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Intraindividual variability of sleep/wake patterns in relation to child and adolescent functioning: A systematic review

Stephen P. Becker[1,2,5], **Craig A. Sidol**[3], **Tori R. Van Dyk**[1,4], **Jeffery N. Epstein**[1,2,3], and **Dean W. Beebe**[1,2]

[1]Division of Behavioral Medicine and Clinical Psychology, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, USA

[2]Department of Pediatrics, University of Cincinnati College of Medicine, Cincinnati, Ohio, USA

[3]Department of Psychology, University of Cincinnati, Cincinnati, Ohio, USA

[4]Department of Psychology, University of Nebraska-Lincoln, Lincoln, NE, USA

Summary

Substantial research attention has been devoted to understanding the importance and impact of sleep in children and adolescents. Traditionally, this has focused on mean sleep variables (e.g., a child's "typical" or average sleep duration), yet research increasingly suggests that intraindividual variability (IIV) of sleep/wake patterns (sometimes referred to as sleep variability or night-to-night variability) regularly occurs and may have implications for adjustment. A systematic search of five electronic databases identified 52 empirical studies published between 2000 and 2015 that examined correlates of sleep IIV in children and adolescents, with a recent increase in the publication rate of such studies. Identified studies were often atheoretical and included post hoc analyses, though IIV in select aspects of sleep does appear to be associated with increasing age/pubertal status, non-White race, physical and neurodevelopmental conditions (e.g., attention-deficit/hyperactivity disorder; autism), psychopathology symptoms (e.g., anxiety, depression, inattention), body weight, stress, aspects of cognitive functioning, and poorer sleep functioning/habits. The limited intervention work examining sleep IIV in adolescents is promising, though studies are needed using more rigorous intervention designs. Clinical sleep recommendations may not only need to address overall sleep duration and sleep habits but also the stability of sleep duration and timing. It will be important for future research examining sleep IIV in children and adolescents to use a developmental framework in advancing theory pertaining to the causes, mechanisms, moderators, and outcomes of sleep IIV in youth, and a conceptual model is proposed to help guide such efforts.

[5]Address correspondence to: Stephen P. Becker, Ph.D., Division of Behavioral Medicine and Clinical Psychology, Cincinnati Children's Hospital Medical Center, 3333 Burnet Avenue MLC 10006, Cincinnati, Ohio, 45229, USA. stephen.becker@cchmc.org. Telephone: +1 (513) 803-2066. Fax: +1 (513) 803-0084.

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Keywords

ADHD; day-to-day; development; fluctuation; intraindividual; night-to-night; sleep; variability; variation; youth

Introduction

Sleep plays a crucial role in development across the life span [1–3]. Given the vast developmental changes that occur in the first two decades of life, substantial research attention has been devoted to understanding the importance and impact of sleep in children and adolescents [4–9]. The majority of this research has focused on sleep duration [10,11], and studies convincingly demonstrate that insufficient sleep is associated with adverse cognitive, behavioral, mental health, and physical health consequences in youth [4–9,12–14]. These findings have led to widely-disseminated recommendations for optimal sleep duration in children and adolescents [15], as well as policy statements regarding school start time in an effort to increase sleep duration, specifically among adolescents [16]. While important, these recommendations relate to overall nightly sleep duration and do not address daily *variations* in sleep. Yet research increasingly demonstrates that intraindividual variability (IIV) of sleep/wake patterns (sometimes referred to as night-to-night variability) regularly occurs and may have implications for adjustment [17–20].

Sleep IIV may be particularly common and relevant in childhood and adolescence given the rapid developmental maturation, complex familial and peer systems, and environmental demands occurring during these developmental periods [21–23], all embedded within an increasingly “24/7” lifestyle for many youth [24,25]. However, children’s sleep IIV has received relatively little attention compared to other sleep parameters, and no review has systematically identified and integrated the extant literature. This review fills that void. Following a recently-published systematic review of sleep IIV in adults, we chose to adopt the methods used by Bei et al. [26] for this review of the pediatric literature. Similar to Bei et al. [26], this systematic review aims to:

1. Examine the scope and characteristics of studies examining correlates of sleep IIV in children and adolescents;
2. Review the extent to which sleep IIV is associated with developmental and external correlates; and
3. Identify gaps in the literature and propose a model to guide future research.

Methods

Methods were consistent with those used by Bei and colleagues [26] as well as with Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [27].

Search Strategy

Systematic searches were conducted in five databases (CINAHL, Embase, PsycINFO, PubMed, Scopus) on December 4, 2015. Filters were applied to include studies published in English on human children and adolescents ≤ 18 years old. Search terms were selected to include all of the following three components: (1) "sleep" in the title or abstract; (2) an implied presence of daily sleep measures, operationalized as containing any of the following terms in the title or abstract: "actigraph*", "diary", "diaries", "log(s)", "daily", "everyday", "night*", "day*", "week*", "month*"; and (3) an implied examination of sleep IIV, operationalized as containing any of the following terms in the title or abstract: "variability", "variation", "(in)stability", "fluctuation", "(ir)regularity", "(ir)regular sleep*", "(ir)regular bedtime", "(ir)regular rise*".

Selection Criteria

Figure 1 provides a flow diagram of the literature search and study selection process. After duplicate records were removed, two authors (SPB and CAS) independently screened each title and abstract for meeting the following inclusion criteria: (1) children or adolescents (mean age ≤ 18 years); (2) empirical study (not a review, commentary, or letter to editor); (3) peer-reviewed article; (4) assessed sleep daily for at least three days; (5) quantitatively examined sleep IIV in relation to non-sleep related factors. Disagreements regarding study eligibility were resolved by discussion. Full-texts of the remaining records were further assessed by both authors independently for inclusion eligibility, with excellent inter-rater reliability (Cohen's kappa = 0.91). Finally, the reference lists of included studies were reviewed for potential additional papers.

Data Extraction and Synthesis

Based on the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [28], the authors developed a data extraction form to ensure systematic coding of study characteristics and quality. Two authors (SPB, CAS) independently conducted the data extraction, with a random selection of 20% of the studies extracted by both authors. Agreement between raters was excellent (95% for study characteristics, 92% for quality assessment).

Quality Assessment

Bei et al. [26] created a study quality rating form based on the Methods Guide for Effectiveness and Comparative Effective Reviews developed by the Agency for Healthcare Research and Quality [29], and the same study quality rating form was used in this review. The study quality domains coded were: (1) having a priori aims/hypotheses regarding sleep IIV, (2) providing a justification of sample size for sleep IIV analyses, (3) sample representativeness for intended study population, (4) the number of continuous days used for evaluating sleep IIV, (5) quality of sleep measures, (6) quality of correlates measures, (7) rates of missing daily data, and (8) quality of inferences and conclusions drawn. See the caption of Figure 2 for the specific codes used for each of the study quality domains.

Results

Search Results

The systematic search procedures described above resulted in 1,397 unique records for title and abstract screening. Of these, 139 records were retained for full-text screening, and 52 met full criteria for data extraction and inclusion in the review (see Figure 1).

Study Characteristics

The characteristics of included studies, in addition to findings pertaining to sleep IIV, are summarized in Table 1.

Context and Design

The 52 studies were published between 2000 and 2015. As shown in Figure 3, there has been a recent increase in the number of studies examining sleep IIV in children and adolescents, with over half (n = 27; 52%) of the identified studies published since 2012 and 25% (n = 13) of identified studies published or in-press and accessible in 2015 alone (the last year included in the systematic search). The majority of studies (n = 47; 90%) used an observational design, and five (10%) used an intervention design; no studies were identified that used an experimental design.

Characteristics of the Samples

Most studies (n = 36; 69%) were conducted in the United States in predominantly non-Hispanic White samples, with remaining studies conducted in Brazil (n = 4), Australia (n = 3), Israel (n = 3), Denmark (n = 2), Canada (n = 2), Germany (n = 1), and Japan (n = 1). The full developmental span from infancy through late adolescence was represented, including 2 studies (4%) conducted with infants/toddlers (ages 0–2 years), 9 (17%) with preschool-aged children (ages 3–5), 23 (44%) with school-aged children (ages 6–12), and 18 (35%) with adolescents (ages 13–18)[1]. Almost three-fourths of studies (n = 37; 71%) focused on youth from general community or school-based samples, with most other studies including youth with mental health or physical health conditions (n = 14; 27%). One intervention study recruited female adolescents with self-reported poor sleep.

Measurements and Analysis of IIV

Studies assessed daily sleep using actigraphy (n = 36), parent-completed sleep diaries (n = 19), and youth-completed sleep diaries (n = 20); studies frequently used both actigraphy and a daily sleep diary and one study used daily phone calls to the adolescent and their parent. The most common indicators for quantifying sleep IIV were individual standard deviation (ISD; n = 27; 52%) and coefficient of variance (CV; n = 13; 25%); the remaining studies used other methods such as variance and multi-level modeling.

To facilitate interpretability and readability, sleep IIV variables are described in six categories in the primary findings below: duration IIV (including sleep duration, time-in-bed, and total sleep time variables), onset IIV (including bedtime and sleep onset latency

[1]When a study spanned across multiple age groups the mean sample age was used for descriptive categorization purposes.

variables), waking IIV (including wake time and wake onset variables), quality IIV (including sleep efficiency, night wakings, and nocturnal movement variables), habits IIV (including sleep habits, night routines, and sleep schedule variables), and sleepiness IIV (see Table 1 for the specific methods/variables used by individual studies in assessing sleep IIV).

Quality Assessment

Study quality is summarized in Figure 2 (see Table S1 in supplement materials for the quality assessment of individual studies). Similar to the review by Bei and colleagues of sleep IIV in adults [26], 77% of studies were judged to have good sample representativeness, 79% were judged to make appropriate inferences and conclusions, 96% used well-validated measures for assessing sleep IIV, and 100% used well-validated measures for assessing correlates. Also as in adults [26], several limitations have been common in studies of sleep IIV in children and adolescents. Only 38% of studies had a priori aims or hypotheses related to sleep IIV, and no studies provided a sample size justification for analyses pertaining to IIV. Approximately one-fourth of studies (27%) examined sleep IIV based on measuring sleep for 14 or more days, and only one-third of studies (37%) had ≤ 10% of data missing.

Primary Findings

To understand correlates of sleep IIV, findings from the 52 studies were grouped into eight themes (see Table 1), recognizing that some findings could logically fit with multiple themes and that developmental context is potentially relevant across all themes. Studies could report separate findings from multiple themes. Further, in an attempt to parse out the variance specific to sleep IIV as opposed to sleep functioning more broadly, findings pertaining to sleep IIV when controlling for mean sleep indicators are described when such analyses were conducted.

Theme A: Development (*n* = 11)

Age (n = 11)—No studies were identified that compared sleep IIV across different age groups. Separate studies indicate that duration IIV is approximately 1 hour in school-aged children [30,31] and approximately 1.5 hours in adolescence [32,33].

Most studies examining age have examined whether sleep IIV is associated with continuously-measured age within a particular age group. Prior to adolescence, the link between age and sleep IIV is unclear. Two studies examined the relation between age and sleep IIV in preschool-aged children [34,35]. Vaughn et al. [35] found no association between age and waking IIV. In contrast, Acebo et al. [34] found greater quality IIV in 36-month-old children as compared to both younger or older children, which the authors suggest may be due to a reorganization of the sleep/wake system around three years of age. Mixed findings have also been reported in samples of school-aged children [36–38]. One study found older age to be significantly associated with both onset IIV and waking IIV [36], whereas another study found no association between age and onset IIV [37]. Another study found mixed findings across age groups depending on the child's race and sex, with non-White boys aged 9–11 years having the greatest duration IIV [38]. Each of these studies had a restricted age span of no more than four years.

There is some evidence of an association between age and sleep IIV in adolescent samples [39–41]. In a study with older and younger adolescent siblings residing in the same family, McHale et al. [39] reported greater duration IIV in older adolescents compared to younger adolescents. Moore et al. [40] found the association between age and duration IIV to remain significant when controlling for demographic and environmental variables. Another study found adolescents to have greater onset IIV and waking IIV compared to teachers with the same morning school start time [42]. Two longitudinal studies examined sleep IIV over time in mid [33] or late [43] adolescence. Telzer et al. [33] found no difference in duration IIV or onset IIV across a single year during mid-adolescence (average ages 14.8 years to 15.9 years). In a longer longitudinal study across the transition from high school to college, there was no change in onset IIV, whereas waking IIV increased over time [43].

