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CLINICAL REVIEW

Beyond the mean: A systematic review on the correlates of daily intraindividual variability of sleep/wake patterns

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SUMMARY

Features of an individual's sleep/wake patterns across multiple days are governed by two dimensions, the mean and the intraindividual variability (IIV). The existing literature focuses on the means, while the nature and correlates of sleep/wake IIV are not well understood. A systematic search of records in five major databases from inception to November 2014 identified 53 peer-reviewed empirical publications that examined correlates of sleep/wake IIV in adults. Overall, this literature appeared unsystematic and post hoc, with under-developed theoretical frameworks and inconsistent methodologies. Correlates most consistently associated with greater IIV in one or more aspects of sleep/wake patterns were: younger age, non-White race/ethnicity, living alone, physical health conditions, higher body mass index, weight gain, bipolar and unipolar depression symptomatology, stress, and evening chronotype; symptoms of insomnia and poor sleep were associated with higher sleep/wake IIV, which was reduced following sleep interventions. The effects of experimentally reduced sleep/wake IIV on daytime functioning were inconclusive. In extending current understanding of sleep/wake patterns beyond the mean values, IIV should be incorporated as an additional dimension when sleep is examined across multiple days. Theoretical and methodological shortcomings in the existing literature, and opportunities for future research are discussed.

Introduction

No two nights' sleep are the same. Daily variations in sleep/wake patterns are common. Over a number of days, features of an individual's sleep/wake pattern such as total sleep time (TST), sleep onset latency (SOL), can be characterized along two dimensions: 1) the individual mean, which quantifies the overall level across the days, and 2) the intraindividual variability (IIV), which quantifies daily variation around the mean. Intraindividual variability is an integral part of human daily sleep/wake patterns, and occurs naturally across all ages [1,2]. Whilst sleep is often measured across multiple days, the existing literature focuses primarily on the individual means. The nature and correlates (i.e., contributors and/or consequences) of IIV in sleep/wake patterns are seldom examined and not well understood.

The relevance of sleep/wake IIV and its contribution to our understanding of sleep/wake patterns beyond what can be learned from examining just the means have not been systematically assessed. From a theoretical perspective, although daily IIV tends to correlate with the individual mean (e.g., those with longer average SOL tend to have greater IIV in SOL, see the correlation matrix in Dillon et al., 2015 [2]), IIV quantifies the degree to which an individual's daily values are different from one another, thus adding information that is concealed when only the average level across these values is examined. It is also possible, that daily IIV and the mean levels of sleep/wake patterns have overlapping but also distinctive etiology. For example, the biological bases that underlie overall sleep/wake patterns are relatively stable across days: the homeostatic drive or sleep propensity rises with increasing time awake, and the circadian clock is typically synchronized to the

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Abbreviations

BMI	body mass index
BT	bedtime
CBT-I	cognitive behavioral therapy for insomnia
CV	coefficient of variance
IIV	intraindividual variability
ISD	intraindividual standard deviation
LO	lights out
MCI	mild cognitive impairment
MSSD	mean square of successive differences
NA	negative affect
PRISMA	preferred reporting items for systematic reviews and meta-analyses
PTSD	posttraumatic stress disorder
PVT	psychomotor vigilance tasks
RT	rise-time
SE	sleep efficiency
SOL	sleep onset latency
TIB	time-in-bed
TST	total sleep time
TWT	total wake time
(%)WASO	(percentage of) wake after sleep onset
"m" and "v"	were attached to a sleep variable to indicate the mean and intraindividual variability of this variable respectively.

dark–light cycles [3]. On a day to day basis however, a wide range of factors (e.g., psychopathology [4,5], personality traits [6], physical illness [7]) can affect the sleep/wake cycles beyond their relatively stable biological regulation, and contribute to IIV of sleep/wake across days. These factors are not well understood, and identifying them can help further current understanding of sleep/wake patterns from a day-to-day perspective.

Further, the study of sleep/wake IIV is of particular importance today, as the advances in technologies and increasing social and economic demands have encouraged a 24-h society [8], in which high daily variations in sleep patterns are common. Social jet lag and shift work, two conditions characterized by significant IIV in sleep/wake patterns, have been associated with restricted sleep duration and/or displacement of sleep timing [9,10], as well as negative health and wellbeing outcomes [11–13]. Direct examinations of sleep/wake IIV in relation to mental and physical health beyond the effects of mean sleep timing/duration/quality are rare, but have demonstrated unique effects of IIV. For example, in a large sample of older adults, controlling for the mean of TST, greater IIV of TST was associated with higher risk for physical health conditions and obesity [14].

Therefore, there are theoretical and empirical grounds for examining daily IIV in sleep/wake patterns. Whilst a number of studies have incorporated IIV in examining sleep over the past decades, this body of literature has not been brought together and systematically examined. This systematic review therefore has the following aims:

1) To examine the scope and characteristics of the existing literature that examined correlates of daily IIV of sleep/wake patterns;
2) To review the extent to which daily IIV in sleep timing, duration, and quality are associated with non-sleep related factors;
3) To identify gaps in this literature and opportunities for future research.

Methods

This systematic review was conducted with a standard protocol in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines [15].

Search strategy

Systematic searches were carried out across five databases (PubMed, CINAHL Plus, PsycInfo, Scopus, and Embase), including records from the inception of each database to November 2014. A filter was applied in all databases to include studies on human adults aged 18 and above. There was no language restriction, and non-English records were translated for review.

Search strategies were decided a priori by the review team after a series of pilot searches. Records that contained all of the following three components were targeted: 1) being related to sleep, operationalized as containing "sleep" in the title, abstract, or subject heading; 2) an implied presence of daily sleep measures, operationalized as containing any of following terms in the title or abstract[1]: "actigraph*", "diary", "diaries", "log(s)", "daily", "everyday", "night*", "day*", "week*", "month*"; 3) an implied examination of 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

After removal of duplicates, two authors (BB and JFW) independently screened the records for eligibility of inclusion. Screening was aided by a checklist that reflected the criteria below. Disagreements were resolved via discussion with the review team.

First, titles and abstracts of all records were screened using the following exclusion criteria: 1) did not include adult humans aged 18 and above; 2) was not an empirical study (e.g., reviews, editorials, correspondences); 3) was not a peer-reviewed publications (e.g., conference abstracts, book chapters); 4) sleep was not assessed daily (e.g., weekly, monthly), or daily assessment was for less than three days, or sleep measurements were based on polysomnography (polysomnographic studies were excluded as they typically have fewer repeated measures, and are prone to confounding factors to IIV that might vary across studies, such as first night effects, sleep environments, and schedules of sleep recordings); 5) daily IIV of sleep parameters were not quantitatively examined in relation to non-sleep related factors (e.g., studies that presented individual standard deviation [ISD] of daily TST but did not relate it to any non-sleep factor). Full-texts of the remaining records were further assessed for eligibility of inclusion with excellent [16] inter-rater reliability, Cohen's kappa = .76, 95% CI = [.67–.86]. To ensure comprehensive coverage, references in

[1] * Replaces multiple characters. E.g., "actigraph*" includes variations such as "actigraph", "actigraphs", "actigraphy". Text in "()" was included as an additional search term. E.g., for "log(s)", both "log" and "logs" were searched.

included studies were reviewed and relevant articles were considered for inclusion based on the above criteria.

Data extraction and synthesis

To systematically extract the essential characteristics of studies, the authors developed a data extraction form based on the STROBE statement, a guideline for reporting observational studies [17]. Data extraction for the whole sample was performed by BB. A randomly selected 25% of the sample was independently extracted by a second rater (JT or RM). Agreement between ratings was good (99.4% for study characteristics, 88.4% for quality assessment), thus no further double extraction was conducted.

Quality assessment

In the absence of a tool for comprehensively assessing the quality of observational studies that did not include direct group comparison, the authors developed a rating tool choosing quality assessment domains and quality rating scales based on Methods Guide for Effectiveness and Comparative Effectiveness Reviews developed by the Agency for Healthcare Research and Quality [18]. Two additional quality domains, the number of continuous days across which IIV was quantified, and the reporting of missing data, were selected because the authors believe they are directly relevant to potential bias in estimating IIV. See the caption of Fig. 2 for rating protocols.

Results

Search results

Systematic searches returned 3,569 unique records for title and abstract screening. Subsequently 164 records were selected for full-text screening, 53 of which were included for final data extraction and review. Refer to Fig. 1 for a flowchart of the selection process.

