: $M = 3.00$, $SD = 2.81$; ANX: $M = 2.96$, $SD = 3.02$; TD: $M = 1.19$, $SD = 1.84$). Notably, the ranges of youth-ARI scores across the different clinical diagnostic groups were similar (0–12 for DMDD; 0–11 for ADHD; 0–11 for ANX), speaking to the transdiagnostic characteristic of irritability. Parent-reported ARI for the DMDD/ADHD subsample was 3.93 ($SD = 3.75$). Parent- and youth-reported ARI agreement was ICC = 0.55.

Nightly sleep duration predicting waking irritability

Decreased nightly sleep duration predicted higher morning grouchiness and frustration, as reported by youth across the entire sample (Grouchiness $b = -.12$, $SE = .05$, $p = .018$; Frustration $b = -.09$, $SE = .05$, $p = .049$) and parents for the DMDD/ADHD subsample (Grouchiness $b = -.10$, $SE = .05$, $p = .044$; Frustration $b = -.16$, $SE = .06$, $p = .005$; see Tables 3 and 4 for all results). Decreased nightly sleep duration predicted higher morning anger and an increased mood change only by parent report for the DMDD/ADHD subsample (Anger $b = -.26$, $SE = .05$, $p < .001$; Mood Change $b = -.21$, $SE = .05$, $p < .001$).

As hypothesized, the association between parent-reported nightly sleep duration and anger was moderated by parent-reported ARI and CL-ARI scores, for the DMDD/ADHD subsample (Parent-report ARI $b = -.03$, $SE = .01$, $p = .027$; CL-ARI $b = -.01$, $SE = .00$, $p = .014$). Specifically, the impact of decreased sleep the night prior on morning anger was stronger in DMDD/ADHD youth with higher trait irritability. All other models were non-significant.

Evening irritability predicting nightly sleep duration

Higher parent-reported evening anger predicted decreased nightly sleep duration for the DMDD/ADHD subsample ($b = -.17$, $SE = .07$, $p = .019$; see Table 5 for full results). No other significant findings emerged (see Appendix S2 Table S2 for full youth-report results).

Age as a moderator

The association between youth- and parent-reported decreased nightly sleep duration and increased morning grouchiness was moderated by age, showing significantly stronger associations in younger participants (Full sample youth-report model: $b = .04$, $SE = .02$, $p = .025$; DMDD/ADHD subsample parent-report model: $b = .06$, $SE = .02$, $p = .004$). In addition, for the DMDD/ADHD subsample, the association between decreased nightly sleep duration and increased morning mood change, as reported by parents, was moderated by age (Age $b = .05$, $SE = .02$, $p = .039$), indicting a stronger association within young participants.

Discussion

The current study examined associations between nightly sleep duration and daily irritability symptoms in a transdiagnostic pediatric sample. Three main findings arose. First, bidirectional associations were found, showing that decreased nightly sleep duration predicted increased morning irritability symptoms according to both youth and parents, and vice versa, evening anger predicted decreased nightly sleep duration, according to parent-report. Second, the parent-reported association between sleep and morning anger was moderated by trait irritability and, therefore, was stronger for youth with elevated levels of irritability. Third, the parent-reported associations between sleep and daily irritability symptoms of grouchiness and mood change were moderated by age and specifically stronger for younger participants.

Our findings demonstrating a negative association between nightly sleep duration and morning anger were robust and consistent across all informants (i.e., youth, parents). These results are in line with existing published data linking sleep and anger in both adults (Krizan & Hisler, 2019; Krizan, Miller, & Hisler, 2020) and youth (Baum et al., 2014; Kenny, Dooley, & Fitzgerald, 2016; Short & Louca, 2015). Our findings add to this existing literature by indicating bidirectionality, with evening anger also impacting nightly sleep duration in our DMDD/ADHD subsample based on parent-report. This observed effect of anger on sleep could be explained by its impact on physiological (e.g., cardiac activity) and cognitive (e.g., rumination) arousal (Hisler & Krizan, 2017; Spielberger, Reheiser, & Sydeman, 1995). Increased pre-sleep arousal impacts sleep throughout the night, inhibiting an individual's ability to fall asleep, as well as impacting sleep quality for the rest of the night (Hisler & Krizan, 2017; Pillai, Steenburg, Ciesla, Roth, & Drake, 2014). Future studies should incorporate

Table 2 Average EMA-rated irritability and sleep duration for youth- and parent-report

	M (*SD*)	
	Youth-report	Parent-report
Sleep duration	8.74 (1.64)	9.22 (1.34)
Anger	1.46 (.92)	1.73 (1.06)
Frustration	1.68 (1.08)	2.10 (1.21)
Grouchiness	1.50 (.85)	1.92 (.99)
Mood change	1.73 (1.07)	1.83 (1.11)