Pubertal status (n = 2)—Two of the studies that examined age also examined pubertal status in relation to sleep IIV [36,40]. Buckhalt et al. [36] did not find pubertal status to be related to either onset IIV or waking IIV in school-aged children. Moore et al. [40] found more advanced pubertal status during adolescence to be associated with duration IIV, but not after controlling for various demographic and environmental variables.

Theme B: Family, cultural, and environmental factors (*n* = 23)

Race/ethnicity (n = 9)—All nine studies examining sleep IIV in relation to race/ethnicity were conducted in the United States, where race/ethnic differences may be particularly relevant. Four studies found at least some evidence for greater sleep IIV among non-White youth as compared to White youth [36,38,40,44], whereas five studies found no race/ethnicity differences in sleep IIV [35,37,41,45,46]. The specific sleep domain examined may explain in part these conflicting findings: three of the studies that found a significant association each examined duration IIV whereas three of the studies reporting a nonsignificant association examined onset IIV [37,45] or waking IIV [35]. Thus, any association between non-White race/ethnicity and sleep IIV may be specific to sleep duration (and related measures). Importantly, one study found the association between non-White race and duration IIV to remain significant after controlling for parent education, family income, and neighborhood distress [40].

Socioeconomic status (SES) (n = 9)—Studies examining family income, income-to-needs ratio, parent education level, and SES composite indices (e.g., Hollingshead) have yielded mixed findings [34,37,39–41,45,47–49]. Of the three studies that examined family income [39–41] two found lower income to be related to greater habits IIV and duration IIV [39,40]. However, an association between lower income and greater duration IIV was no longer significant when controlling for other family and environmental factors [40]. Consistent with this latter finding, a series of studies by El-Sheikh and colleagues found income-to-needs ratio to be generally unassociated with onset IIV or habits IIV [37,45,47], though in one study family economic hardship was significantly associated with children having greater onset IIV [37]. Studies have not found an association between parent education level and children's onset IIV [37,40] or duration IIV when controlling for other important demographic/environmental variables such as age and parent income [37,40]. Among studies that used a composite measure of SES, one did not report an association with

duration IIV when the composite included family income and parent education measured five years prior to the sleep assessment [48]. In contrast, two other studies using more indicators to assess SES found lower SES to be associated with greater onset IIV and greater duration IIV [34,49]. There may be complex interrelations with other family, cultural, and environmental factors. El-Sheikh et al. [37] did not find income-to-needs ratio to be bivariately associated with onset IIV, but rather income-to-needs ratio interacted with child race in predicting onset IIV: Black children whose families were worse off financially had greater onset IIV than other Black children, whereas no significant effect was found for White children regardless of family income-to-needs ratio.

Family structure and functioning (n = 8)—Whereas El-Sheikh et al. [37] did not find single parent status to be associated with children's onset IIV, Troxel et al. [50] found a complex association. White adolescents from two-parent homes had lower onset IIV compared to White adolescents from single-parent homes, whereas no association was found between family structure and onset IIV for Black adolescents [50]. Another study found inconsistent evidence for children in regular or therapeutic foster care to have greater or similar duration IIV, onset IIV, quality IIV, or habits IIV than children not in foster care, with findings generally indicating similar sleep IIV patterns between children in or not in foster care [51].

Family stress and conflict may be more relevant than family structure. In a study of preschool-aged children from low-income families, family stress and the impact of family stressors on the child were both associated with greater duration IIV and onset IIV, although parenting behaviors were unassociated with duration IIV or onset IIV [52]. Mixed findings were also reported in a study of adolescents, which found most family variables to be unassociated with duration IIV, although both less adolescent-father intimacy and greater adolescent-mother conflict were associated with greater duration IIV [48]. In a study of Mexican American adolescents, McHale et al. [39] found greater adolescent-parent conflict (with both mothers and fathers) to be associated with greater duration IIV. In a longitudinal study of school-aged children, marital conflict predicted greater onset IIV two years later, and onset IIV was reciprocally associated with greater marital conflict over time [53]. This study also found complex associations between marital conflict and race as well as SES in relation to onset IIV, with the association between marital conflict and greater onset IIV limited to Black children and children from lower SES backgrounds [53]. Spilsbury et al. [54] found home environment to be unassociated with duration IIV when covariates were controlled. In contrast, greater encouragement of children's social maturity (e.g., consistent enforcement of family rules, enacting self-care routines) was associated with less duration IIV, though this association was found only for girls and not for boys [54].

Sleep environment (n = 4)—Sleep environment appears to be associated with sleep IIV [36,47,55,56]. Buckhalt et al. [36] found that sharing a bedroom, as well as a higher number of individuals sharing the child's bedroom, is associated with greater onset IIV and greater waking IIV. Storfer-Isser et al. [55] found that a poorer sleep environment (e.g, falling asleep while listening to loud music, watching television, with lights on) was associated with greater duration IIV amongst adolescents. Spruyt et al. [56] found more adaptive bedtime

routines (e.g., bedtime hugs, putting on pajamas) to be associated with less duration IIV and less quality IIV. Finally, Bagley et al. [47] found that most individual sleep environment variables (e.g., noise, uncomfortable bed) were unassociated with children's habits IIV, with the sole exception of warmer temperature being associated with greater IIV. However, a sleep environment composite (e.g., noise, uncomfortable bed, room temperature, electronics in room) was found to be a significant intervening variable of the association between income-to-needs ratio and greater habits IIV [47].

Time spent on activities (n = 3)—How much time is spent on after-school activities is heavily influenced by family, cultural, and environmental demands and expectations, and is associated with adolescents' duration IIV [46,48,57]. Kuo et al. [48] found more time spent with peers and less time spent at school to be associated with greater duration IIV. Fuligni and Hardway [46] similarly found that more time spent socializing with friends and playing a computer outside of school were significantly associated with greater duration IIV, whereas time spent studying, watching television, or helping the family were unassociated with duration IIV. In a longitudinal study assessing sleep on three occasions across adolescence (9^{th}, 10^{th}, and 12^{th} grades), nightly increases in time spent studying outside of school was followed by shorter sleep that night, with this association increasing in strength across high school [57].

Community factors (n = 3)—Paralleling findings on families, community *structure* may be less linked to youth sleep IIV than community-related *stress* [37,40,58]. One study found community poverty to be unassociated with onset IIV [37]. Another study found more neighborhood distress to be significantly correlated with duration IIV, though this association was no longer significant when controlling for other demographic and environmental variables [40]. In a three-month longitudinal study of children exposed to violence (either intimate-partner or community violence), Spilsbury et al. [58] found that children who were physically assaulted during the violent event did not differ in duration IIV from children who were not physically assaulted. However, children who had witnessed a homicide during the violence exposure event tended to have greater duration IIV than children who did not witness a homicide during the violence exposure event [58].

Theme C: Physical factors and health (*n* = 18)

Sex (n = 9)—Studies have not found sex differences in sleep IIV in preschool-aged [34,35] or school-aged [36,45] children. One study spanning childhood and adolescence also found no association between sex and duration IIV [41]. There is some indication that females may have greater onset IIV [59] and greater duration IIV [46,48], though mixed findings are reported based on the specific onset IIV and duration IIV variables examined and no sex differences were found in waking IIV or quality IIV [59]. Another study also conducted with adolescents did not find any sex difference in duration IIV [60].

Body mass index (BMI), obesity, and nutrition (n = 10)—No relation was found between sleep IIV with BMI in three studies conducted with school-aged children [31,45,56]. In contrast, in a community sample of adolescents greater duration IIV was significantly associated with higher BMI, and this association remained significant when

controlling for a range of other variables associated with BMI [40]. However, neither of the two studies that compared obese and non-obese youth found differences in sleep IIV [56,60], and two studies drawing from the same sample of Mexican-American adolescents did not find duration IIV to be associated with BMI [39,48].

Nevertheless, these and other studies have found sleep IIV to be associated with some adverse metabolic and nutrition outcomes. In a study of school-aged children, duration IIV was unassociated with most metabolic markers (e.g., glucose, cholesterol) but was associated with significantly higher triglyceride levels in obese children specifically [56]. Another study of school-aged children found duration IIV to be unassociated with food energy density, plasma leptin, or plasma ghrelin, but duration IIV was associated with a higher daily intake of sugar from sugar-sweetened beverages as well as greater dietary energy from added sugar, even when controlling for mean sleep duration [61]. In a sample of adolescents, greater duration IIV was associated with higher daily caloric, fat, and carbohydrate intake, but not protein intake, beyond demographic characteristics and mean sleep duration [60]. Duration IIV was also associated with greater consumption outside of meals, particularly after dinner [60]. In the same sample, duration IIV, but not mean sleep duration, was significantly positively associated with multiple abdominal obesity measures (e.g., android/gynoid fat mass ratio, visceral and subcutaneous adipose tissue, total fat area), and mediation analyses indicated that the association between duration IIV and abdominal obesity measures is accounted for in part by greater energy intake, especially from fats and carbohydrates [32]. The one study examining caffeine use did not find an association between caffeine intake and onset IIV or waking IIV [36].

Other (n = 6)—Scattered studies looked at other health outcomes. Having asthma was significantly associated with greater onset IIV in children [45] but not with duration IIV in adolescents [40]. The one study examining sleep IIV in relation to autonomic nervous system functioning did not find onset IIV to be related to respiratory sinus arrhythmia reactivity or skin conductance level reactivity [45]. One study examined adolescents' duration IIV in relation to white matter microstructure in the brain, and found that one index of duration IIV (but not mean sleep duration) was associated with lower white matter integrity 1.5 years later [33]. Two studies examined duration IIV in relation to subjective measures of perceived physical health, with differing results. In a cross-sectional study in mid-adolescence, duration IIV was unassociated with either parent- or youth-reported perceived health [62]. In a longitudinal study in late adolescence, duration IIV at the first time-point (T1) was significantly associated with poorer self-rated physical health at the follow-up time-point approximately two years later (T2), even when controlling for sex, family SES, T1 mean sleep duration, and T1 physical health [48].

Theme D: Psychosocial, emotional, and behavioral functioning (*n* = 10)

Emotional functioning (n = 8)—Studies examining sleep IIV in relation to anxiety and depressive symptoms report mixed findings. In a sample of preschool-aged children, both onset IIV and waking IIV were associated with greater parent-reported internalizing problems, and onset IIV was also associated with more anxious/depressed behaviors specifically [63]. The only study conducted with school-aged children focused on pre-sleep

worries and found more worrying about schoolwork (but not worries about family, friends, or other things) to be associated with greater habits IIV [47]. In adolescence, some studies report no association between duration IIV and mood [48,62]. However, two larger studies link greater duration IIV to greater adolescent anxiety/depression [39,46], even after controlling for mean nightly sleep duration and the difference between weekend and weekday sleep duration [46]. One study reported different effects based on the sleep domain examined, whereby anxiety or depression were unassociated with waking IIV concurrently or over time but did predict greater onset IIV approximately 6 months later [43]. Reciprocal associations were also found in that onset IIV predicted greater anxiety (but not depression) over time [43]. Finally, one study conducted with youth exposed to a violent event did not find an association between duration IIV and posttraumatic stress symptoms specifically [58].

Behavioral functioning (n = 6)—Studies generally report a significant association between sleep IIV and poorer behavioral functioning. In a seminal study of preschool students, Bates et al. [52] found both duration IIV and onset IIV to be associated with poorer teacher-rated preschool adjustment and behavior, whereas having a late bedtime, mean nightly sleep duration, and total daily sleep were unassociated with preschool functioning. In another preschool study, greater onset IIV was positively associated with a measure of behavioral reactivity, although waking IIV was unassociated with teacher-rated inattention problems [35]. In contrast, another study showed that preschoolers' waking IIV, but not onset IIV, was associated with more parent-rated inattention problems, and both waking IIV and onset IIV were associated with higher parent-rated externalizing behavior problems and aggression specifically [63]. Among adolescents, one study did not find an association between duration IIV and either parent- or teacher-rated externalizing behavior problems [62]. However, a longitudinal study of Mexican-American adolescents found duration IIV to be positively associated with adolescent self-ratings of engaging in risky behavior (e.g., getting drunk/high, skipping school), both concurrently [39] and prospectively over a two-year period when controlling for baseline risky behaviors as well as mean sleep duration [48].

Social functioning (n = 2)—Both studies that examined onset IIV and waking IIV in relation to social functioning were conducted in preschool-aged children, with mixed findings [35,63]. Vaughn et al. [35] found onset IIV to be associated with children initiating more negative interactions assessed using classroom observations, but waking IIV was not associated with peer acceptance assessed using sociometric nominations and mean sleep duration was more clearly associated with preschoolers' social functioning. Yokomaku et al. [63] found that waking IIV was associated with greater social problems and withdrawn behaviors specifically, whereas onset IIV was unassociated with social problems or withdrawal.