Study characteristics

Characteristics of included studies are summarized in Table 1.

Context and design

The 53 included studies were published between 1979 and 2014, with nearly half (49.1%) published since 2010. Most studies (81.1%) were of an observational nature (i.e., did not include manipulations of sleep/wake parameters); among these, all but one were conducted in naturalistic settings ($n = 42$); the exception [19] was a semi-naturalistic study that instructed no napping or sleep deprivation. Seven studies involved interventions (e.g., cognitive behavioral therapy for insomnia; CBT-I) that did not specifically target, but might have an effect on IIV of sleep [5,20–25]. Three studies applied an intervention or experimental procedures that aimed to change IIV of sleep/wake patterns directly [26–28].

Characteristics of the samples

Most studies (83.0%) were conducted in North America or Europe in predominantly white samples. Over half ($n = 31$, 58.5%) of the included studies examined relatively healthy adults (e.g., community samples, university students), one third of which ($n = 10$) included only older adults. The remaining 22 studies included samples of individuals with mental and/or physical health conditions.

Measurements and analyses of IIV

Most (94.3%) of included studies measured daily sleep subjectively via self-report using daily logs (e.g., daily sleep diary, daily questionnaires; $n = 38$) and/or objectively using actigraphy ($n = 20$). The most common methods used for quantifying IIV were ISD and coefficient of variance (CV), which were used by 66.0% ($n = 35$) and 9.4% ($n = 5$) of included studies respectively. The remaining 13 studies employed various other methods such as mean square of successive differences (MSSD), variance, and interquartile range. Only 15.1% ($n = 8$) of included studies controlled for the mean values of sleep variables when examining correlates of IIV [2,14,24,29–33]: six controlled for the mean value (e.g., SOLm) of the sleep variable for which IIV was examined (e.g., SOLv) [2,14,24,30–32], and others controlled for the means of either total sleep [14,29] or wake [33] time when sleep timing IIV was examined.

Quality assessment

Quality assessment of individual studies is presented in supplementary material and summarized in Fig. 2. Included studies had several strengths: most had reasonably representative samples (88.7%), used well validated measurements for sleep/wake patterns and for their correlates (96.2%), and drew inferences that were supported by the data (88.7%). However, there were some important limitations. First, the literature appeared unsystematic and post hoc, with nearly a third of included studies not having a priori aims or hypotheses that pertained to sleep/wake IIV. Second, only two studies [4,34] provided sample size justifications for analyses related to IIV (three studies had large sample sizes and hence likely sufficient power [2,14,35]). Third, whilst over half of studies based IIV on daily sleep/wake patterns measured for 14 or more consecutive days, none justified whether the duration was sufficient for the method employed in quantifying IIV. Finally, although missing data could impact the quality of IIV estimated, half of the studies did not report the number of days when data were missing; among those that did report it, rates of missing days were reasonable (<10% in about two thirds, 10%–20% in one third).

Primary findings

The 53 included studies examined correlates of IIV in sleep timing ($n = 24$), duration ($n = 36$), and quality ($n = 25$), as well as daytime naps ($n = 5$). Findings of included studies are presented in the following five themes based on the nature of correlates. Studies that examined correlates from multiple themes appear in each theme.

Theme A. Demographic and environmental factors ($n = 15$)

Studies in this theme focused on age, sex, ethnicity, and cohabitation as correlates of sleep/wake IIV. Overall, older age and cohabitation was associated with less variable sleep timing, and minority race was associated with more variable sleep duration and quality.

Age ($n = 9$). In both community [36–38] and outpatient insomnia [5] samples, younger age was consistently associated with more variable self-report bedtime (BT) and rise-time (RT). Findings on self-report sleep duration IIV in community samples were less consistent, with some studies reporting younger age associated with more variable nighttime TST (controlling for TSTm) [2], time-in-bed (TIB) [37], and daytime nap duration [37], whilst another study (females only) reported nonsignificant association between age and TSTv (controlling for TSTm) [31]. In both community [2] and posttraumatic stress disorder (PTSD) [30] samples, younger

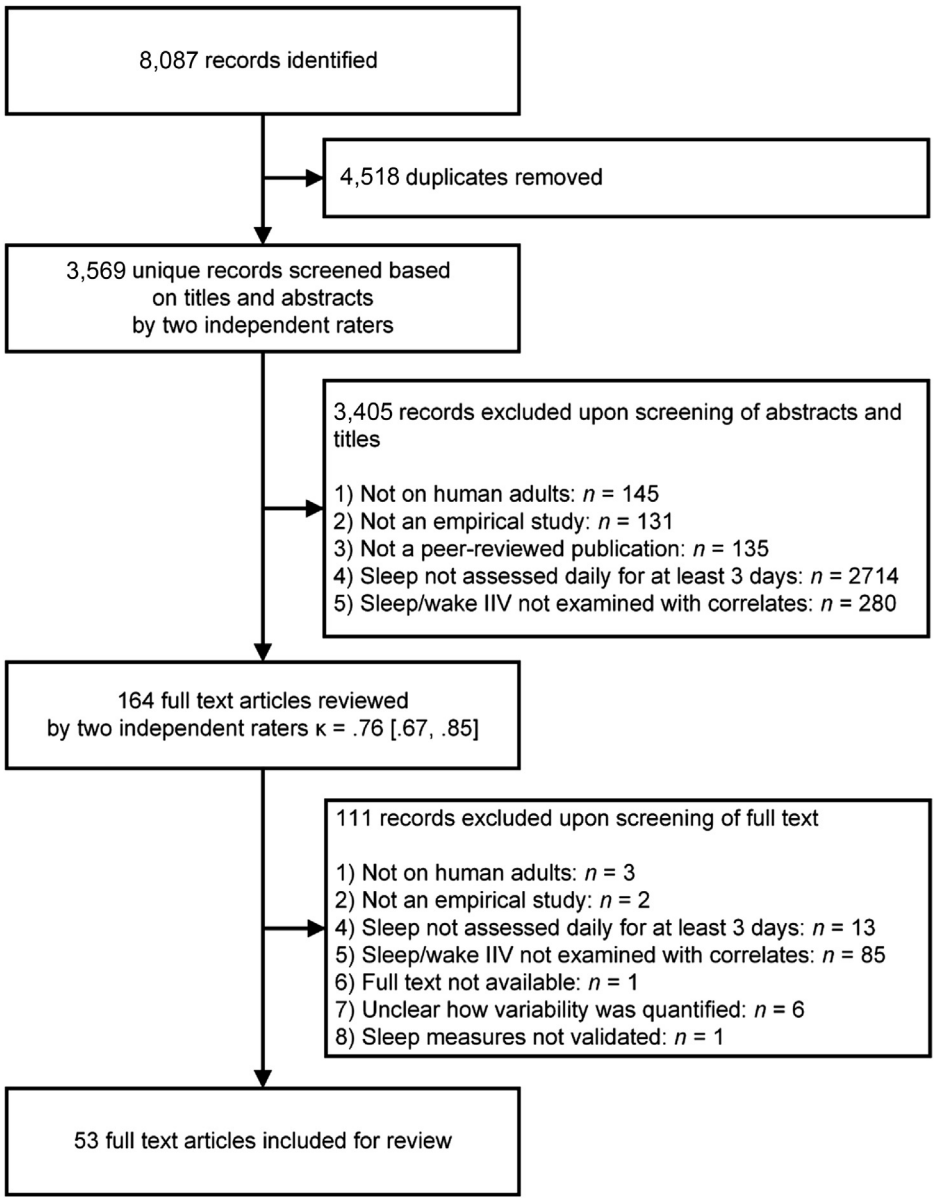

Fig. 1. Flowchart of study selection, *n* indicates the number of studies, IIV = intraindividual variability.

age was associated with more variable self-report and actigraphy-assessed nighttime awakenings respectively after controlling for respective means. Controlling for SOLm, younger age was also associated with greater SOLv in a community sample [2], but with lower SOLv in those with insomnia complaints [24].

Two studies examined longitudinal changes in self-report sleep/wake IIV over 10 y in community samples of middle aged [39] and older [37] adults. Variability in BT and RT did not change significantly over time among middle aged adults and among older adults who lived alone, but was lower at 10-y follow-up among older adults who cohabitate. Both studies reported nonsignificant change in the IIV of daily nap duration.