Table 3 Youth-reported nightly sleep duration predicting morning irritability symptoms and with youth-report ARI and Cl-ARI as moderators

	β (*SE*)		
Outcome	Full sample	Youth-reported ARI	CL-ARI
Anger	−.06 (.05)	−.00 (.01)	.01 (.00)
Frustration	−.09 (.05)*	.00 (.01)	−.00 (.00)
Grouchiness	−.12 (.05)*	.01 (.01)	.00 (.00)
Mood change	−.05 (.05)	−.01 (.01)	−.00 (.00)

ARI, Affective Reactivity Index; CL-ARI, Clinician Affective Reactivity Index. Age was included in all models as a covariate.
*$p < .05$.

objective measures of physiological arousal (e.g., electrocardiogram, electrodermal activity) and sleep (e.g., actigraphy) to investigate the interplay between anger, sleep, and increased arousal in youth with irritability.

Interestingly, our findings suggest specificity for sleep-irritability associations, as similar patterns did not emerge with other negative (e.g., sadness) or positive (e.g., happiness) mood symptoms (see Appendix S1 for full results), suggesting potential causality between daily sleep duration and momentary irritability symptoms in youth, that should be explored further.

Overall, findings were more statistically robust for the parent-report models based on the DMDD/ADHD subsample rather than for the youth-report models that were based on the full sample. One potential explanation could be higher irritability levels in the DMDD/ADHD subsample, diagnoses that are typically enriched with irritability, compared to the full sample that also included ANX and TD groups. Alternatively, this discrepancy could also be driven by youth reporting lower levels of irritability compared to their parents in this study (see Table 2), a common pattern found in previous studies on youth psychopathology (Kircanski et al., 2018; Mallidi et al., 2023; Stoddard et al., 2014). Future studies aiming to replicate current findings may help delineate whether this discrepancy is driven by informant effects or symptom severity by including EMA data for parents and youth across several clinical diagnoses.

Age emerged as a significant moderator, showing that the impact of decreased sleep on morning irritability is stronger for younger participants. As emotion regulatory and general emotional processes develop from middle childhood throughout adolescence, this age effect is not surprising (Zeman, Cassano, Perry-Parrish, & Stegall, 2006). This observed age effect also informs a critical and practical target for intervention, specifically in terms of providing education to parents and clinicians on how healthy sleep, particularly sufficient duration, can decrease next-day irritability symptoms earlier relative to later in childhood. Future studies could experimentally restrict sleep duration in a systematic way to examine sleep deprivation's impact on irritability in youth. Other demographic variables, specifically sex and ethnicity, did not emerge as significant predictors of sleep duration, nor as moderators for the irritability-sleep associations (but see: e.g., Moore et al., 2011; See Appendix S1 for full results). These null findings might reflect the homogeneity of our sample, which was majority male and not Hispanic or Latino (See Table 1). Future work should test our findings in a more diverse sample to see if these effects emerge.

Our study has several strengths, including its prospective, ecologically valid EMA protocol that collected naturalistic, in vivo sleep–wake data and momentary irritability symptoms over the course of a week. Second, our study includes a transdiagnostic sample of youth with various clinical diagnoses. Third, data were obtained from youth, parents, and clinicians, providing a broader insight into the temporal dynamics of sleep duration and irritability symptoms, as perceived by different informants.

From a treatment perspective, our findings suggest that insufficient sleep could be a potential treatment target to improve irritability in youth, particularly in those experiencing clinically impairing levels of irritability as seen in ADHD and DMDD. Findings also highlight the potential clinical importance of decreasing evening irritability to improve sleep duration in this clinical population. While clinical irritability is a common and impairing symptom in pediatric psychopathology, effective treatments are still under development and testing (e.g., cognitive behavioral therapy [CBT]; Naim et al., 2021). CBT for insomnia (CBT-I) protocols are efficacious for treating sleep disturbances in youth and clinical samples and could be added as a supplement to other treatment protocols for youth with irritability delivered in both in-person and virtual settings (Taylor & Pruiksma, 2014; Werner-Seidler, Johnston, & Christensen, 2018). Sleep education and mindfulness protocols can be implemented in the community setting to improve sleep-related health outcomes, including general mood and irritability in youth (e.g., Lever, Murphy, Duffield, & Fullagar, 2021; Tamura & Tanaka, 2014; Wolfson, Harkins, Johnson, & Marco, 2015).

Table 4 Parent-reported nightly sleep duration predicting morning irritability symptoms and with parent-report ARI and Cl-ARI as moderators

	β (*SE*)		
Outcome	Full sample	Parent-reported ARI	CL-ARI
Anger	−.26 (.05)**	−.03 (.01)*	−.01 (.00)*
Frustration	−.16 (.06)*	−.02 (.01)	−.00 (.00)
Grouchiness	−.10 (.05)*	−.00 (.01)	−.00 (.00)
Mood change	−.21 (.05)**	−.01 (.01)	−.01 (.00)

ARI, Affective Reactivity Index; CL-ARI, Clinician Affective Reactivity Index. Age was included in all models as a covariate.
*$p < .05$.
**$p < .001$.