Theme E: Cognition and learning (*n* = 8)

Intellectual ability (n = 3)—Studies examining sleep IIV in relation to children's intellectual ability report mixed findings. Araújo et al. [64] did not generally find an association between onset IIV and children's visuospatial IQ scores. Similarly, Suratt et al.

[44] did not find an association between duration IIV and children's scores on an intelligence subtest measuring visual-construction skills, but did find greater duration IIV to be associated with poorer performance on subtests measuring word knowledge and verbal reasoning. Buckhalt et al. [36] also found waking IIV and onset IIV to be associated with lower overall IQ and onset IIV was associated with poorer verbal ability specifically, but these associations were only present for Black children and not White children.

Specific neurocognitive functions (n = 5)—Two studies examined sleep IIV in relation to preschoolers' neurocognitive functioning [35,65]. Vaughn et al. [35] found greater waking IIV to be associated with poorer effortful control but unassociated with receptive vocabulary. Hoyniak et al. [65] did not find an association between a composite measure of sleep IIV (including duration IIV and onset IIV domains) and sustained attention, though sleep IIV was associated with longer target P3 latencies assessed with electroencephalography (EEG) which is a neurophysiological measure of attentional processing. Three studies examined sleep IIV in relation to the neurocognitive functioning of school-aged children [30,44,66]. Consistent with the findings by Hoyniak and colleagues [65], Suratt et al. [44] found no association between duration IIV and sustained attention and also found no association with working memory. Another study examining working memory found effects based on time of day, with quality IIV and duration IIV both associated with poorer working memory performance in the morning but not in the afternoon [30]. Further, children with lower overall working memory performance were particularly vulnerable to the previous night's sleep quality, and a quadratic effect was found for duration IIV whereby morning working memory performance was poorer when sleep duration deviated from the average by either "too little" or "too much" [30]. Finally, Gruber and Sadeh [66] found greater duration IIV and quality IIV to be associated with poorer performance on complicated neurocognitive tasks requiring sustained attention for extended periods of time and working memory but not simple neurocognitive tasks requiring motor skills and short-term memory, and only for typically developing boys and not boys with attention-deficit/hyperactivity disorder (ADHD).

Academics (n = 1)—The one study examining school grades did not find an association between duration IIV and adolescents' grades [39].

Theme F: Neurodevelopmental disorders (*n* = 12)

ADHD (n = 8)—One study examined sleep patterns in 7-week-old boys at familial risk for ADHD [67]. Though infants at familial risk for ADHD did not differ from comparison infants in nighttime duration IIV (i.e., 7p.m.–7a.m.), the infants at risk for ADHD did have greater daytime duration IIV (i.e., 7a.m.–7p.m.) than comparison infants [67]. Studies directly examining sleep IIV in children with ADHD compared to typically developing peers report mixed findings [66,68–72]. Gruber et al. [68] found that boys with ADHD did not differ from boys without ADHD in sleep IIV (i.e., onset IIV, duration IIV, waking IIV, sleepiness IIV) assessed with daily diaries, but boys with ADHD did have greater onset IIV and duration IIV assessed with actigraphy. Further, one index of duration IIV was better able than mean sleep variables or other sleep IIV variables to distinguish between boys with and without ADHD [68]. Other studies have found greater onset IIV in children with ADHD

than in comparison children, but report mixed evidence regarding any differences between children with and without ADHD in measures of waking IIV, duration IIV, or quality IIV [66,69,70]. Hvolby et al. [69] found children with ADHD to have greater onset IIV than healthy controls as well as psychiatric controls. In contrast, two other studies did not find evidence for greater sleep IIV (i.e., duration IIV, onset IIV, or waking IIV) in children with ADHD compared to children without ADHD [71,72], and another study did not find diagnosis/medication of ADHD to be associated with adolescents' duration IIV [40]. It is important to note, however, that one of these studies used baseline data from a medication trial during which families were asked to maintain a set bedtime, which may have impacted the ability to detect night-to-night variability [71]. In addition, the two studies that failed to find any group differences in sleep IIV in children with and without ADHD excluded children taking medication for ADHD [72] and/or with an internalizing comorbidity [71,72], which may have resulted in children with more severe ADHD being excluded from participation. Findings are mixed in whether taking medication for ADHD or having a comorbid psychiatric diagnosis impacts sleep IIV in children with ADHD [69–71].

Autism and other developmental disabilities (n = 3)—The three studies examining sleep IIV in children with autism and other developmental disabilities were drawn from the same sample of children [73–75]. An initial cross-sectional study did not find differences in sleep IIV (i.e., onset IIV, duration IIV, waking IIV, quality IIV) between children with autism, children with a developmental delay (but not autism), or typically developing children [74]. Further analyses found no differences in sleep IIV when children in these three groups were subdivided into those with and without elevated ADHD symptoms [75]. A follow-up study examined sleep IIV over a six-month period and found that children in either of the neurodevelopmental disorder groups had greater duration IIV and quality IIV than their typically developing peers, though within-child variability was greater than between-child variability for all three groups [73]. Less mature developmental age was also associated with greater waking IIV, duration IIV, and quality IIV [74].

Fragile X syndrome (n = 1)—One study found greater duration IIV, onset IIV, and duration IIV in boys with fragile X syndrome compared to control children [76].

Theme G: Sleep functioning (*n* = 13)

Mean sleep variables (n = 8)—Sleep IIV is generally unassociated with mean sleep variables (i.e., mean sleep duration, mean sleep quality, mean sleep latency) in preschool-aged children, aside from an association between waking IIV and greater mean sleep activity [35]. Studies examining sleep IIV and mean sleep variables in school-aged children offer mixed findings. One study found onset IIV to be associated with greater mean sleep activity, shorter mean sleep duration, and poorer mean sleep quality [36]. Other studies found onset IIV to be associated with shorter mean sleep duration but unassociated with mean sleep quality [37,45]. Duration IIV does appear to be associated with children having shorter mean sleep duration [44,61]. Likewise, greater onset IIV and duration IIV are associated with shorter mean sleep duration in adolescents [33,46].

Sleep schedule, habits, and problems (n = 8)—Onset IIV, waking IIV, and habits IIV are not associated with children's self-reported sleep/wake problems [36,37,47]. Preschoolers with a late bedtime have greater onset IIV and waking IIV than other preschoolers [63]. School-aged children have greater duration IIV on weekends than weekdays, but greater waking variability on weekdays than weekends [77]. Similar, adolescents have greater onset IIV and waking IIV during vacation periods than school periods [59], and greater duration IIV is likewise associated with a larger difference between weekday and weekend sleep duration [33]. Adolescents with good overall sleep hygiene have less duration IIV than adolescents with poor sleep hygiene [55].

Daytime sleepiness and napping (n = 4)—Two studies did not find an association between onset IIV, waking IIV, or habits IIV and children's daytime sleepiness [36,47]. However, the time of day when sleepiness is assessed may be important when examining associations with sleep IIV: Spruyt et al. [31] found that sleepiness rated early in the day was unassociated with duration IIV or onset IIV whereas sleepiness rated in the afternoon was associated with multiple sleep domains including greater onset IIV and greater duration IIV. There does appear to be an association between napping and greater onset IIV, waking IIV, and duration IIV [36,77].

Snoring (n = 1)—Among children with adenotonsillar hypertrophy, those who snored most nights had greater duration IIV than children who did not snore on most nights [44].

Theme H: Sleep interventions (*n* = 5)

Three studies have examined school-based interventions aimed at improving adolescents' sleep functioning [78–80]. Bei et al. [78] conducted a pilot study of a six-session mindfulness-based group in nine adolescent females with self-rated poor sleep. Though some positive intervention effects were found for sleep generally, findings for sleep IIV were mixed [78]. Sousa and colleagues evaluated a one-week sleep hygiene program delivered to students in 11^{th} [79] and 12^{th} [80] grades. An initial open trial found reduced onset IIV following the sleep hygiene program [79], and a subsequent study found that students randomized to receive the program had less onset IIV and waking IIV following the program compared to baseline whereas no change in sleep IIV was found in the control group [80]. McHale et al. [41] examined whether a workplace intervention designed to reduce employees' work-family conflict impacted the duration IIV of employees' children in a group-randomized trial (work teams were randomized to intervention or usual practice conditions). No change in duration IIV was found in children whose parents received the intervention, whereas children in the control group had increased duration IIV from baseline to follow-up one year later [41]. Finally, children with ADHD and initial insomnia had decreased onset IIV following a brief sleep hygiene intervention [81]. Children who continued to have initial insomnia following the sleep hygiene intervention entered into a double-blind crossover trial of melatonin, and no difference in onset IIV was found between melatonin and placebo [81]. Of note, intervention studies examining sleep IIV in children and adolescents are largely limited by small sample sizes, short follow-up periods, lack of a randomized design, and absence of active control groups.

Discussion

Summary of Findings

Intraindividual variability (i.e., night-to-night changes within a person, rather than across people) in sleep/wake patterns is common [17,46] and may be especially characteristic of child and adolescent sleep [30,42,59,82]. However, until very recently this aspect of sleep has largely been ignored in both youth and adults, despite emerging literature suggesting that sleep IIV may be just as important as mean sleep duration [30,32,48,52,60,68]. Bei and colleagues [26] systematically reviewed the adult literature and reported sleep IIV to be related to a variety of demographic, physical, and mental health outcomes. Recognizing that sleep patterns and correlates likely differ across the developmental spectrum, this review uniquely focused on correlates of sleep IIV in children and adolescents.

Overall, effect sizes tended to be small and results were mixed across many domains. Even so, several sets of findings were more consistent and point to promising areas of investigation. First, there is greater duration IIV and onset/waking IIV with more advanced pubertal status and age, suggesting that adolescence may be a developmental period when sleep IIV may be particularly impactful [5]. The mechanisms contributing to pronounced sleep IIV in adolescence will be important to evaluate in future research. Potential mechanisms include biological changes associated with puberty and brain maturation, increased academic and extra-curricular demands, and shifting interpersonal relationships including increasing prioritization of the peer group and decreasing parental supervision/monitoring [5,6]. Interestingly, Bei and colleagues [26] found younger age to be associated with greater sleep IIV in adults. It is tempting to conclude that adolescence and early adulthood may be when sleep IIV is most prevalent. However, no published study has examined sleep IIV across the full pediatric developmental spectrum, much less the lifespan. It is thus premature to draw conclusions regarding the possibility that the prevalence and impact of sleep IIV follows an inverted U-shaped curve across the lifespan, though this possibility should be investigated in future research.

Second, sleep IIV was frequently associated with poorer behavioral functioning, including externalizing behavior, aggression, inattention, and risky behavior. These associations were largely consistent across age ranges and reporters (e.g., adolescents, parents, teachers). Intriguingly, although studies examining sleep IIV in relation to global measures of social functioning (e.g., peer acceptance, social problems) reported mixed findings, sleep IIV was associated with adolescents spending *more* time with their peers. Although this latter finding could be viewed as evidence of sleep IIV being associated with better peer functioning, additional studies are needed. Spending more time with friends can be a positive aspect of peer functioning and social acceptance, but those friends could engage in and encourage externalizing behaviors (e.g., delinquency, alcohol/substance use, risk-taking) that may themselves be associated with greater sleep IIV. Moreover, it is likely that associations between sleep IIV and peer functioning and associated outcomes are moderated by parental monitoring and the quality of the parent-teen relationship [83]. These considerations underscore the importance of future research considering both costs and benefits, as well as moderating factors, that may be associated with sleep IIV.

Third, several studies examined sleep environments/schedules and sleep interventions that may impact – or stabilize – sleep IIV. Similar to the findings of Bei et al. [26], less optimal sleep environments (e.g., watching TV) and less structured environmental schedules (e.g., weekends, vacation periods) were reliably found to be related to increased sleep IIV. This suggests that clinical sleep recommendations around optimizing environmental factors may both address sleep duration and stabilize sleep. Although promising, sleep intervention findings were mixed with respect to sleep IIV, perhaps due to differences in intervention types and study designs.

Finally, several other interesting and important correlates of sleep IIV were identified, although with more mixed evidence. As in the adult literature [26], studies conducted in children and adolescents indicate that sleep IIV is associated with race/ethnicity (non-White youth having greater sleep IIV), physical health conditions (conditions such as asthma associated with greater sleep IIV), body weight (higher BMI correlated with more sleep IIV in adolescents), psychopathology (greater symptom severity associated with greater sleep IIV), and worse sleep parameters (greater sleep activity and shorter sleep duration associated with greater sleep IIV). Stress also appeared to be associated with more sleep IIV in both adults and youth; however, the types of stressors differed in a developmentally consistent manner; family stress and conflict, lower family SES, and community stress were particularly salient in youth. Napping has also been examined within both youth and adults but with different correlates: daytime napping was associated with greater nighttime sleep IIV in youth, whereas daytime napping IIV was associated with younger age and self-reported health conditions in adults [26].