Sex (n = 3). Findings on the association between sex and sleep/wake IIV were inconclusive. Each of the three identified studies targeted a different age group. In a middle-aged community sample, females had greater actigraphy TSTv than males (controlling for TSTm) [32], but this was not the case when sleep was measured via self-report among university students (TSTm not controlled for) [40]. Among university students, males had significantly greater self-report RTv than females [40], but this was not the case among older adults [37]. The older adults study also found no significant sex differences in the IIV of self-report BT, TIB, or daily nap duration [37].

Race/ethnicity (n = 4). In a large sample of older community adults, greater IIV of actigraphy sleep midpoint and TST was associated with minority race (controlling for TSTm) [14]. Two studies compared actigraphy sleep/wake IIV in Black and Caucasian groups: both reported Black race being associated with more variable sleep quality, as indicated by more variable sleep fragmentation (controlling for its mean) [32], as well as sleep efficiency (SE) and SOL [35]; however, differences in sleep duration IIV were inconsistent, with one reporting Black race being associated with greater TSTv (not controlling for TSTm) [35] and the other a nonsignificant difference (controlling for TSTm) [32]. One study that examined differences between White and Hispanic university

students in self-report BTv and RTv found nonsignificant differences [40].

Cohabitation (n = 2). Two studies examined the relationship between self-report sleep/wake IIV and cohabitation in mid-old aged community adults, and both found that cohabitation was associated with less variable sleep timing [37,39] and duration [37].

Other correlates. One study examined the association between self-report TSTv and education level, as well as between TSTv and duration of daylight in females, and reported that controlling for TSTm, neither association was significant [31]. Another study focused on caregiving, and found that compared to non-carers, carers of dementia patients had significantly more variable actigraphy TST and SE (findings on SOL, wake after sleep onset (WASO), and self-report sleep quality were not significant) [41]. Lastly, one study examined the effects of sleep environment in insomnia patients, and reported that with ≥6 h TIB, the home environment was associated with greater actigraphy TSTv than a sleep laboratory [42].

Theme B. Physical health (n = 8)

Studies in this theme primarily focused on physical health conditions, body weight, and perinatal periods. Due to the heterogeneity of methodology, definitive conclusions cannot be drawn. Nevertheless, there is evidence that the presence of physical health conditions was associated with more variable sleep duration, higher body mass index (BMI) or weight gain was associated with more variable sleep timing, and the immediate postpartum period was associated with an overall more variable sleep/wake IIV. Two additional studies examined inflammatory biomarkers and estradiol as correlates.

Health conditions (n = 4). In a large community sample of older adults, controlling for TSTm and other covariates, more variable actigraphy sleep midpoint and TST were associated with higher rates of diabetes, heart conditions, and poorer self-reported health [14]. Similarly among older adults, controlling for age, greater self-report (but not actigraphy) daily nap duration IIV was associated with higher number of self-reported health conditions [34]. Consistent with these findings, patients with chronic kidney disease, and especially those with end-stage renal disease on dialysis had significantly more variable perceived sleep quality than healthy controls [7]. The onset of a serious physical illness, however, did not contribute to changes in self-report BTv and RTv over a 10-y period in middle-aged community living adults [39].

Body weight (n = 3). In older adults, after controlling for TSTm and other covariates, more variable actigraphy sleep midpoint was significantly associated with higher BMI in males and higher rates of obesity in females [14]. In the same study, more variable actigraphy TSTv was significantly associated with higher BMI and higher rates of obesity, such that each hour increase in the ISD of TST was associated with 63% and 22% increase in obesity odds in males and females respectively [14]. Among young adults starting university, more variable self-report sleep timing was associated with significantly greater weight gain, after controlling for depressive symptoms and other covariates [40]. However, a study of young females going through menstrual cycles, which also controlled for TSTm, found no significant association between self-report TSTv and weight, body fat, BMI, daily kilocalorie intake, or physical activity [31].

Childbearing (n = 2). Caring for a newborn is associated with more variable sleep/wake patterns. A longitudinal study on healthy women found that IIV in actigraphy sleep timing, duration, and quality all changed significantly from ~24 weeks gestation to 6 weeks postpartum, with the highest IIV observed during the first postpartum week [43]. However, IIV in actigraphy sleep midpoint did not change significantly from the 2nd to the 12th week postpartum [44].

Other correlates. Consistent with the association between physical health conditions and more variable sleep duration, higher inflammatory biomarkers (IL-6 and TNF-α) were linked to more variable self-report sleep timing and duration in older adults, particularly among those without sleep complaints [45]. Across menstrual cycles, higher mean estradiol has been associated with greater self-report TSTv after controlling for TSTm [31].

Theme C. Psychological factors and function (n = 29)

Studies in this theme focused on sleep/wake IIV in relation to bipolar and unipolar depression symptomatology, cognitive function, sleep-related daytime consequences, stress, and chronotype. We also briefly mention studies that examined other psychopathologies and personality traits as correlates.

Bipolar symptomatology (n = 6). Findings from the two studies that compared patients in remission from bipolar disorder with healthy controls found that patients had significantly more variable sleep duration and quality on actigraphy [4,46] and sleep diary [46]. In both studies, sleep/wake IIV was also a significant predictor of caseness (patient versus control status). Millar and colleagues [46] found that after controlling for daily mood ratings, actigraphy TSTv was among the best set of predictors for caseness, along with sleep diary TSTm and SOLm. In the study of Geoffroy et al. [4], actigraphy fragmentation index IIV was a significant predictor of caseness, along with TSTm, SOLm, and self-report sleep-related daytime function, which together correctly classified caseness in 89% of participants. Among patients with bipolar disorder during an interepisode period, greater number of life-time depressive episodes was associated with greater self-report BTv, SEv, and WASOv, and higher current depressive symptom severity was associated with greater self-report SOLv [47]. Although the number of life-time manic episodes moderately associated with greater WASOv, past or current manic symptom severity did not share notable relationships with other aspects of sleep/wake IIV [47].

Sleep/wake IIV has also been examined among individuals at risk for bipolar disorder. Among university students, those at high risk for bipolar disorder reported significantly more variable actigraphy sleep timing, duration, and quality (SE and fragmentation index, but not SOL or %WASO) [48], as well as more variable self-report sleep duration [49] than those at low risk. These results are consistent with findings from a study of healthy adults showing that hyperthymic temperament, a risk factor for bipolar spectrum disorders, was associated with significantly greater actigraphy TSTv [50].

Depressive symptoms (n = 7). There is some evidence that depression is associated with more variable sleep patterns. In a large community sample of older adults, more variable actigraphy sleep midpoint was associated with higher rates of antidepressant use [14]. However, among undergraduate students, self-report sleep timing IIV, a construct related to sleep midpoint, was not significantly associated with depressive symptom severity [40]. In the same large community sample, antidepressants use was also associated with more variable actigraphy sleep duration [14]. Consistent with this finding, other community based studies using both actigraphy [51,52] and self-report [2] found that more variable sleep duration was associated with higher depressive symptom

Table 1
Characteristics of included studies and summary of findings.