Table 5 Parent-reported evening irritability symptoms predicting nightly sleep duration for the full sample and with parent-reported ARI and Cl-ARI as moderators

	β (*SE*)		
Outcome	Full sample	Parent-reported ARI	CL-ARI
Anger	−.17 (.07)*	−.02 (.02)	−.01 (.00)
Frustration	−.04 (.06)	−.01 (.02)	−.01 (.00)
Grouchiness	−.03 (.06)	.01 (.02)	−.01 (.00)
Mood change	−.06 (.05)	−.01 (.01)	−.01 (.00)

ARI, Affective Reactivity Index; CL-ARI, Clinician Affective Reactivity Index. Age was included in all models as a covariate.
*$p < .05$.

There are also several limitations in the current study. First, sleep duration was based on subjective estimation and rounded to the nearest hour. While daily subjective estimates of sleep are commonly used in research (e.g., Bauer & Blunden, 2008; Dietch, Sethi, Slavish, & Taylor, 2019; Gregory, Van der Ende, Willis, & Verhulst, 2008; Wolfson et al., 2003) and show sufficient agreement with actigraphy, particularly for reported bed and wake times, future work would benefit from integrating objective and passive measures (e.g., actigraphy) to control for mood-congruent biases (e.g., "I am in a bad mood so I must have gotten poor sleep") and to further validate estimates of sleep timing (Konjarski et al., 2018; Mazza, Bastuji, & Rey, 2020; Sadeh, 2011; Sadeh & Acebo, 2002). There are additional sleep indices (e.g., sleep variability) that were beyond the scope of the current study, that future research should investigate in relation to irritability given their relevance to well-being and affect in youth (Mathew et al., 2023; Moore et al., 2011). Objective estimates of sleep would also allow researchers to investigate other sleep indices, such as sleep onset latency and waking after sleep onset. Considering the available work suggesting sleep fragmentation in youth with DMDD (Delaplace et al., 2018), assessing these additional sleep behaviors is an important next step. Second, as irritability is frequently associated with ADHD (Cardinale et al., 2021; Karalunas, Gustafsson, Fair, Musser, & Nigg, 2019; Liu et al., 2019) and, as sleep problems are common in ADHD (Craig et al., 2020; Dimakos, Gauthier-Gagné, Lin, Scholes, & Gruber, 2021), disentangling the effects of irritability on sleep from those of ADHD symptoms is of value. Since ADHD symptoms were not included in our current EMA protocol, future work should investigate these pathways by modeling both ADHD-related symptomatology (e.g., hyperactivity) and irritability when testing associations with sleep. Third, EMA parent-report was limited to the DMDD/ADHD subsample. While sleep-irritability associations were found across the full sample, these were stronger and bidirectional in the DMDD/ADHD subsample, suggesting that youth with elevated irritability are potentially more sensitive to the effect of sleep on daily irritability, and vice versa, perpetuating a cycle. Research would benefit from future work that collects EMA sleep-irritability data across different informants and clinical groups to further elucidate the current study's findings.

Conclusions

Overall, this work adds to the literature on sleep-mood dynamics showing significant and bidirectional associations between momentary irritability and sleep duration while measured ecologically in vivo. Findings highlight sleep duration as a potential treatment target in the context of clinical irritability. Future work could integrate EMA to develop and deliver data-driven and personalized interventions by which patients improve their sleep habits in vivo and in real-time.

Supporting information

Additional supporting information may be found online in the Supporting Information section at the end of the article:

Appendix S1 Table S1. Demographic information by diagnostic group.

Appendix S2 Table S2. Youth-reported evening irritability symptoms predicting nightly sleep duration and with the youth-reported ARI and Cl-ARI as moderators.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author based on NIH guidelines.

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Key points

- Insufficient sleep is strongly related to mood dysregulation. However, real-time reciprocal sleep-irritability associations are yet to be explored.
- Using ecological momentary assessment, we tested daily relationships between irritability and nightly sleep duration in a transdiagnostic pediatric sample.
- According to youth- and parent-report, decreased sleep duration was associated with increased morning irritability. A bidirectional association between parent-reported nightly sleep duration and anger was found—increased evening anger related to decreased nightly sleep duration, and decreased sleep duration related to increased morning anger.
- Age and trait irritability moderated the effect of sleep duration on momentary irritability symptoms, which was stronger for younger youth with higher trait irritability.
- Findings highlight sleep duration as a potential treatment target for clinical irritability in youth.

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