Several significant correlates were identified in the present review within youth, but have yet to receive empirical attention in adults. These include: ADHD (diagnosis associated with greater sleep IIV), nutrition (higher sugar, fat, carbohydrate, and daily calories associated with greater sleep IIV), aspects of intellectual functioning (lower perceptual organization and verbal comprehension associated with greater sleep IIV), complex neurocognitive tasks (poorer performance associated with more sleep IIV), developmental disability (autism and other developmental disabilities associated with greater sleep IIV), and snoring (presence of snoring associated with sleep duration IIV). In sum, in children and adolescents sleep IIV is correlated with a wide range of outcomes, though in many instances a particular outcome was examined in only a few studies, making replication in new samples an important direction for future research which should also shed light on the discrepant findings reported in studies to date.

There may be several reasons for the mixed results among studies examining sleep IIV in children and adolescents. First, some associations became nonsignificant when controlling for other factors, but not all studies included similar (or any) covariates. This suggests the potential for complex relationships and the need for more sophisticated methodological (e.g., experimental and longitudinal designs) and statistical (e.g., structural equation modeling, multilevel modeling) approaches. Likewise, studies differed in whether they controlled for mean sleep functioning variables (e.g., mean sleep duration) when examining sleep IIV in relation to external correlates. Such covariation is critical in order to evaluate whether sleep IIV is uniquely associated with adjustment above and beyond the contribution

of mean sleep functioning (and vice versa). Of note, multiple studies that did control for mean sleep functioning did find unique effects for sleep IIV specifically [33,39,46,48,52,60,61]. Second, most studies examined youth within a restricted age range. Many associations (e.g., sex, BMI) were found in adolescents that were not found in younger children, further highlighting adolescence as a particularly important stage in development to examine the impact of sleep IIV. Third, significant correlates within domains often depended on the aspect of sleep variability examined (e.g., variability in duration versus timing), and many studies reported on only selected aspects of sleep IIV. Fourth, and especially relevant for adolescence [84–86], studies did not routinely specify whether sleep IIV was specific to school nights, or whether weekends or vacation/holiday periods were also included. The few studies that differentiated between school night and non-school night sleep suggest that adolescents have greater sleep IIV on weekends or during vacation periods [59,77], though the impact of this increase in sleep IIV remains unexamined and is a key direction for future research. Finally, because much of the research conducted was post hoc, it is likely that differing aspects of study designs contributed to mixed findings. For example, in regards to the relationship of sleep IIV with ADHD diagnosis, studies that excluded youth for taking medications or having comorbidities may have selected youth with less severe symptomology or less chaotic home environments, and therefore less variable sleep.

Future Directions

Theoretical Context—Notably lacking from the pediatric sleep IIV literature is a unifying theory to guide hypothesis-driven, systematic research. As Bei and colleagues [26] suggest, nightly variations in sleep may have a distinct etiology from an individual's mean overall sleep and thus it is important to understand (1) factors related to sleep IIV, (2) mechanisms of such nightly variability, and (3) the directionality of these relationships, all within the context of youth development. Figure 4 depicts a proposed theoretical model to guide future research addressing these questions. The themes identified in this review establish an initial set of factors that appear to be related, potentially bidirectionally, to pediatric sleep IIV. These factors are also often interrelated in complex ways. For example, while physical health and emotional and behavioral functioning may independently be related to sleep IIV, their interrelations [87–89] suggests the need for research to consider moderating and mediating factors as well as cascading interrelations across development.

Importantly, a theoretical model of sleep IIV in youth should be considered within a developmental framework. Sleep IIV and its related factors must be regarded both within their present context and within the context of prior relevant events and milestones. Factors most salient during infancy are likely different from those in childhood and adolescence and a "one size fits all" approach is inadequate. By extension, future studies should be designed within a developmental framework and should contribute to the understanding of how sleep IIV may differ – and have a differential impact – across the developmental spectrum.

Methodological and Analytical Considerations—Correlational research is helpful, but there is evidence of bidirectional relationships in this area of research, or even cyclic relationships [90]. Directional research, including experimental work, longitudinal studies, and treatment trials, can help untangle such interrelations, inform research on underlying

mechanisms, and provide critical information on the most effective and temporally critical points of intervention. More advanced statistical models also should be considered when exploring predictors or outcomes of sleep IIV. For example, more complex mediation and moderation analyses are needed to advance the theoretical framework for sleep IIV [91]. Researchers also should move toward daily-level examination of constructs. Objectively assessed sleep is almost always measured on a daily basis, yet most studies thus far report only averaged or mean variability values. Presenting the combination of averaged and daily-level statistics is appropriate to best understand the relative impact of within-person fluctuation in sleep and the relationship between constructs beyond between-person differences. Finally, likely an artifact of the post hoc nature of this research, sample size justifications and a priori power analyses were not included in studies. It is possible that some effects were nonsignificant due to being underpowered and may have contributed to mixed findings. In line with the need for systematic, hypothesis-driven research, future studies should consistently report effect sizes and whenever possible be conducted with sufficient power to detect effects. Relatedly, as discussed in Bei et al. [26], there are limitations to some of the commonly-used metrics for assessing sleep IIV (e.g., without controlling for mean sleep duration, larger variability metrics can be an artifact of larger means); the field would benefit from using more sophisticated methods that allow for computing variability in studies with small sample sizes and few measurement points [92]. Although many of the limitations in this body of research relate to the post hoc nature of studies, this is not to say these studies are not important or needed. In fact, it is likely that there are many existing datasets that have examined only mean sleep variables, and it is recommended that investigators leverage these existing datasets to further advance the study of sleep IIV.

Limitations

As also seems to be the case with adults [26] research into pediatric sleep IIV has been too heterogeneous to allow for a meta-analysis or to assess risk of reporting and publication bias. For many domains there were so few studies that it was difficult to draw conclusions. Indeed, there are developmentally-relevant outcome domains which appear not to have been studied with respect to sleep IIV at all (e.g., alcohol/substance use, delinquent behaviors, suicidality). Further, many of the included studies did not include sleep IIV as a primary focus, but happened to present relevant findings (e.g., tables showing standard deviations across different groups). Although including this information in the current review provided a more comprehensive picture of the literature, this approach may also weaken inferences. It is also possible that studies examined sleep IIV but did not report null findings, either in text or tables, which may contribute to publication bias in this area. In addition, we limited our review to published studies written in English, although it is worth noting that many studies included in in this review were conducted outside of English-speaking countries.

Conclusion

This is the first systematic review of the correlates of sleep IIV among children and adolescents. Although findings were mixed across many domains, it is important to note the variety of developmental, psychosocial, physical health, cognitive, and emotional and behavioral correlates of pediatric sleep variability that have either been shown consistently

or seem promising. Given the rapid acceleration in studies on sleep variability, we are optimistic that more refined, developmentally-sensitive, theory-driven, and directional research will clarify the causes, mechanisms, and consequences of daily fluctuations in the sleep of youth.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

ADHD	attention-deficit/hyperactivity disorder
BMI	body mass index
CV	coefficient of variance
EEG	electroencephalography
IIV	intraindividual variability
IQ	intelligence quotient
ISD	individual standard deviation
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SES	socioeconomic status
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology

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*The most important references are denoted by an asterisk.

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Practice Points

1. A systematic review examining the correlates of sleep IIV in children and adolescents identified 52 studies published between 2000 and 2015, with a recent increase in the number of studies examining sleep IIV in children.
2. The limited literature with varied methodological and assessment procedures limit drawing firm conclusions, though sleep IIV in youth does appear to be associated with increased age/pubertal status, non-White race, physical and neurodevelopmental conditions, psychopathology, body weight, stress, aspects of cognitive functioning, and poorer sleep functioning/habits.
3. The limited intervention work examining sleep IIV in adolescents is promising, though more work is required using more rigorous intervention designs.
4. Clinical sleep recommendations around optimizing environmental factors may need to address stability of sleep duration and timing, in addition to overall sleep duration and sleep habits.

Research Agenda

1. Research examining sleep intraindividual variability (IIV) in children and adolescents is generally post hoc and atheoretical, with a clear need for studies that advance theory pertaining to the cause, mechanisms, moderators, and outcomes of sleep IIV.
2. It is important for research examining sleep IIV to be rooted in a developmental framework.
3. Cross-sectional observational studies will continue to have merit, but studies using prospective and experimental designs are particularly needed.
4. Intervention studies are needed that use larger sample sizes, longer follow-up periods, and the presence of an active control group within a randomized design.
5. Empirically and theoretically relevant covariates should be included in studies examining sleep IIV in youth, and it is important to also control for mean sleep variables in order to evaluate the role and importance of sleep IIV specifically.
6. It is important for future studies to report bivariate associations pertaining to sleep IIV, including both null and significant correlations.
7. We recommend consistent terminology in future studies, and following Bei et al. [26] recommend the term “intraindividual variability” (IIV).

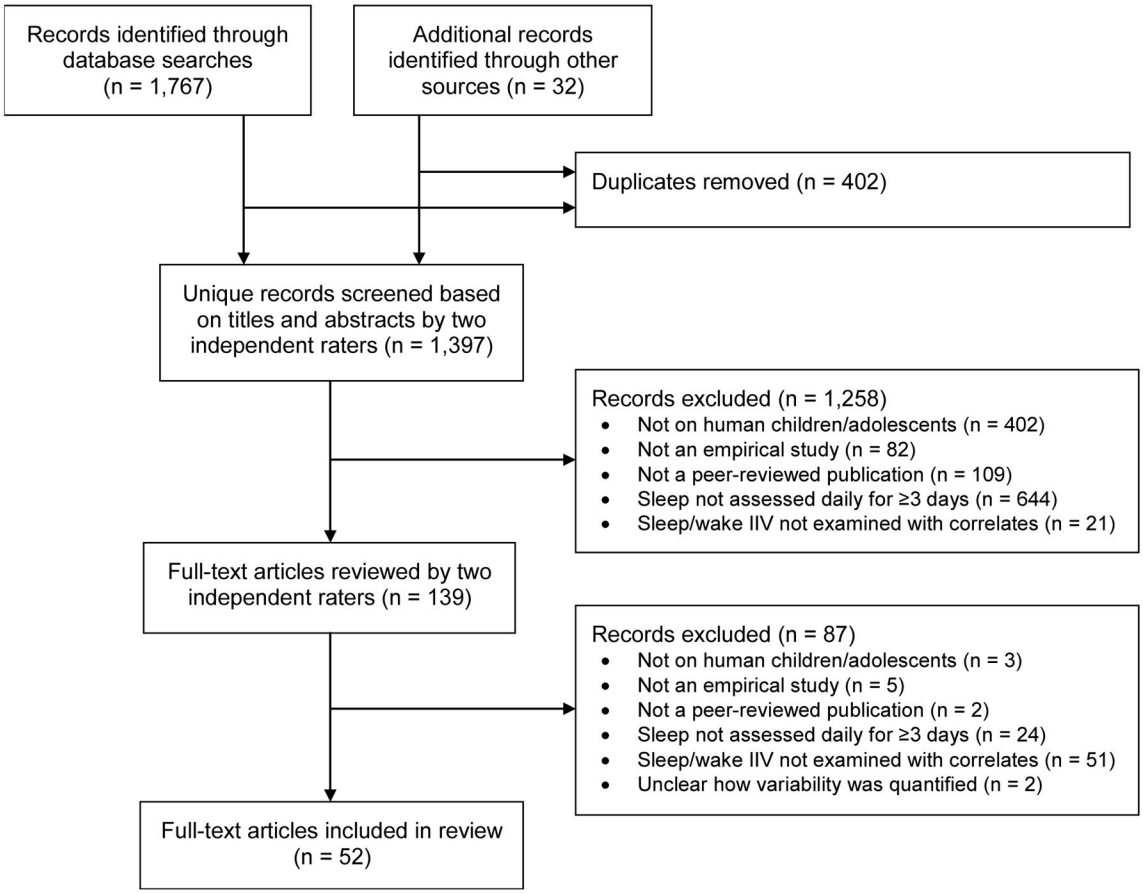

Figure 1.

Flow diagram of study selection.

Note. n = number of studies, IIV = intraindividual variability.