	Design	Sample: N, type, race/ethnicity (country)	Age (mean ± SD or range), %F	IIV method: Nr of days, measure, quantification	Theme: correlate(s)	Covariate(s)	Findings on IIV
Ankers & Jones, 2009 [48]	Obs: hypomanic risk vs Ctrl	55 Uni, NR (UK)	21.44 (3.36), 70.9%	Seven, acti & diary, ISD	C: risk of hypomania (bipolar)	Internal state, hypomanic interpretation	BTv & RTv: hypomanic risk group > Ctrl; BTv predicted group membership controlling for covariates; TSTv: hypomanic risk group > Ctrl; SEv & Fragmentation: hypomanic risk group > Ctrl; SOLv & %WASO: NS b/w groups.
Ari & Shulman, 2012 [58]	Obs: two time points in 1st & 2nd academic semesters	150 Uni, 88.2% Isreali (IL)	22.99 (1.75), 76.4%	Seven, diary, average difference from mean	C: adjustment to college	None	TSTv: low at both times in well-adjusted group; high in 1st low in 2nd semester in re-adjusted group.
Bijlenga et al., 2013 [59]	Obs: Pts vs Ctrl	24 ADHD & DSPD vs. Ctrl, NR (NL)	32.4 (10.1), 50.0%	Five, diary, variance	C: Comorbid ADHD & DSPD	None	SOTv: ADHD & DSPD > Ctrl
Bliwise et al., 2005 [39]	Obs: two time points 10 y apart	31 Com, NR (US)	66.5 (8.0), 67.7%	14 & 7, diary, variance	A: age, cohabitation; B: Onset of physical illness.	None	BTv & RTv: NS differences b/w T1 & T2 (with or without physical illness onset b/w time points); Cohabitation with -BTv & -RTv at T2 Napv: NS difference b/w T1 & T2.
Bonnet & Alter, 1982 [26]	Exp: 2 wk BL, 38 d regular sleep in lab, 4 wk habitual sleep, 2 wk FU	12 Uni, NR (US)	19–28, .0%	14 for BL FU, 7 for manipulation, diary, ISD	C: mood, vigilance, body temperature, momentary arousal	None	BTv, RTv, TSTv: regular < irregular conditions Mood, cognitive performance, sleep architecture: NS regular vs irregular conditions; Body temperature: regular < irregular conditions
Buman et al., 2011 [20]	Int: RCT for sleep complaint, Exercise vs health education Ctrl	36 Com, 92% White (US)	61.42 (6.72), NR	14 BL, 7 at 6 & 12 mo after BL, diary, CV	D: exercise for sleep complaints	None	BTv & RTv: NS b/w Exercise & Ctrl; TIBv: Exercise < Ctrl at 6 mo (moderate); SOLv: Exercise < Ctrl at 12 mo (moderate); nWASOv: NS b/w Exercise & Ctrl.
Buysse et al., 2010 [53]	Obs: Insomnia (chronic) vs Ctrl (healthy)	92 Com (older), 95.6% White (US)	71.16, 66.3%	14, acti & diary, ISD & mixed model	C: depressive symptoms; D: Insomnia symptoms.	None	BTv: Insomnia < Ctrl; RTv: Insomnia > Ctrl; TIBv: NS Insomnia vs Ctrl; TSTv: Insomnia > Ctrl on diary, NS on acti SEv & WASOv: Insomnia > Ctrl (diary & acti); SOLv: Insomnia > Ctrl on diary, NS on acti; Qualityv: Insomnia > Ctrl. Insomnia group: only TIBv ~ +depressive symptoms, weak relationship b/w diary IIV & sleep quality, sleepiness, or depressive symptoms
Carney et al., 2006 [63]	Obs: Good vs Poor sleepers based on PSQI	243 Uni, 79% White, 14% Black (US)	20.98 (3.24), 87.9%	14, diary (SRM), ISD	D: Good vs Poor sleep	Depressive symptoms	BTv: Poor > Good sleepers, NS after controlling for depressive symptoms; RTv: Poor > Good sleepers with/without controlling for depressive symptoms.
Cheek et al., 2004 [61]	Obs: Women with insomnia vs healthy Ctrl	121 Com, 80% White (US)	46.57 (4.07), 100.0%	Five, diary & PSG initiation/termination, ISD	D: Insomnia symptoms	Age	BTv ~ -sleep quality; SOLv: Insomnia > Ctrl; WASOv: NS b/w Insomnia & Ctrl; Qualityv: Insomnia > Ctrl;
Dautovich et al., 2012 [34]	Obs: Naturalistic observation	103 Com (older), 96.1% White (US)	72.90 (6.86), 64.1%	14, acti & diary, ISD after detrending based on the whole sample	B: Self-report Nr. health conditions	Age	Napv (diary not acti): +Nr health conditions
Dillon et al., 2014 [2]	Obs: Naturalistic observation	592 Normal sleepers, 70.1% White, 29.9% Black (US)	52.3 (19.5), 50.3%	14, diary, ISD & multilevel modeling	A: age; C: depressive symptoms.	Mean values, age, sex, race, depressive symptoms	TSTv: ~ +depressive symptoms, -age, age x sex, sex x race, age x sex x race (all small); SOLv: ~ +SOLm (large), -age (small), +female (small), black race (small); nWASOv: +nWASOm (large), +education (small), -age (small), +female (small); WASOv: +WASOm (large), -age (small); Within-person variability > b/w-person variability.
Edinger et al., 1992 [21]	Int: 2, 4, or 6 wk BL, 4 wk relaxation therapy, 2 wk assessment, 4 wk CBT, 2 wk assessment, 3-mo FU.	Seven Insomnia (sleep maintenance), 100% White (US)	61.9 (55–68), 57.1%	14 for diary, 7 for SAD, ISD	D: insomnia intervention	None	TIBv & TSTv: decreased over time on diary, NS change on SAD; SEv: decreased over time on both diary & SAD; SOLv: decreased over time on dairy, NS on SAD; nWASOv: NS change over time on diary; decreased after CBT on SAD, WASOv decreased over time;

(*continued on next page*)

Table 1 (*continued*)

	Design	Sample: N, type, race/ethnicity (country)	Age (mean ± SD or range), %F	IIV method: Nr of days, measure, quantification	Theme: correlate(s)	Covariate(s)	Findings on IIV
							Qualityv: NS change over time on diary; Napv: NS change over time. Multivariate analyses: intervention reduced overall variability on both diary & SAD. Most changes occurred after CBT but not after RT.
Eidelman et al., 2010 [47]	Obs: Naturalistic observation of IIV followed by interviews & questionnaires	21 Inter-episode bipolar Pts, 71.4% White (US)	37.0 (10.65), 85.7%	Seven, diary, ISD	C: bipolar age of onset, lifetime manic/depressive episodes, manic/depressive symptoms	None	BTv: NS for all correlates (but moderate ~ +depressive episodes); SOTv: ~ +depressive symptoms (large), NS ~ other correlates; TSTv: NS ~ all correlates; SEv: ~ +depressive episodes (large), NS ~ other correlates; WASOv: ~ +depressive episode (large), NS ~ manic episodes (but moderate), NS ~ other correlates.
Espie et al., 1989 [22]	Int: RCT of 8 wk relaxation, stimulus control, paradoxical intention, imagery relief placebo, or no treatment. 2 wk BL, assessments at 6 wk, 3, 6, & 17 mo FU	70 Insomnia (sleep onset), NR (UK)	44.9 (15.3), 67.1%	14 for BL, seven for other assessments, diary with SAD, ISD	D: insomnia symptoms	None	TSTv: ~ -time, NS treatment effect, significant treatment x time effect; SOLv: ~ -time, -treatment, significant treatment x time effect; Only active treatment improved sleep. Stimulus control improved sleep patterns, relaxation improved perceived sleep quality. Most results maintained at all FU.
Fainstein et al., 1997 [23]	Int: three groups with sleep disturbance: with depression, with dementia, with neither. Compared day start & end IIV on 21-d melatonin treatment.	41 Insomnia, NR (AR)	74 (12), 68.3%	Three, diary, CV	C: cognitive & psychiatric comorbidity; D: sleep intervention.	None	BTv: significant decrease in dementia but not other two groups.
Fichten et al., 2005 [62]	Obs: three groups of poor (research criteria insomnia), medium, good sleeper.	148 Com (older), NR (CA)	69 (55–87), 65.5%	Seven, diary, ISD	D: good vs poor sleepers & their estimation of time	None	TSTv: NS group differences; SOLv: poor sleepers > other groups; WASOv: poor sleepers > other groups; Poor sleepers more variable in wake (SOL + WASO), yet this does little to explain their biased perception of own sleep problems.
Geoffroy et al., 2014 [4]	Obs: bipolar in remission vs healthy Ctrl matched on age & sex.	55 Bipolar & Ctrl, NR (FR)	53.82 (10.30), 54.5%	21, acti (with diary), ISD	C: bipolar in remission	None	TIBv & TSTv: Bipolar remission > Ctrl; SEv: Bipolar remission > Ctrl; SOLv: NS group differences; WASOv: Bipolar remission > (trend) Ctrl; Fragmentationv: Bipolar remission > Ctrl; TSTm, SOLm, Fragmentationv, PSQI daytime function correctly classified 89% of study participants as cases or controls.
Hauri & Wisbey, 1992 [42]	Obs: 1 wk home acti then 3 d lab acti with ≥6 h TIB.	36 Insomnia, NR (US)	45 (24–69), 63.9%	Seven at home three in lab, acti, ISD	A: home vs lab setting in insomnia	None	TSTv: home > lab.
Hayes et al., 2014 [55]	Obs: three groups of aMCI, non-aMCI, & "Intact".	45 Com (older), NR (US)	86.9 (4.3), 88.9%	182, movement based bed mats (validated against acti), Inter-quartile range	C: cognitive function	None	WASOv: aMCI < Intact or naMCI; non-aMCI showed sleep disturbance that was intermediate to that of aMCI & intact.
Hoaki et al., 2011 [50]	Obs: 1 wk acti & questionnaires.	56 Healthy, NR (JP)	26.9 (5.9), 30.4%	Seven, acti, ISD	C: hyperthymic temperament (bipolar)	Daytime illuminance, ACTH	TSTv: NS correlation with hyperthymic temperament, but ~ +hyperthymic temperament when controlling for covariates.
Innes et al., 2013 [57]	Obs: 1 wk BL, then 1 night sleep restriction to 4 h, then normal sleep.	16 Healthy, NR (NZ)	24.9 (20–37), 50.0%	Six, acti (with diary), ISD	C: microsleep after sleep restriction	None	SOTv of BL: ~ -number of microsleeps following sleep restriction (large).
Kang & Chen, 2009 [29]	Obs: 2 wk diary followed by assessments	160 Uni, 100% Chinese (CN)	20.3 (1.9), 49.4%	14, diary, Nr of nights/W with >1 h shift in BT: low	C: subjective sleep, fatigue, sleepiness.	TSTm	26.9% low, 38.8% intermediate, 34.4% high. BTv: with poorer subjective sleep (large, more so in

				(<1), intermediate (1−3), high (>3).			intermediate & high groups); NS ~ fatigue or sleepiness.
Khawaja et al., 2013 [30]	Obs: 2 wk acti with questionnaires	23 Veteran with PTSD & sleep disturbance, NR (US)	52.8 (10.3), 13.0%	14, acti, ISD	A: age; C: PTSD.	nWASOm	nWASOv: ~ -age (large), -TSTm (large).
Knutson et al., 2007 [35]	Obs: three days' acti, twice ~one year apart	669 Com, 44% Black (US)	42.9 (3.7), 57.0%	Three, acti (with diary), Formula provided	A: race, daily vs yearly	Age, race, sex, weekend	TIBv, TSTv, SEv, SOLv: daily IIV > yearly IIV; black > white.
Kramer et al., 1999 [36]	Obs: 2 wk diary & acti in Older vs Younger	21 (Older) & 19 (Younger) Healthy, NR (NL)	65.1 (4.4) & 20.8 (2.2), .0%	14, diary, ISD	A: age	None	BTv: Younger > Older; RTv: Younger > Older.
Kubo et al., 2009 [19]	Obs: 1 wk home diary (no naps/sleep deprivation/ caffeine/alcohol); nine days lab (Day 1 adaptation, Day 2 BL, four days simulated night shift, three days simulated day shift)	10 Healthy, NR (JP)	22.9 (3.2), .0%	Seven, diary, ISD	C: recovery pattern from simulated shift schedules	None	Recovery patterns related to home BTv (moderate), RTv (large), but not to alertness & performance during the simulated night shifts.
Lemola et al., 2013 [52]	Obs: 1 wk home acti with diary	441 Com, 66.6% White, 33.3% Black (US)	56.85 (11.38), 60.4%	Seven, acti (with diary), CV	C: SWL, psychological distress	Gender, age, marital status, education, BMI, ethnicity, twin status.	TSTv: black > white; M < F in black; ~ -SWL, +distress (i.e., mood & anxiety).
Manber et al., 1996 [27]	Exp: 12 d BL, 4 wk natural vs regular sleep manipulation within 1hr window of habitual sleep timing (all asked to sleep ≥7.5 h, light & activity upon awakening, minimize coffee), FU at 5 wk post for 1 wk	39 Uni (sleepy & irregular), NR (US)	18.8 (.97), 69.2%	Seven, diary, ISD	C: daytime sleepiness; D: sleep quality.	None	Good compliance with manipulation for regular vs natural conditions. BTv: ~ +sleepiness at BL; SEm increased & SOLm decreased in regular but not natural group; NS differences in WASOm; When not sleep deprived, regular group had greater & longer lasting reduction in daytime sleepiness.
McBean & Montgomery-Downs, 2013 [44]	Obs: from beginning of 2nd postpartum week, PVT every morning for 12 wk.	71 Healthy (primiparas), 90.1% White (US)	26.3 (4.1), 100.0%	Seven, acti & diary, ISD	B: time since giving birth; C: PVT, daytime function.	Age	SMv: NS change across W2−W12; SMv at W2 ~ +PVT lapses at W2, W5−W13; NS ~ slope of change in PVT lapses over time; SMv ~ +daytime impairments.
McCrae et al., 2006 [64]	Obs: four groups: with/ without insomnia by complaint vs no complaint.	Sample 1: 310, Sample 2: 103, Com (older), Sample 1: 77.7% White, 22.0% Black; Sample 2: NR (US)	60−96, Sample 1: 51.3%, Sample 2: NR	14, diary, ISD	D: insomnia & sleep complaints	Age, education, sex, medications, health conditions	BTv & RTv: NS group differences.
McCrae et al., 2012 [54]	Obs: 2 wk diary	72 Com (older), “Mostly” White (US)	70.18 (7.09), 66.7%	14, diary, ISD	C: cognitive function (inductive reasoning, processing speed)	Age, education, complaint duration	TSTv & TWTv: NS ~ inductive reasoning or processing speed.
Merklinger-Gruchala et al., 2008 [31]	Obs: daily self-report of TST over menstrual cycle.	95 Com, 100% Polish (PL)	29.48 (3.13), 100.0%	28.88 (3.83), diary, CV	A: age, education, duration of daylight; B: estradiol levels etc (see results).	TSTm	TSTv: ~ +estradiol; NS ~ age, birth weight, education, energy intake, physical activity, weight/height, body fat, BMI, age at menarche, length of menstrual cycle during collection, mean duration of daylight.
Meyer & Maier, 2006 [49]	Obs: 4 wk SRM, comparing bipolar risk, unipolar risk, & Ctrl	141 Uni, 100% native German speaker (DE)	18.18 (2.14), 70.7%	28, SRM, ISD	C: risk for bipolar & unipolar.	None.	TSTv: bipolar risk > both unipolar risk & Ctrl; NS b/w Ctrl & unipolar risk; results hold excluding those with unipolar or bipolar disorder.
Mezick et al., 2009 [32]	Obs: nine days acti, norepinephrine from overnight urine on nights two & four.	184 Com, 57.1% White, 40.8% Black (US)	59.5 (7.2), 47.3%	Nine, acti, ISD	A: race, sex; C: stress;	Sex, race, age, BMI, apnea-hypopnea index, medication use, & the relevant mean	TSTv: NS b/w black & white, F > M; ~ +stressful life events, NS ~ norepinephrine. Fragmentationv: black > white; NS b/w sexes. NA as moderator: in those with higher NA, Fragmentationv (but not TSTv) ~ +stressful life

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Table 1 (*continued*)