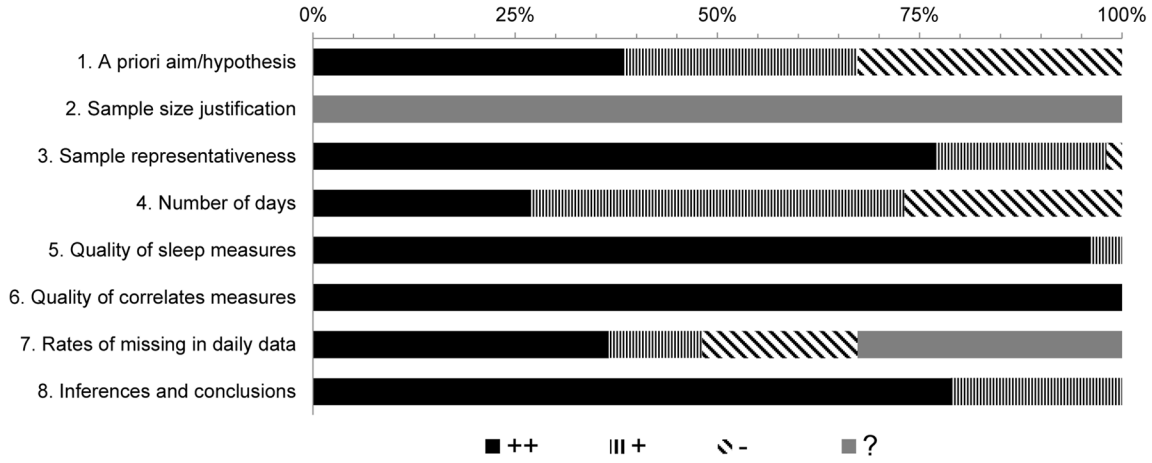

Figure 2.

Summary of quality assessment for included studies.

Note. 1. A priori aim/hypothesis: whether there were aims/hypotheses specific to intraindividual variability (IIV) of sleep/wake patterns; "++" indicates specific aims/hypotheses related to IIV; "+" indicates IIV implied but not explicitly stated, e.g., difference in sleep patterns; "-" indicates no aim/hypothesis specific to IIV. 2. Sample size justification: whether sample size was justified; "++" indicates justified, "+" indicates justified based on outcomes other than sleep/wake variability, "?" indicates unjustified. 3. Sample representativeness: representativeness of samples for the intended study population and for conclusions drawn, with "++", "+", and "-" indicating "good", "fair", and "poor". 4. Number of days: the number of continuous days variability was based on; "++" indicates ≥ 14, "+" indicates ≥7 and <14, and "-" indicates <7. 5. Quality of sleep measures: "++" indicates well validated, "+" indicates not well validated. 6. Quality of correlates measured: "++" indicates well validated, "+" indicates not well validated. 7. Rates of missing in daily data: "++" indicates ≤10%, "+" indicates ≤20% and >10%, "-" indicates >20%, and "?" indicates not reported. 8. Inferences and conclusions: quality of inferences and conclusions drawn, with "++", "+", and "-" indicating "good", "fair", and "poor".

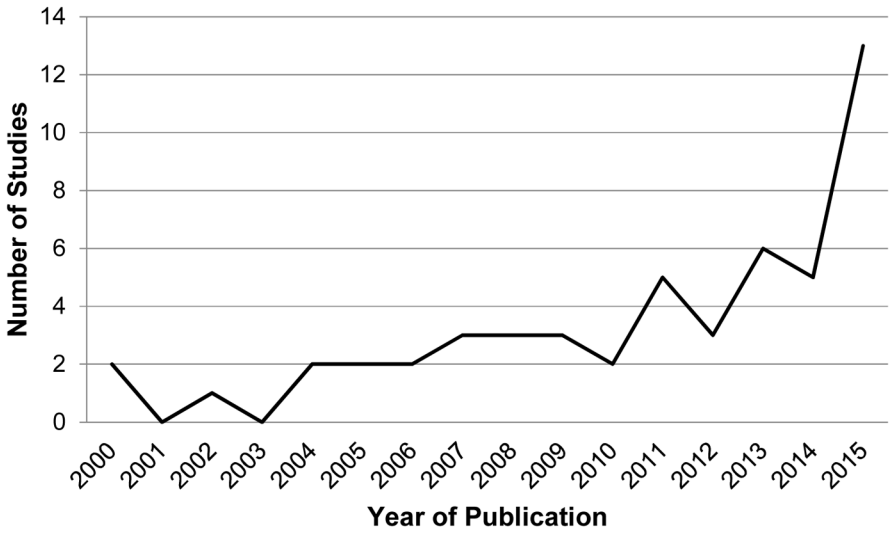

Figure 3.

Number of articles included in review by year of publication.

Note. One of the 2015 articles is an advance online publication awaiting pagination in a journal issue.

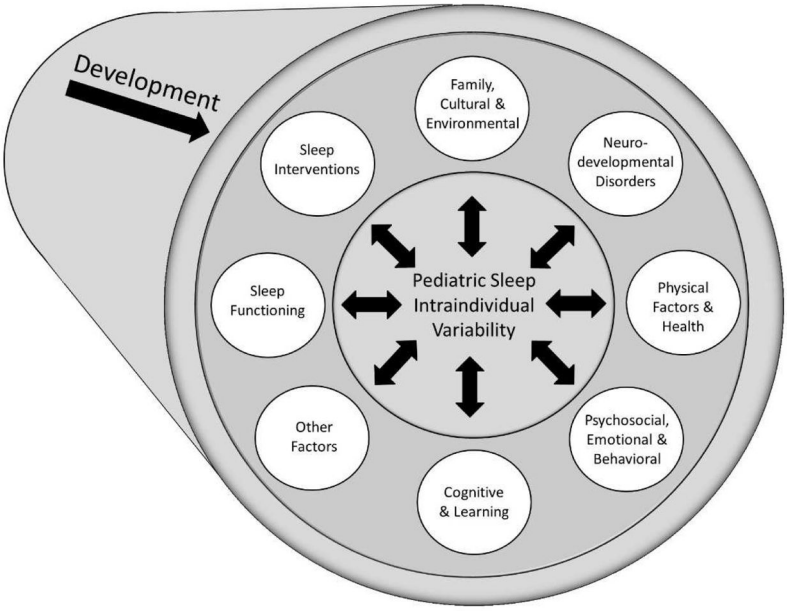

Figure 4.

Proposed theoretical model for intraindividual variability (IIV) of sleep/wake patterns in children and adolescents.

Table 1

Characteristics of included studies and summary of study findings

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
Acebo et al. (2005) [34]	Obs.	N=169; community; USA	12–60 mths	50%	91% White, 6% Multiracial, 2% African American, 0.5% Asian American, 0.5% Hispanic.	~7 days; actigraphy & diary (PR); CV based on actigraphy	A: Development B: Fam/Cultural/Environmental C: Physical	Age, sex	• Greater actigraphy-measured wake minutes IIV and SE IIV for 36-month-olds compared to both younger and older children. • No sex differences in sleep IIV using actigraph or diary variables. • Sex × age interactions for bedtime IIV (diary) and sleep time IIV (actigraphy), but no consistent pattern of interaction effects. • Controlling for age and sex, lower family SES associated with greater bedtime IIV (diary), sleep start time IIV (actigraphy), and sleep period IIV (actigraphy).
Anders et al. (2011) [73]	Obs.: short-term longit. with 3 groups	T1 N=194 (AUT n=68; DD w/o AUT n=57; TYP n=69) T2 N=179 T3 N=173; clinical; USA	T1: 2.0–5.5 (3.7±0.9) T2: 3 mths after T1 T3: 6 mths after T1	AUT=81 % , DD=74%, TYP=70%	White: AUT=59%, DD=47%, TYP=70%. Other races/ethnicities NR.	7 days at each time point; actigraphy & diary (PR); ISD based on actigraphy	F: Neurodev.	Ethnicity; mother's age, marital status, and education	• Sleep variability predominantly due to within-child variation as opposed to between-child variation. • AUT and DD groups had more BT IIV, SE IIV, and 24hr sleep IIV than TYP. No group differences in SOL IIV.
Araújo et al. (2013) [64]	Obs.	N=31; school; Brazil	10.0±1.5	46.2%	NR	15 days; diary (PR); variation	E: Cognition/Learning	N/A	• Weekday bedtime IIV significantly negatively associated with WISC-III Picture Completion subtest scores (r = −0.39) but nonsignificantly associated with Perceptual Organization Index or

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									Performance IQ scores (*r*s = −0.29 and −0.27, respectively). • Weekend bedtime IIV nonsignificantly associated with WISC-III scores (*r*s = −0.15 – −0.19).
Bagley et al. (2015) [47]	Obs.	N=271; community; USA	10–12.67 (11.33±7.74 mths)	53%	62% White, 38% Black.	~7 days; actigraphy & diary (PR); CV based on actigraphy	B: Fam/Cultural/Environmental D: Psychosocial G: Sleep	Sex, ethnicity, medication use, BMI	• Sleep environment variables (e.g., noise, uncomfortable bed) unassociated with sleep schedule IIV, with the sole exception of warmer temperature being associated with greater sleep schedule IIV (*r*=0.15). • Pre-sleep worries (e.g., about family, friends) unassociated with sleep schedule IIV, with sole exception of worries about schoolwork (*r*=0.14). • Income-to-needs ratio unassociated with sleep schedule IIV. • Sleep schedule IIV unassociated with child-rated sleep/wake problems or daytime sleepiness. • In path model with covariates, sleep environment composite, but not pre-sleep worries composite, significantly associated with sleep schedule IIV. Sleep environment was a significant intervening variable of the association between income-to-needs ratio and sleep schedule IIV.

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
Bates et al. (2002) [52]	Obs.	N=202 (n=184 for primary analyses); low-income community; USA	4–5 (4.9±0.51 for n=167 Head Start families; 4.9±0.71 for n=35 university preschool families)	53% and 43% of Head Start and university preschool families, respectively	Head Start (University): 90% (86%) White, 7% (3%) African American, 3% (11%) Asian American/Other.	4 weeks; diary (PR); squared deviation	B: Fam/Cultural/Environmental D: Psychosocial	N/A	• Night sleep IIV and bedtime IIV both significantly correlated with poorer preschool adjustment, more behavior problems, family stress, and impact of family stressors on child; no association between mean bedtime, night sleep duration, or total daily sleep on preschool adjustment/behavior or family stress. Sleep IIV unassociated with family cohesion, parental warmth, parental monitoring, or inductive parenting strategies. • Sleep disruption (latent variable including night sleep IIV, bedtime IIV, and mean bedtime) mediated the association between family stress and child adjustment.
Bei et al. (2013) [78]	Interv.: 6-session school program	N=10 (n=9 who completed the program); school sample with self-reported poor sleep; Australia	13–15	0%	NR	7 days (immediately before and after the school term when the intervention was conducted); actigraphy; ISD	H: Intervention	N/A	• Small effect of improved bed time regularity (Cohen's $d = 0.27$). • Small deteriorating effect of rise time regularity (Cohen's $d = -0.21$).
Bei et al. (2014) [59]	Obs.: compare school year and vacation	N=146; community; Australia	16.2±1.0	47.3%	59.59% Australian, 26.71% Asian, 5.48% European, 2.05% African, 2.05% Middle Eastern, 4.11% Other.	4 weeks (last week of school and the following 2 weeks of vacation, and first week of next term); actigraphy; variation	C: Physical G: Sleep	N/A	• Sleep IIV higher during vacation than school days, particularly for bedtime and rise time. • Females had greater SOL IIV than males, but females and males did not differ in IIV in other sleep domains.

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
Buckhalt et al. (2007) [36]	Obs.	N=166; community; USA	7–11 (8.72±0.29)	45%	69% White, 31% Black	7 days; actigraphy & diary (PR); CV based on actigraphy	A: Development B: Fam/Cultural/Environmental C: Physical E: Cognition/Learning	Age, sex, puberty status	• Older age associated with greater sleep onset IIV and wake time IIV (*r*s = .26 and .16, respectively). • Puberty status unrelated to sleep IIV. • Boys and girls did not differ on sleep IIV. • Controlling for SES, White children had less sleep onset IIV than Black children (no difference in wake time IIV). • Sleep onset IIV, but not wake time IIV, associated with greater sleep activity, lower SE, and shorter sleep duration as measured with actigraphy (*r*s = 0.16, −0.14, and −0.18, respectively). • Sleep IIV unassociated with child-reported sleepiness or sleep/wake problems. • Controlling for age, sex, and puberty status, napping duration on weekdays associated with greater wake time IIV (*r* = 0.22). Napping on weekends associated with sleep onset and wake time IIV (*r*s = 0.18 and 0.17, respectively). • Both sleep onset IIV and wake time IIV associated with child sharing a bedroom, number of persons sharing the child's bedroom, and persons-to-bedroom ratio (*r*s = 0.12–0.29).