	Design	Sample: N, type, race/ethnicity (country)	Age (mean ± SD or range), %F	IIV method: Nr of days, measure, quantification	Theme: correlate(s)	Covariate(s)	Findings on IIV
							events, greater TSTv & Fragmantationv ~ +norepinephrine.
Millar et al., 2004 [46]	Obs: remitted bipolar I patients vs age gender matched Ctrl	38 remitted bipolar & Ctrl, NR (UK)	46.55 (10.77), 57.9%	Five, acti & diary, ISD	C: remitted bipolar pts vs Ctrl	Daily mood ratings	Acti: NS group difference on TSTv, SOLv, SEv, WASOv (multivariate); remitted bipolar > Ctrl: TSTv & WASOv (univariate); Diary: remitted bipolar > Ctrl: TSTv, SOLv, SEv, WASOv (multivariate); remitted bipolar > Ctrl: TSTv, SOLv, & SEv (univariate); Best group membership model: acti TSTv, diary TSTm, diary SOLm.
Minors et al., 1998 [37]	Obs: diary during "typical week", comparisons of data 10 years	112 Com (older), NR (UK)	73.00, 80.0%	Seven, diary, Variance	A: age, gender, cohabitation	Gender	BTv: T1 > T2 (NS trend) in cohabitation, NS for living alone; RTv: T1 > T2 in cohabitation, NS for living alone; TIBv: T1 > T2 in cohabitation, NS for living alone; Napv: ~ +cohabitation at T1 but not T2; NS change b/w two times. All above variables ~ -age at T1 but not T2; NS ~ sex.
Monk et al., 1991 [38]	Obs: 2 wk diary	34 (Older) & 30 (Younger), Com, NR (US)	83.1 (80–91) & 25.5 (21–30), 42.2%	14, diary, ISD	A: age	None	BTv & RTv: Younger > Older.
Ogawa et al., 2011 [24]	Int: 1 wk BL, 2 wk placebo	380, Insomnia, 100% Japanese (JP)	48.5 (17.0), 63.2%	Seven, diary, Categorical (BL SOL fluctuation <−30, ±30, >30 min groups) & ISD	A: age; D: insomnia.	SOLm	SOLv: ~ +age, +habitual SOLm, -habitual TSTm, past benzodiazepines use; significantly greater SOL reduction in those with larger BL SOL fluctuation (<30 & >30 min) compared with smaller (±30 min).
Okun et al., 2011 [45]	Obs: 1 or 2 wk baseline diary	222 Com (older), 94.1% White (US)	73.7 (7.1), 67.1%	7 or 14 d, diary, ISD	B: Inflammation biomarkers (IL-6, TNF-α); D: Group (Good Sleepers, Insomnia, Bereaved, Carers).	Age, sex, BMI, SF-36, depressive symptoms, stress	BTv: NS b/w groups; ~ +TNF-α; RTv: Good Sleepers < other groups; ~ +IL-6 in Good Sleepers. TIBv: Good Sleepers < Insomnia, ~ +IL-6 in Good Sleepers; TSTv: Good Sleepers < other groups.
Ong et al., 2007 [33]	Obs: 1 wk diary at BL, comparing Morning, Intermediate, & Evening chronotypes	312 Insomnia, NR (US)	48.86 (14.08), 59.0%	Seven, diary, ISD	C: chronotype in insomnia patients	TWT	BTv: NS group difference (univariate); RTv: Evening > Morning/Intermediate chronotypes (univariate); Evening chronotype more variable BTv & RTv (multivariate).
Patel et al., 2014 [14]	Obs: <1 wk acti.	6038 Com (older), NR (US)	79.91, 49.4%	≥5 for M, three for F, acti (with diary), ISD	A: race; B: health outcomes; C: cognitive function, antidepressant use.	TSTm, demographics, mental/physical health history, antidepressants, benzodiazepines, life style factors, cognitive function.	SMv ~ +minority race, +diabetes, +heart failure, +antidepressants, -cognitive function, -subjective health, -TSTm, +BMI in M (not F), +obesity in F (not M); TSTv ~ +minority race, +diabetes, +coronary artery disease, +heart failure, +antidepressants, -cognitive function, -subjective health, -TSTm, +BMI, +obesity.
Roane et al., 2014 [40]	Obs: diary for 9wk at the start of university.	132 Uni, 62.9% White, 18.9% Hispanic (US)	18.6 (.4), 54.0%	Average 56, diary, Mean range of a 4-d moving window	A: sex, ethnicity; B: weight changes; C: depressive symptoms, chronotype.	Sex, ethnicity, depressive symptoms, chronotype, interaction b/w sex & sleep variables	BTv: ~ +weight gain, +eveningness, NS ~ sex, ethnicity, depressive symptoms; RTv: M > F, ~ +weight gain, +eveningness, NS ~ ethnicity, depressive symptoms; TSTv: NS sex difference; significantly predicted weight gain for F but not F.
Roumelioti et al., 2010 [7]	Obs: up to 2 wk diary for pts, 1 wk for Ctrl	183 pts (CKD, ESRD) & Ctrl, 74.3% White (US)	52.65, 37.2%	14 & 7, diary, ISD	B: CKD & ESRD	Age, sex, & race	Qualityv: ESRD > CKD > Ctrl; NS ~ phosphorus level, hemoglobin, bicarbonate & diabetes.
Rowe et al., 2008 [41]	Obs: 1 wk home acti & diary	133 Com (older carers of dementia & noncarers), 96.2% White (US)	72.31 (7.04), 66.3%	Seven, acti & diary, CV	A: care-giving of dementia patients	Age, education, depression, total Nr of medications	TSTv: Carers > non-carers both acti & diary; SEv: Carers > non-carers both acti & diary; SOLv: NS group difference on either acti or diary; WASOv: NS group difference on either acti or diary; Qualityv: NS group difference.
	Int: RCT on 4 biweekly CBT-I vs Sleep Hygiene for PI or	81 Insomnia, 58% White (US)	54.2 (13.7), 12.5%	14, acti & diary, ISD	D: type of insomnia, subjective sleep,	None	If not specified, findings apply to both subgroups or both acti & diary.

Sánchez-Ortuño & Edinger, 2012 [25]	CMI, POST & six month FU assessments.				treatment related changes.		Total sample during BL: TSTv & SEv: CMI > PI (trend); PI (not CMI) acti (not diary) TSTv ~ +PSQI. SOLv: CMI > PI (diary not acti); NS ~ PSQI. WASOv: NS CMI vs PI; ~ +PSQI in PI (not CMI). Change based on CBT-I sample: TSTv, SEv, SOLv, WASOv: BL > POST on diary (not acti), NS POST vs FU; NS b/w BL TSTv, SEv & FU PSQI; BL acti (not diary) SOLv in PI (not CMI), & BL acti (not diary) WASOv in CMI (not PI) ~ +PSQI at FU. POST diary SEv, SOLv, WASOv (but not TSTv) reduction ~ +reduction in PSQI in CMI (not PI).
Sánchez-Ortuño et al., 2011 [65]	Obs: 2 wk diary in PI or IMD	187 Insomnia, 59.7% White, 33.9% Black (US)	47.14 (14.53), 67.7%	14, diary, mean square of successive differences	D: subtype of insomnia	Sex	TSTv: IMD > PI; SEv, SOLv, WASOv: NS b/w PI & IMD.
Shen et al., 2008 [28]	Exp: 2 wk BL, 4 wk experimental phase for irregular participants. Experimental group: increase regularity of BT, RT, routines with review & weekly feedback; Ctrl group: learn factors affecting performance.	62 Uni (bipolar spectrum), 71.8% White, 11.3% Black (US)	19.70 (18–24), 71.8%	14, diary, ISD	C: mood lability, bipolar manic & depressive symptoms	None	TSTv: during BL, TSTv ~ +depressive symptoms (small), higher across-day symptom variability (small); NS ~ manic symptoms, within-day symptom variability. During Experimental phase, significant decrease for both groups; decrease Experimental > Ctrl. End of Experimental phase, Experimental (large) but not Ctrl group significantly less variable than BL. Increased lifestyle regularity did not result in changes in correlates.
Signal et al., 2007 [43]	Obs: 1 wk acti & diary at ~24 wk gestation (T1), 1 wk before delivery (T2), 1 wk after delivery (T3), 6 wk/7 wk postpartum (T4)	19 Healthy (pregnant), NR (NZ)	34 (29–40), 100.0%	Seven, acti (with diary), ISD	B: gestation, postpartum stage	Parity	All variables changed significantly over time, T3 most variable: TIBv: T2, T3 > T1, T4; TSTv: T3 > T1, T4; SEv, WASOv, IIV of 24hr sleep episodes: T3 > T1, T2, T4.
Suh et al., 2012 [5]	Int: 1 wk diary at first & last week of a 7-session CBT-I group program	455 Insomnia, NR (US)	48 (14), 57.6%	Seven, diary, Composites from mean square of successive differences of sleep variables	A: age; C: depressive symptoms, chronotype; D: insomnia, treatment response.	Age	Behavioral Schedule Component Score (BCS): BTv, LOv, WTv, RTv, TIBv; Insomnia Symptom Composite Score (ICS): SOLv, WASOv, TSTv. BCS: ~ -age (BTv, LOv, TIBv), +eveningness (all five variables), +depressive symptoms (LOv, WTv, RTv, TIBv), NS ~ ISI. Independent predictors of BCS are + eveningness, +depressive symptoms, & their interaction (BCS ~ +eveningness among those with higher but not lower depressive symptoms). ICS: ~ +depressive symptoms (TSTv), NS ~ ISI or chronotype. CBT-I reduced IIV in all sleep variables except BT & LO. High BL BCS group had significantly higher BL & reduction in depressive symptoms. ISI decreased, but NS b/w high vs low BL BCS or high vs low BL ICS groups.
Taub & Hawkins, 1979 [6]	Obs: 2 wk sleep chart for regular vs irregular groups	36 Uni, NR (US)	18–24, .0%	14, sleep chart with 30 min periods, Categorical "regular vs irregular" based on questionnaire, confirmed on CV	C: personality traits	None	Irregular group lower on: dominance, sociability, self-acceptance, self-control, achievement via conformance, & intellectual efficiency, but higher on flexibility.
Vanderlind et al., 2014 [51]	Obs: 3 wk acti sandwiched b/w two assessment sessions (T1 & T2)	35 Uni, NR (US)	19.83 (1.25), 40.0%	21, acti (with diary), ISD	C: depressive symptoms, subjective sleep,	None	TSTv: small correlation with T1 +depressive symptoms, NS ~ T2 depressive symptoms; small correlation ~ -cognitive control; NS ~ PSQI or rs11932595 (gene).