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									• Caffeine intake unassociated with sleep onset IIV or wake time IIV. • Sleep IIV generally unassociated with cognitive functioning, aside from sleep onset IIV being significantly associated with poorer verbal ability (r = −0.21). • Controlling for age, sex, and puberty status, significant race × variability interactions in predicting IQ and verbal ability: greater variability associated with lower IQ (both sleep onset and wake time variability) and verbal ability (sleep onset variability only) for Black but not White children.
de Souza et al. (2012) [42]	Obs.	N=165; school; Brazil	Sample 1: 15±0.5 Sample 2: 15±0.6	Sample 1: 37% Sample 2: 43%	NR	7 days; diary (SR); SD	A: Development	N/A	• Adolescents had more BT IIV and WT IIV than teachers.
Doane et al. (2015) [43]	Longit.	T1 N=82, T2 N=76, T3 N=71; university; USA	T1: 18.05±0.41 (spring of high school senior year); T2 5.2±0.96 mths after T1 (fall of first college year); T3 4.1±0.84 mths after T2 (spring of first college year)	T1 & T2: 24% T3: 23%	54% White, 23% Hispanic, 13% Multiracial, 5% Black, 5% Asian American/ Pacific Islander	4 nights; actigraphy & diary (SR); ISD based on actigraphy	A: Development D: Psychosocial		• WT IIV increased from T1 to T2 (Cohen's d = 0.59). No change in sleep start IIV across time-points. • WT IIV unassociated with anxiety or depression, concurrently or over time. • Sleep start IIV was not significantly stable over time (marginally significant). • T1 anxiety marginally associated with T2 sleep start IIV, and in turn, T2 sleep start IIV marginally associated with T3 anxiety. • T1 depression significantly associated with T2 sleep

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									start IIV; sleep start IIV was not associated with subsequent depression.
El-Sheikh et al. (2013) [37]	Obs.	N=276; community; USA	9.44±0.71	52%	66% White, 34% Black	7 nights; actigraphy; CV	A: Development B: Fam/Cultural/Environmental G: Sleep	Age, single-parent household, medications, presence of asthma	• No race difference in sleep onset IIV. • Sleep onset IIV significantly correlated with fewer sleep minutes (r = −0.17) but not with SE or child-rated sleep/wake problems. • Sleep onset IIV significantly correlated with having greater family economic hardship (rs = 0.15 – 0.22). • Sleep onset IIV not significantly correlated with child age, medication status, single-parent status, income-to-needs ratio, maternal education, or community poverty. • After controlling for covariates, significant ethnicity × income-to-needs ratio interaction in predicting sleep onset IIV: Black children who were worse off financially had greater IIV than other Black children; no significant effects for White children. • After controlling for covariates, greater family economic hardship remained significantly associated with greater sleep onset IIV.
Erath & El-Sheikh (2015) [45]	Longit.	N=339 (T1 N=282; T2 N=211; some additional children were recruited at T2	T1: 8–10 (9.42±0.71) T2: 10.42±0.67	T1: 46% T2: 45%	T1: 64% White, 36% Black T2: 63% White, 37% Black	7 nights; actigraphy; CV	B: Fam/Cultural/Environmental C: Physical G: Sleep	Sex, race, BMI, SES, presence of asthma	• Neither T1 nor T2 sleep onset IIV associated with sex, race, BMI, respiratory sinus arrhythmia reactivity,

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
		who did not participate at T1); community; USA							or skin conductance level reactivity. • Asthma status significantly associated with T1 and T2 sleep onset IIV (*r*s = 0.12 and 0.14, respectively). • Lower SES associated with sleep onset IIV at T1 (*r* = −0.14) but not at T2. • T1 sleep onset IIV significantly associated with fewer sleep minutes (*r* = −0.18) but not SE at T1 • T1 sleep onset IIV unassociated with T2 sleep onset variability. T2 sleep onset IIV unassociated with T2 sleep minutes or SE.
Fuligni & Hardway (2006) [46]	Obs.	N=761; school; USA	"approximately 14–15 years of age" (9th grade students)	49%	30.0% Mexican; 4.5% Other Latino; 29.9% Chinese; 10.8% Other Asian; 17.9% White; 12.7% Other (e.g., Black, Middle Eastern); 1.3% Unknown	14 nights; daily diary (SR); variance	B: Fam/Cultural/Environmental C: Physical G: Sleep	Total sleep duration	• Race unassociated with sleep time IIV. • Girls had more sleep time IIV than boys. • Sleep time IIV associated with obtaining less sleep across all days (*r* = −0.20), particularly on school nights (*r* = −0.31). Sleep time IIV associated with obtaining more sleep on non-school nights (*r* = 0.18). • Sleep time IIV significantly correlated with spending more time socializing with friends and more time playing on a computer outside of school (both *r*s = 0.10), but uncorrelated with time spent studying, watching TV, or helping the family. The significant correlations remained when controlling for daily sleep

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									time and non-school night/ school night difference. • Sleep time IIV uncorrelated with number of daily demands experienced each day. • Sleep time IIV significantly correlated with greater anxiety, depression, and fatigue (*r*s = 0.23, 0.16, and 0.20, respectively), and less happiness (*r* = −0.09). With the exception of happiness, all of these associations remained significant when controlling for daily sleep time and non-school night/ school night difference.
Gillen-O'Neel et al. (2013) [57]	Longit.	N=535; school; USA	T1: 9th grade; 13.94–16.22 (14.88±0.39) T2: 10th grade T3: 12th grade	47.9%	44% Asian American; 36% Latino; 20% European American	14 days; diary (SR); multilevel modeling	B: Fam/Cultural/Environmental	Having a test/quiz at school that day	• More time spent studying outside of school associated with obtaining less sleep that night, with this association growing increasingly stronger across high school. • Reduced sleep mediated the association between spending extra time studying and next day academic problems.
Goodlin-Jones et al. (2008) [74]	Obs./Group	N=194 (AUT n=68; DD w/o AUT n=57; TYP n=69); clinical; USA	2–5 (3.7±0.93)	75%	NR (see Goodlin-Jones et al., 2009)	7 nights; actigraphy & diary (PR); ISD based on actigraphy	F: Neurodev.	N/A	• No group differences in sleep IIV. • Less mature developmental age was significantly associated with greater sleep end IIV, sleep percentage IIV, SE IIV, and nap duration IIV.
Goodlin-Jones et al. (2009) [75]	Obs./Group	N=186 (AUT n=66; DD w/o AUT n=53; TYP n=67); clinical; USA	2–5 (3.68±0.93)	75%	60% White, 10% Hispanic, 3% Black, 3% Asian American, 24% Multiracial	7 nights; actigraphy & diary (PR); ISD based on actigraphy	F: Neurodev.	N/A	• No difference in sleep variability measures (i.e., sleep start, sleep duration, night waking, SE, sleep activity variability)

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									between children with clinically elevated ADHD symptoms (>70th percentile) on the CBCL (*n*=21 of 186) or TRF (*n*=15 of 99) and children with non-elevated scores.
Gould et al. (2000) [76]	Obs./Group	N=21 (fragile X syndrome n=13; controls n=8); clinical; Australia	Fragile X group: 4.7–11 (8.04±1.65) Control group: 6.1–11 (8.14±1.83	100%	NR	14 days; diary (PR); variance	F: Neurodev.	N/A	• Boys with fragile X syndrome had greater sleep duration IIV, sleep onset latency IIV, and sleep termination IIV than comparison boys. • CBCL Attention Problems score significantly positively correlated with sleep onset latency IIV in the comparison boys but not boys with fragile X.
Gruber & Sadeh (2004) [66]	Obs./Group	N=49 (ADHD n=24; controls n=24); clinical; Israel	ADHD: 7–11 (8.94±1.25) Controls: 7–10 (8.83±1.01)	100%	NR	5 nights; actigraphy; ISD	E: Cognition/Learning F: Neurodev.	N/A	• Compared to controls, boys with ADHD had greater sleep onset IIV, sleep duration IIV, and true sleep time IIV. • Boys with ADHD did not differ from controls in rise time IIV, SE IIV, percentage of motionless sleep IIV, or number of night wakings IIV. • Greater sleep quantity IIV and sleep quality IIV associated with poorer performance on neurocognitive tasks in control boys. No association between sleep IIV and neurobehavioral functioning in boys with ADHD.
Gruber et al. (2000) [68]	Obs./Group	N=102 (ADHD n=38; controls n=64); clinical; Israel	ADHD: 6–14 (9.6±2.7) Controls: 7.5–11.5 (9.4±1.7)	100%	NR	5 nights; actigraphy and diary (SR); ISD	F: Neurodev.	Age	• Actigraphy: Compared to controls, boys with ADHD had greater sleep onset IIV,

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
						using both actigraphy and diary (separately)			sleep duration IIV; and true sleep time IIV. Boys with ADHD did not differ from controls in sleep percent IIV, longest sleep period IIV, or number of night wakings IIV. • Actigraphy: True sleep time IIV was the strongest sleep measure in distinguishing between boys with or without ADHD in stepwise discriminant analysis. • Diary: Boys with and without ADHD did not differ on any sleep IIV measure (bedtime, rise time, night wakings, sleep onset latency, daytime tiredness).
He et al. (2015) [32]	Obs.	N=305; community; USA	16.72±2.3	52.46%	78.7% White	7 nights; actigraphy and diary (SR); ISD	C: Physical	Age, race, sex, BMI percentile, Tanner stage	• Mean sleep duration variability was 1.2±0.6h. • Males and females did not differ on sleep duration IIV. • Controlling for covariates, sleep duration IIV, but not mean sleep duration, was significantly associated with multiple abdominal obesity measures (ie, android/gynoid fat mass ratio, android/whole body fat mass proportion, visceral adipose tissue, subcutaneous adipose tissue, total fat area); only abdominal measure unassociated with sleep duration variability was gynoid/whole body fat mass proportion. • Mediation analyses indicated that the association between sleep duration IIV and abdominal

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									obesity measures is mediated in part by greater energy intake, especially from fats and carbohydrates.
He et al. (2015) [60]	Obs.	N=324; community; USA	16.72±2.27	51.85%	79.32% White	7 nights; actigraphy and diary (SR); ISD	C: Physical	Age, sex, race, BMI percentile	• Normal weight, overweight, and obese teens did not differ in sleep duration IIV. • Controlling for covariates and mean sleep duration, sleep duration IIV significantly associated with greater daily caloric intake, fat intake, and carbohydrate intake, but not with protein intake. • Controlling for covariates and mean sleep duration, sleep duration IIV significantly associated with greater weekend morning, afternoon, and nighttime snack consumption, as well as school day nighttime snack consumption. Sleep duration IIV unrelated to energy intake and nutritional consumption.
Hoyniak et al. (2015) [65]	Obs.	N=15; community; USA	2–3 (2.79±0.28)	45%	NR	7 days; actigraphy and diary (PR); SD based on actigraphy	E: Cognition/Learning	Age, # target trials kept, % of correct trials	• Sleep IIV (a composite measure including sleep duration IIV and sleep onset IIV domains) significantly associated with longer target P3 latency (r= 0.61), and this association remained significant when controlling for covariates. • Sleep IIV unassociated with P3 amplitude or sustained attention.

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
Hvolby et al. (2008) [69]	Obs./Group	N=206 (n=45 with ADHD; n=64 psychiatric controls; n=97 healthy controls); clinical; Denmark	5.75–12.33 (8.42±NR)	74%	NR	5 days; actigraphy and diary (PR); variance based on actigraphy	F: Neurodev.	Sex, family type	• Controlling for covariates, children with ADHD had greater sleep onset latency IIV than both psychiatric control and healthy control children. • Children with ADHD who did and did not have a comorbid diagnosis of ODD did not differ in sleep onset latency IIV.
Kelly & El-Sheikh (2011) [53]	Longit.	N=176 (T2 n=142); community; USA	T1: 8.68±0.36 T2: 2 years after T1	44%	69% European American; 31% African American	7 nights; actigraphy and diary (PR); CV based on actigraphy	B: Fam/Cultural/Environmental	Sex, ethnicity, age, SES, externalizing and internalizing symptoms	• Controlling for covariates and other sleep domains, T1 sleep onset time IIV significantly predicted T2 marital conflict. Likewise, T1 marital conflict significantly predicted T2 sleep onset time IIV. • Controlling for covariates, significant T1 marital conflict × race interaction in predicting T2 wake time IIV: T1 marital conflict associated with greater T2 wake time IIV for African American but not European American children. • Controlling for covariates, significant T1 marital conflict × SES interaction in predicting T2 sleep onset time IIV: T1 marital conflict associated with greater T2 sleep onset time IIV only for children from lower SES backgrounds.
Kjeldsen et al. (2014) [61]	Obs.	N=676; school; Denmark	8–11 (~10.0±0.6)	~52%	~6.7% had 0 parents born in Denmark; 12.6% had 1 parent born in Denmark; 80.7% had both parents born in Denmark	8 nights; actigraphy and diary (PR and SR); variance based on actigraphy	C: Physical G: Sleep	Age, sex, pubertal status, height, weight, screen time, physical activity, parental education, ethnicity, mean sleep duration	• Sleep duration IIV significantly correlated with less mean sleep duration (r = −0.14). • Controlling for covariates, sleep duration IIV significantly associated

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									with more dietary energy from added sugar and greater sugar-sweetened beverage intake. • Sleep duration IIV was unassociated with food energy density, fasting plasma leptin, or fasting plasma ghrelin.
Könen et al. (2015) [30]	Obs.	N=110; school; Germany	8–11 (9.88±0.61)	59%	NR (77% were native German-speakers)	31 days; diary (SR); ISD & multilevel modeling	E: Cognition/Learning	N/A	• ICCs indicated that overall variance in sleep variables attributable to within-person fluctuations. All sleep variables had a “substantial” average intraindividual SD, with mean bed time SD, wake time SD, and TIB SD all >1hr. • Within-person sleep quality significantly correlated with less within-person daytime tiredness (morning, noon, and afternoon) and better within-person WM performance (morning and noon, but not afternoon). • Controlling for daily trends and other within-person sleep variables, within-person sleep quality associated with better morning WM performance with the effect particularly pronounced in children with lower average performance levels. Within-person sleep quality unassociated with noon or afternoon WM performance. • Controlling for daily trends and other within-person sleep variables, within-person TIB had an

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									asymmetric inverted-U-shaped association with morning WM performance: both less TIB than usual and more TIB than usual associated with poorer morning WM performance. Within-person TIB unassociated with noon or afternoon WM performance. • Controlling for daily trends and within-person sleep variables, within-person tiredness associated with poorer afternoon WM performance but unassociated with morning or noon WM performance.
Kuo et al. (2015) [48]	Longit.	N=246; community; USA	T1: 17.72±0.57 T2: 19.60±0.66	49%	100% Mexican American	7 nights; nightly phone calls at T1; variance	B: Fam/Cultural/Environmental C: Physical D: Psychosocial	Sex, family SES	• Sleep duration IIV unassociated with family SES, T1 sleep duration, T1 or T2 BMI, T1 or T2 depression, T1 physical health, or T1 risky behaviors. • Sleep duration IIV unassociated with most family and school/peer context variables (assessed at T1), with the exceptions of associations with less intimacy with father (r = −0.25), greater conflict with mother (r = .25), greater time spent with peers (r = 0.20), and less time spent at school (r = −0.18). These associations remained significant or marginal when controlling for covariates and the other context variables; being female was marginally associated with greater sleep duration variability in the regression model.

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									• Controlling for covariates, T1 sleep duration, and T1 of the outcome variable, sleep duration IIV at T1 was a significant predictor of poorer self-rated physical health and greater risky behaviors at T2.
Landau et al. (2010) [67]	Obs./Group	N=44 (n=26 at familial risk for ADHD; n=18 controls); clinical; Israel	7 weeks (45 days±0.15)	100%	NR	5 days; actigraphy and diary (PR); ISD using both actigraphy and diary (separately)	F: Neurodev.	Age	• Nighttime sleep (7pm–7am): Boys with familial risk for ADHD did not differ from control boys in actigraphy-measured sleep duration IIV, diary-measured sleep duration IIVy, actigraphy-measured quiet sleep duration IIV, or diary-measured night wakings IIV. • Daytime sleep (7am–7pm): Boys with familial risk for ADHD had greater actigraphy-measured quiet sleep duration IIV, diary-measured wakings IIV, and diary-measured sleep duration IIV than control boys. No group difference on actigraphy-measured sleep duration IIV.
Marco et al. (2012) [49]	Obs.	N=155; school; USA	12.6±0.6 (7th grade students)	40%	47.1% White; 24.5% Hispanic; 9% Black; 7.1% Asian; 2.6% Native American; 3.9% Other; 5.8% Unknown	1 week; actigraphy and diary (SR); ISD using actigraphy	B: Fam/Cultural/Environmental	Sex, pubertal status, race, # of medical conditions, # of psychological conditions	• In multivariate analyses including SES, sleep, and contextual variables (e.g., neighborhood condition, # of people in home), only lower SES was associated with greater school-night sleep IIV. • Controlling for covariates, lower SES was significantly associated with sleep onset latency IIV, total sleep period IIV, and number of minutes asleep IIV.

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
McHale et al. (2011) [39]	Obs/Group	N= 469; community; USA	Older Sibling (15.7±1.6) Younger Sibling (12.8±0.58)	49.5%	100% Mexican American	7 days; telephone interview (SR); sum of difference scores across nights	A: Development B: Fam/Cultural/Environmental C: Physical D: Psychosocial E: Cognition/Learning	N/A	• Older adolescents exhibited more sleep duration IIV than younger adolescents • Sleep duration IIV unassociated with GPA or BMI. • School night sleep duration IIV was positively linked to depressive symptoms and risky behavior. • Higher levels of acculturation into Anglo culture of both mothers and fathers was associated with greater sleep duration IIV. • Youth from higher income families had less sleep duration IIV than youth from low income families. • Adolescent conflict with both mothers and fathers was linked to more sleep duration IIV.
McHale et al. (2015) [41]	Interv.: Employee work-place interv.	N=93 (intervention n=57, control n=36); employee children; USA	BL: 9–17 (13.34±2.30) FU: 12 months later	~50%[b]	67% White; 20% Asian/ Pacific Islander; 9.6% Hispanic; 1.6% Black; 1.6% Multiracial	8 days; telephone interview (SR); ISD	A: Development B: Fam/Cultural/Environmental H: Intervention	Income, ethnicity, workplace interv. targets, age, sex, day in study	• Child age significantly associated with greater sleep duration IIV. • Sex, ethnicity, parent income, and workplace intervention targets were unassociated with sleep duration IIV. • When including age, sex, and day in study in the model youth in the control group had greater sleep duration IIV from BL to FU. No change in sleep duration IIV in intervention group.
Moore et al. (2009) [62]	Obs.	N=247; community; USA	13–16 (13.6±0.7)	51.4%	54.3% non-White, 45.7% White	5–7 days; actigraphy; ISD	C: Physical D: Psychosocial	Age, sex, minority status, parent education, parent	• Sleep duration IIV was not significantly associated with externalizing

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
								income, BMI, preterm status, vacation status, asthma	behaviors (rated by parents or teachers), depression or anxiety (rated by teen), or perceived health (rated by teen or parent; association with parent-rated health was marginally significant, $r = .11$, $p = .06$).
Moore et al. (2011) [40]	Obs.	N=247; community; USA	12.94–16.67 (13.67±0.75)	51.4%	54.3% non-White, 45.7% White	3–7 days; actigraphy; CV	A: Development B: Fam/Cultural/Environmental C: Physical F: Neurodev.	Age, health	• Greater TST IIV in non-White teens compared to White teens, and among teens living in distressed neighborhoods compared to teens living in non-distressed neighborhoods. • TST IIV significantly correlated with older age ($r = 0.15$), more advanced pubertal status ($r = 0.14$), more neighborhood distress ($r = 0.17$), less parent education ($r = -0.13$), less parent income ($r = -0.23$). Only older age and non-White ethnicity remained significantly associated with TST IIV when controlling for other demographics. • TST IIV significantly correlated with higher BMI ($r = 0.25$). This association remained significant when controlling for age, ethnicity, asthma status, ADHD status, and preterm birth status. Asthma, pre-term birth, and ADHD unassociated with TST IIV.
Moreau et al. (2014) [70]	Obs.	N=82 (ADHD n=41; controls n=41); clinical; Canada	6–13 (ADHD: 9.7±1.7; controls: 9.6±1.6)	58.5%	NR	7 days; actigraphy and diary (PR); ISD based on actigraphy	F: Neurodev.	N/A	• Children with ADHD had greater SOL IIV and nocturnal motor activity IIV than controls, but no group differences in TST IIV, WASO IIV, or SE IIV.

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									• In medication subgroup analyses, only the unmedicated subgroup of children with ADHD had greater SOL IIV than controls. • In psychiatric comorbidity subgroup analyses, only the comorbid subgroup of children with ADHD had greater SOL IIV than controls; children with ADHD who had elevated comorbidity symptoms had greater SE IIV than controls and other children with ADHD. • Children with ADHD had greater nocturnal motor activity IIV than controls, irrespective of medication status or comorbid symptoms.
Owens et al. (2009) [71]	Obs./Group	N=125 (ADHD medication naïve n=80; controls n=45); clinical; USA	6–14 (ADHD: 10.2±2.0; controls: 10.3±2.6)	67% (ADHD: 77%, controls: 50%)	84% White 16% non-White	5–12 days; actigraphy and diary (SR&PR); ISD based on actigraphy	F: Neurodev.	N/A	• Children with and without ADHD did not differ in SOL IIV or sleep time IIV. • Children with ADHD who did and did not have comorbid ODD did not differ in SOL variability or sleep time variability.
Poirier & Corkum (2015) [72]	Obs./Group	N=100 (ADHD medication naïve n=50;controls n=50); clinical; USA	ADHD: 8.99±1.68; controls: 9.37±1.64	82%	NR	4–7 days; actigraphy; ISD	F: Neurodev.	N/A	• Main effect of sleep duration variability for all children. • Children with and without ADHD did not differ in sleep onset latency variability, sleep duration variability, sleep minutes variability, or SE variability.

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
Sousa et al. (2007) [79]	Interv.: week-long (50 min./day) sleep hygiene program	N=58; school; Brazil	15.98±0.93	22%	NR	2 weeks each at baseline and post-intervention; diary (SR); ISD	H: Intervention	N/A	• Bedtime variability was reduced following the sleep hygiene program.
Sousa et al. (2013) [80]	Interv,: week-long (50 min./day) sleep hygiene program	N=34 (intervention n=18, control n=16); school; Brazil	(16.8±0.6)	16%	100% Brazilian	7 days; diary (SR); ISD	H: Intervention	N/A	• The intervention group had less bedtime and wake time variability following the intervention compared to baseline, whereas no change in sleep variability was found in the control group.
Spilsbury et al. (2004) [38]	Obs.	N=755; community; USA	8–11 (9.5±0.8)	50%	64.6% White, 31.3% African American, 2.1% Biracial, 1.3% Hispanic, 0.4% Native American, 0.3% Asian	7 days; diary (SR); CV	A: Development B: Fam/Cultural/Environmental C: Physical	Vacation status, health problems, behavioral problems, sleep disorders, caregiver education, preterm status.	• Non-White boys and girls ages 10–11 had the greatest sleep duration IIV across the week. Excluding children who completed the diary during summer break or family vacation, non-White boys ages 10–11 had the largest variation in sleep across the week. • Non-White boys ages 10–11 and non-White girls age 8 had the greatest sleep duration IIV on the weekend. • Nearly 10% of the sample had a CV >15%, and 3% had a CV >20%, with the highest proportions of children with CVs >15% found among non-White boys ages 9–11.
Spilsbury et al. (2005) [54]	Obs.	N=449; community; USA	8–11 (9.5±0.9)	50%	53.7% White, 46.3% Black	7 days; diary (SR); CV	B: Fam/Cultural/Environmental	Age, sex, ethnicity, preterm, health conditions, school or vacation status, caregiver education, median annual income	• Sleep duration variability was not associated with quality of home physical environment. • Controlling for covariates, greater encouragement of maturity was associated with less sleep duration

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									variability for girls but not boys. • A more favorable home environment was significantly correlated with less sleep duration variability, but this association did not remain when controlling for covariates (specific home environment domains were also unassociated with sleep duration variability when controlling for covariates).
Spilsbury et al. (2014) [58]	Obs./Short-term longit.	T1 N=46, T2 N=33; community; USA	T1: 8–16 (11.4±2.5) T2: 3 mths. later	43.5%	60.9% Black, 23.9% White, 6.5% Hispanic, 8.7% Multiracial	7 days; actigraphy and diary (SR); CV based on actigraphy	B: Fam/Cultural/Environmental	Age, sex, ethnicity, health problems, caregiver education, preterm status, income, school or vacation status, PTS sx, previous year's exposure to violence, violence program services	• Controlling for covariates, children who were physically assaulted during a violence exposure event did not have different sleep duration variability (averaged across time-points) than children who were not physically assaulted during a violence exposure event. • Controlling for covariates, children who witnessed a homicide during a violence exposure event had marginally greater sleep duration variability (averaged across time-points) than children who did not witness a homicide during a violence exposure event. • Controlling for covariates, sleep duration variability was unassociated at either time-point with posttraumatic stress symptoms.