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Table 1 (*continued*)

	Design	Sample: N, type, race/ethnicity (country)	Age (mean ± SD or range), %F	IIV method: Nr of days, measure, quantification	Theme: correlate(s)	Covariate(s)	Findings on IIV
Waters et al., 2011 [60]	Obs: 4 wk home acti with diary comparing schizophrenia Pts & Ctrl	13 Schizophrenia Pts & Ctrl, NR (AU)	43.56 (6.48), 30.8%	28, acti (with diary), ISD	genes, cognitive control C: schizophrenia psychopathology	None	TSTv: Pts > Ctrl (trend); SEv & SOLv: Pts > Ctrl (trend).
Westerberg et al., 2010 [56]	Obs: 2 wk home acti & diary	20 aMCI, Ctrl, NR (US)	71.8, 75.0%	14, acti & diary, ISD	C: cognitive function	None	TIBv, TSTv, SEv, & SOLv: NS b/w groups; ~ -logical memory (small – moderate), but NS ~ 24-h recognition.

Notes. "+" and "−" indicate statistically significant positive and negative association between two variables, "<" and ">" indicate statistically lower (earlier in sleep timing) or higher (later in sleep timing) than, "~" = associated with, "Insomnia" refers to samples with clinically significant symptoms of insomnia based on diagnostic interview or research criteria for insomnia, "m" and "v" attached to a sleep variable indicate the mean and IIV of this variable respectively, A (theme) = demographic and environmental factors, ACTH = adrenocorticotropic hormone, acti = actigraphy, ADHD = attention deficit hyperactivity disorder, aMCI = amnesic mild cognitive impairment; B (theme) = physical health, b/w = between, BL = baseline, BMI = body mass index, BT = bedtime, C (theme) = psychological factors and function, CBT-I = cognitive behavioral therapy for insomnia, CKD = chronic kidney disease, CMI = insomnia with comorbid psychiatric disorders, Com = community sample, Ctrl = control group, CV = coefficient of variance, D (theme) = insomnia and sleep complaints, diary = daily record such as sleep diary and sleep log, DSPD = delayed sleep phase disorder, Effect sizes: wherever reported, effect sizes were reported as small (.1 ≤ r < .3 or .2 ≤ Cohen's d < .5), moderate (.3 ≤ r < .5 or .5 ≤ Cohen's d < .8), large (r ≥ .5 or Cohen's d ≥ .8), ESRD = end stage renal disease, Exp = IIV experimentally manipulated, F = female, Fragmentation = actigraphy fragmentation index, FU = follow-up, IIV = intraindividual variability, IMD = insomnia related to mental disorder, Int = involves intervention that might influence IIV, ISD = individual standard deviation, ISI = Insomnia Severity Index, LO = lights out, M = male, NA = negative affect, Nap = daily nap time, NR = not reported, Nr. = Number of, NS = non-significant, Obs = observational studies, PI = primary insomnia, POST = post-intervention, PSQI = total scores of Pittsburgh Sleep Quality Index, Pts = patients, PTSD = posttraumatic stress disorder, PVT = psychomotor vigilance task, Quality = sleep diary subjective sleep quality, RCT = randomized controlled trial, RT = rise-time, SAD = Sleep Assessment Device (Somtrak ST-100), SD = standard deviation, SE = sleep efficiency, SF-36 = 36 item Short Form Survey, SM = Sleep Midpoint, SOL = sleep onset latency, SOT = time of sleep onset, SRM = Social Rhythm Metric, SWL = satisfaction with life, T1, T2, … = the first, second, … time point, TIB = time-in-bed, TST = total sleep time, TWT = total wake time, Uni = university students, vs. = versus, wk = week, WASO = wake after sleep onset, with n and % signifying the number or percentage, WT = time of awakening, x = by, or variable interaction.

severity [2,51] and mood disturbance [52]. Findings from studies of insomnia patients are similar: more variable self-report sleep timing, duration, and quality [5], as well as more variable actigraphy sleep duration [53] were associated with significantly higher depressive symptoms.

Cognitive function (n = 5). Findings on cognitive function are inconclusive. Among community dwelling older adults, more variable actigraphy sleep midpoint and TST were each associated with lower cognitive function based on modified mini-mental state and mini-mental state examination [14]. In a somewhat younger sample however, IIV of self-report TST and TWT were not found to be significantly associated with two specific aspects of cognitive functioning – inductive reasoning and processing speed [54]. In a university sample, higher actigraphy TSTv had only a small correlation with lower cognitive control [51].

Comparing individuals with amnestic mild cognitive impairment (MCI), non-amnestic MCI, and healthy controls, Hayes et al. [55] found that the amnestic MCI group had significantly less variable objective WASO than the other two groups. However, Westerberg et al. [56] did not find significant differences in other aspects of actigraphy-measured sleep (TIBv, TSTv, SEv, and SOLv) between amnestic MCI and healthy controls; they did report that these variables share small to moderate correlation with lower logical memory, but little with 24-h recognition.

Daytime consequence (n = 6). Sleep/wake IIV has been studied in relation to daytime fatigue, sleepiness, performance on psychomotor vigilance tasks (PVT), and microsleeps after sleep restriction. In an unselected university population, self-report BTv was associated with poorer subjective sleep but not with fatigue or daytime sleepiness after controlling for self-report TSTm [29]; however, among university students who were irregular sleepers and endorsed daytime sleepiness, greater self-report BTv was associated with higher daytime sleepiness [27]. In insomnia patients, the relationship between actigraphy sleep/wake IIV and daytime sleepiness was reported to be weak [53]. In postpartum women, more variable actigraphy sleep midpoint during postpartum week 2 was associated with greater numbers of PVT lapses at postpartum week 2 and week 5–13; across the first 12 postpartum weeks, more variable sleep midpoint was also associated with greater daytime impairments [44].

Two studies in this theme examined habitual sleep timing IIV in relation to the effects of experimental manipulation of sleep on daytime consequences. Kubo and colleagues [19] simulated night- and day-shift in the sleep laboratory, and found that among healthy adults, recovery sleep patterns were related to baseline self-report BTv and RTv at home, but not to alertness performance during the simulated night-shifts. Similarly, Innes et al. [57] found that in healthy adults, more variable actigraphy time of sleep onset during home baseline was associated with significantly lower number of microsleeps when sleep was experimentally restricted to 4 h, suggesting regular sleepers may be more prone to microsleeps after sleep restriction. They speculated that regular sleepers may choose to be regular because they otherwise may experience greater daytime impairments, whilst irregular sleepers may choose irregular sleep times because they may not experience substantially increased sleepiness from disruption to sleep patterns [57].