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
Spruyt et al. (2011) [56]	Obs./Group	N=308 (normal weight n=155, overweight n=53, obese n=100); clinical; USA	4–10 (7.2±1.3)	49%	71.4% White 18.8% Black 9.7% Other	7 days; actigraphy; CV	C: Physical	Age	• Controlling for age, neither weekday nor weekend TST variability associated with BMI *z*-scores in healthy weight, overweight, or obese groups. • Controlling for age, TST variability did not differ between weekends and weekdays for normal weight or overweight children, whereas obese children had greater TST variability on weekends than weekdays. • Controlling for age, weekday TST variability was significantly associated with higher triglyceride levels in obese children (r=0.31) but not in normal weight or overweight children. • Controlling for age, neither weekday nor weekend TST variability significantly associated with glucose, insulin, cholesterol, lipoprotein, or C-reactive protein levels for normal weight, overweight, or obese children.
Spruyt et al. (2012) [31]	Obs.	N=18 (ADHD n=15; other disorders n=3); clinical (STP); USA	9.4±1.7	83%	88.9% Caucasian	7 days; actigraphy and diary (PR); variance	B: Fam/Cultural/Environmental C: Physical G: Sleep	N/A	• Children had a TST variability of 1hr 3min (week: 59min, weekend: 49min), BT variability of 1hr 41min (week: 28min, weekend: 37min), SOL of 20min (week: 18min, weekend: 19min), WASO of 1hr (week: 56min, weekend: 47min), WT of 39min (week: 16min, weekend: 32min), and % SE of 9.63 (week: 9.18, weekend: 6.99).

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									• In general, ≥50% of the variance across sleep domains was attributable to within-child daily differences. • More adaptive bedtime activities (eg, bedtime hugs, brushing teeth, putting on pajamas) were significantly associated with less TIB variability and less SE variability. • Children's self-rated sleepiness at the beginning of the camp day was unassociated with sleep domains; greater sleepiness in the afternoon was significantly associated with multiple sleep domains including lower SOL variability and greater TST variability. • Sleep variability unassociated with BMI or eating behaviors/food patterns.
Spruyt et al. (2015) [77]	Obs.	N=24; community; USA	3–9 (5.4±1.7)	45.8%	100% Black	14 days at 3 separate time points over 3 months; actigraphy; ISD	G: Sleep	N/A	• Greater TST variability on weekends than weekdays. Sleep offset latency more variable on weekdays than weekends. • Greater TST variability was associated with shorter napping sleep offset latency (r_s = −0.81), greater nighttime sleep fragmentation variability was associated with shorter napping wake after sleep onset (r_s = −0.74) • Greater nighttime sleep period time variability was associated with greater nap sleep period time on

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									weekdays (r_s = 0.93) but not weekends. • Greater weekend nighttime SOL variability was associated with less daytime sleep fragmentation (r_s = −0.91).
Storfer-Isser et al. (2013) [55]	Obs.	N=517; community; USA	16–19 (17.7±0.4)	50%	60% White 36% Black 2% Other	5–7 days; actigraphy & diary (SR); CV based on actigraphy	B: Fam/Cultural/Environmental G: Sleep	N/A	• Better overall sleep hygiene significantly correlated with less sleep duration variability (r = −0.21). • Better physiological, behavioral arousal, sleep environment, and daytime sleep habits were each significantly correlated with less sleep duration variability (rs = −0.12, −0.12, −0.21, −0.22, respectively). Cognitive/ emotional and sleep stability habits were not correlated with sleep duration variability. • Adolescents with poor sleep hygiene had greater sleep duration variability than adolescents with good sleep hygiene.
Suratt et al. (2007) [44]	Obs./Group	N=56 (low snore n= 20, high snore n= 36); children with adenotonsillar hypertrophy; USA	6–12 (8.69±1.93)	46%	64% White 34% Black 2% Asian	6 days; actigraphy and diary (SR), CV based on actigraphy	B: Fam/Cultural/Environmental E: Cognition/Learning G: Sleep	Snore group status	• Greater TIB variability significantly associated with shorter mean TIB. • Greater TIB variability significantly associated with lower vocabulary and similarities intelligence testing scores (assessed with WISC-III). • TIB variability unassociated with block design intelligence scores (assessed on WISC-III), sustained attention

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									(assessed with the Connors' CPT), memory (assessed with the WRAML), or breathing variables assessed with PSG. • Greater TIB variability in Black children compared to White children. • Greater TIB variability in the high snoring group compared to the low snoring group.
Telzer et al. (2015) [33]	Longit.	N=48; community, USA	T1 (14.8) T2 approximately 1 year later (15.9) DTI scan 3 months later (16.4)	44%	Not reported	14 days at each time point; diary (SR), ISD	A: Development C: Physical G: Sleep	Mean sleep duration & weekend-weekday sleep time difference	• Daily sleep duration variability averaged over 1.5h at T1 and T2. • No difference between T1 and T2 in bedtime variability or sleep duration variability. • Males and females did not differ in bedtime variability or sleep duration variability. • T1 sleep duration variability significantly correlated with greater weekend-weekday sleep duration at T1 (r=0.43) and less total sleep time at T2 (r=−0.39). • T1 bedtime variability significantly correlated with shorter sleep duration at T2 (r=−0.40). • T2 bedtime variability significantly correlated with T2 sleep duration variability (r=0.41). • Controlling for covariates, T1 sleep duration variability (but not bedtime variability) was associated

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									with less FA in several white matter tracts (index of white matter integrity). • Neither sleep duration variability nor bedtime variability at T2 were associated with FA.
Tininenko et al. (2010) [51]	Obs./Group	N=79 (therapeutic foster care n=17, regular foster care n=15, low income community n=18, upper middle income community n=29); community; USA	3–7 (5.25±1.05)	48%	82.3% White 7.6% Latino 6.3% Native American 3.8% Black	5 days; actigraphy and diary (PR), ISD based on actigraphy	B: Fam/Cultural/Environmental	N/A	• Children in therapeutic foster care had greater sleep duration variability than upper middle income community children; no other differences in sleep duration variability between therapeutic foster care, regular foster care, low income community, or upper middle income community children • Children in regular foster care had greater sleep latency variability than low income community children; no other differences in sleep latency variability between therapeutic foster care, regular foster care, low income community, or upper middle income community children. • No group differences in other sleep quantity, sleep quality, or sleep schedule variability domains.
Troxel et al. (2014) [50]	Obs.	N=242; community; USA	14–19 (15.7±1.3)	47%	57% Black 43% White	7 days; actigraphy and diary (SR); ISD based on diary	B: Fam/Cultural/Environmental	Age, sex, BMI, depressive sx, financial strain, family conflict, parental education	• In unadjusted models, adolescents from single-parent homes had greater BT variability (1.4±0.6h) compared to adolescents from two-parent homes (1.2±0.6h); family structure unassociated with BT variability when controlling for covariates

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									• Significant race × family structure interaction in predicting BT variability: White adolescents from two-parent households had lower BT variability compared to White adolescents from single-parent households, whereas there was no effect of family structure on BT variability for Black adolescents.
Vaughn et al. (2015) [35]	Obs.	N=62; school; USA	3–5 (4.15±0.62)	65%	66% White 29% Black 5% Other	7 days; actigraphy, diary (PR); ISD based on actigraphy	A: Development B: Fam/Cultural/Environmental C: Physical D: Psychosocial E: Cognition/Learning G: Sleep	Age, ethnicity, sex	• Sleep onset IIV was not significantly correlated with any other sleep measure. • Wake time IIV was significantly correlated with greater sleep activity (r = 0.26) but no other sleep measure. • Wake time IIV was unassociated with sex age, or ethnicity. • Controlling for covariates, wake time IIV was significantly associated with initiating negative interactions (r = 0.28), ego-undercontrol (r = 0.28), and the self-correction score on the Head to Toes task (r = 0.33). • Controlling for covariates, wake time IIV was unassociated with sociometry-assessed peer functioning, ego resiliency, receptive vocabulary, or teacher-rated attention.
Weiss et al. (2006) [81]	Interv.: Sleep hygiene followed by crossover melatonin trial	N=27 with ADHD and initial insomnia (>60min); clinical; Canada	6.5–14.7 (10.29)	90.9%	87.9% White, 6.1% Aboriginal, 3.0% Asian, 3.0% Black	40 days (10 baseline, 10 following sleep	H: Intervention	N/A	• Compared to baseline, SOL variability following sleep hygiene intervention was

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
						hygiene interv., 10 on melatonin, and 10 during placebo); actigraphy and diary (PR); ISD using both actigraphy and diary (separately)			significantly reduced based on diary (baseline: 47.7min, post interv.: 29.1min) and marginally reduced based on actigraphy (baseline: 53.26min, post interv.: 40.57min). • No difference between placebo and melatonin treatment in diary- or actigraphy-assessed SOL variability.
Yokomaku et al. (2008) [63]	Obs./Group	N=135 (late BT[c] group n=68, non-late BT group n=67); school; Japan	4–6 (late BT=4.7±0.6; non-late BT=4.6±0.6)	50%	100% Japanese	2 weeks; diary (PR); variation	D: Psychosocial G: Sleep	N/A	• Children with late BT had greater BT variability and WT variability than children with non-late BT. • WT variability was significantly correlated with greater withdrawn behaviors (r = 0.22), social problems (r = 0.27), thought problems (r = 0.19), attention problems (r = 0.32), aggressive behavior (r = 0.26), internalizing problems (r = 0.19), externalizing problems (r = 0.20), and total problems (r = 0.27) assessed using the CBCL, but was unassociated with somatic complaints, anxious/depressed behaviors, or delinquent behaviors. • BT variability was significantly correlated with greater anxious/ depressed behaviors (r = 0.17), delinquent behavior (r = 0.20), aggressive behavior (r = 0.22), internalizing problems (r = 0.20), externalizing problems (r = 0.21), and total problems (r = 0.24)

Study	Design	Sample: N, type, country	Age range (M±SD)[a]	% male	Race/ Ethnicity	IIV method: NR of days/weeks, measures, quantification	Theme(s)	Covariate(s)	Findings on sleep IIV
									assessed using the CBCL, but was unassociated with withdrawn behavior, somatic complaints, social problems, thought problems, or attention problems.

Note. ADHD = attention-deficit/hyperactivity disorder; ANS = automatic nervous system; AUT = autism; BMI = body mass index; BT = bedtime; CBCL = Child Behavior Checklist; Com = community sample; CPT = continuous performance test; Ctrl = control group; CV = coefficient of variance (calculated as the standard deviation of sleep duration divided by mean sleep duration); DD = developmental delay; diary = daily record such as sleep diary or sleep log; DTI = diffusion tensor imaging; FA = fractional anisotropy; Fam = Family; ICC = intraclass correlation; IIV = intraindividual variability; IQ = intelligence quotient; Interv. = intervention; ISD = individual standard deviation; longit. = longitudinal; mths = months; Neurodev. = Neurodevelopmental. ODD = oppositional defiant disorder; PR = parent-report; PSG = polysomnography; PTS = posttraumatic stress; SD = standard deviation; SE = sleep efficiency; SES = socioeconomic status; SOL = sleep onset latency; SR =self-report; STP = Summer Treatment Program (day treatment camp for children with ADHD); sx = symptoms; TIB = time-in-bed; TRF = Teacher's Report Form; TST = total sleep time; TV = television; TYP = typically developing; TWT = total wake time; wk = week; WASO = wake after sleep onset; WISC-III = Wechsler Intelligence Scale for Children Third Edition; WM = working memory; w/o = without; WRAML = Wide Range Assessment of Memory and Learning; WT = wake time.

[a] All ages are in years unless otherwise specified.

[b] Text states the sample to be 47.22% male, whereas table indicates the sample to be 50.54% male.

[c] Late bedtime defined as meeting one of the following three criteria: going out from their home with adults after 21:00hr ≥ 2 nights/week, going to bed after 23:00hr ≥4 nights/week, and returning home after 21:00hr ≥3 nights/week.