Chronotype (n = 3). All three studies on chronotype assessed sleep using sleep diary. Among university students, evening chronotype was associated with significantly more variable BT and RT after controlling for depressive symptoms [40]. In insomnia patients, evening chronotype was associated with significantly more

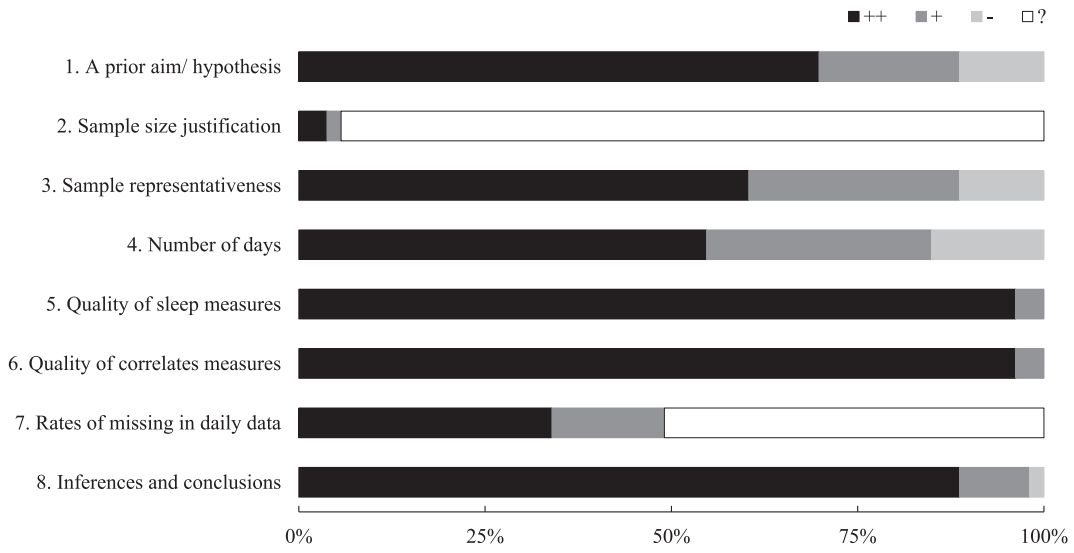

Fig. 2. Summary of quality assessment for included studies. 1. A priori aim/hypothesis: whether there were aims/hypotheses specific to intraindividual variability (IIV) of sleep/wake patterns; "++" indicates specific aims/hypotheses related to IIV; "+" indicates IIV implied but not explicitly stated, 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 measures: "++" indicates well validated, "+" indicates not well validated. 7. Rates of missing in daily data: "++" indicates ≤10%, "+" indicates ≤20% and >10% (none reported > 20%), and "?" indicates not reported. 8. Inferences and conclusions: quality of inferences and conclusions drawn, with "++", "+", and "-" indicating "good", "fair", and "poor".

variable behavioral sleep/wake variables such as sleep timing [5,33] and TIB [5], especially among those with higher depressive symptoms [5]; the relationship between chronotype and the IIV of actual sleep duration and quality was however, not significant [5].

Stress (n = 2). We found two studies that examined the relationship between sleep/wake IIV and stress, a cross-sectional study on stressful life events, and a longitudinal study during adjustment to the natural stressor of transition to college. The first study was conducted in a community adult sample using actigraphy [32], and found that greater TSTv was associated with higher number of stressful life events, but was not related to a biomarker of stress, norepinephrine; in addition, the authors reported a moderating role of negative affect (NA), such that in those with high but not low NA, greater IIV in actigraphy fragmentation index was associated with higher number of stressful life events and higher norepinephrine, whilst greater TSTv was associated with higher norepinephrine. In the second study measuring sleep using sleep diary, Ari and Shulman [58] classified adjustment of young adults transitioning into college based on NA and stress, and found that TSTv was low at both first and second academic semester in the "well adjusted" group, and was high in the first and low in the second semester in the "re-adjusted" group.

Other correlates. Consistent with the aforementioned associations between psychopathology and greater sleep/wake IIV, individuals with comorbid attention deficit hyperactivity disorder and delayed sleep phase disorder had significantly more variable self-report SOL [59], and those with schizophrenia tended to have more variable actigraphy TST, SE, and SOL [60] compared to healthy controls. With a focus on personality, Taub and Hawkins [6] compared university students who were self-reported regular and irregular sleepers, and found that irregular sleepers were significantly lower on dominance, sociability, self-acceptance, self-control, achievement via conformance, and intellectual efficiency, but higher on flexibility.

Theme D. Insomnia and sleep complaints (n = 14)

This theme included seven observational and seven intervention studies on samples with insomnia or sleep complaints. Overall, those with insomnia or poor sleep had more variable sleep quality compared to healthy controls, but findings on sleep timing or duration were inconclusive. Interventions that therapeutically target insomnia or poor sleep (e.g., CBT-I) reduce sleep/wake IIV, especially when sleep was measured through self-report. It was noted that, except for one study [24], studies described in this theme did not control for the mean value of the sleep variable when its IIV was examined.

Insomnia and poor sleep (n = 8). Compared to healthy controls and good sleepers, individuals with insomnia symptoms have consistently been shown to have greater IIV on variables related to sleep quality, such as SOL (sleep diary [53,61,62] but not actigraphy [53]), SE (sleep diary and actigraphy [53]), WASO (sleep diary [53,62] and actigraphy [53]), and self-report sleep quality [53,61]. However, greater IIV in diary-based report of SOL and WASO did not explain why insomnia patients underestimated sleep duration and overestimated time awake [62].

Differences in sleep timing and duration IIV between those with and without insomnia symptoms were less consistent. Compared to healthy controls, BTv in individuals with insomnia symptoms was either lower based on actigraphy [53], or not significantly different based on self-report when the analysis did [63] or did not [45,64] control for depressive symptom severity. A number of studies using either actigraphy or sleep diary found that those with insomnia disorder [45,53] or symptoms [63] had more variable RT [45,53,63] compared to healthy controls; however, McCrae et al. [64] did not find significant differences in self-report RTv among four groups of with/without insomnia by with/without sleep complaint. Three studies examined sleep duration IIV in relation to insomnia symptoms, all compared community older adults who had insomnia symptoms with those who did not. Findings on sleep

diary assessed TIBv are inconclusive, with one study [45] reporting greater variability in the insomnia symptom group, and a second reporting non-significant difference [53]. These two studies [45,53] also examined sleep diary TSTv and found significantly greater variability in the insomnia symptom group. However, a third study found non-significant differences [62]. The group differences in sleep diary TSTv, however, were not present when TST was derived from actigraphy data [53].

One study examined IIV of self-report sleep parameters creating a composite score of variables related to voluntary sleep behaviors (e.g., BT, RT) and separately a composite score of sleep variables that are involuntary and reflect insomnia symptoms (e.g., SOL, WASO). This study of a large outpatient insomnia sample, found that insomnia severity was not related to either composite score [5]. In another insomnia sample, self-report TSTv was greater in insomnia related to a mental disorder than primary insomnia [65].

Sleep interventions (n = 7). Four of the seven intervention studies used CBT-I [5,21,22,25], and reported overall reduced sleep/wake variability after intervention. In a large outpatient insomnia sample, group CBT-I reduced IIV in all sleep diary variables except BT and lights out (LO) [5]. This is consistent with other CBT-I based intervention studies that found significantly reduced IIV in sleep diary measured sleep duration [21,22,25], SE [21,25], SOL [21,22,25], and WASO [21,25] (but not subjective sleep quality or daytime nap duration [21]) post-intervention. Further, most results were maintained at follow-up [21,22,25]. In contrast, results on changes in objectively measured sleep/wake IIV varied by sleep variable [21] or were nonsignificant [25].

A study comparing regular exercise as a sleep-improving intervention with a health education control condition in adults with sleep complaints [20] found that the intervention group self-reported lower TIBv and SOLv at 6 and 12 mo respectively, even though sleep timing IIV or SOLm did not change significantly. Finally, a 21-d melatonin trial for individuals with sleep disturbance showed significant reduction in self-report BTv among those with comorbid dementia, but not among those without [23].

Findings have been mixed on the relevance of baseline or post-treatment sleep/wake IIV to insomnia treatment outcomes. Ogawa et al. [24] found that after two weeks of placebo treatment, insomnia patients with greater self-reported baseline SOLv had greater SOLm reduction. Suh et al. [5], however, reported no significant difference in the reduction of insomnia severity after CBT-I between those with high versus low baseline IIV based on either behavioral or insomnia variability composite scores derived from sleep diary. Sanchez-Ortuno and Edinger [25] found that pre-to post-intervention reduction in sleep diary SEv, SOLv, WASOv (but not TSTv) were associated with greater reduction in sleep complaints in insomnia with comorbid psychiatric disorders but not in primary insomnia; in addition, there was no significant association between baseline TSTv or SEv (findings were mixed for SOLv and WASOv) and self-report sleep quality at 6 mo follow up.

Theme E. Experimentally manipulating IIV (n = 3)

Three studies experimentally reduced sleep/wake IIV and examined the consequences. The first study was carried out by Bonnet and colleagues in the early 1980s [26], who experimentally manipulated sleep schedules of 13 healthy university student. The manipulation imposed 38 d of regular sleep in the laboratory (sleep duration was determined from baseline, sleep timing was determined based on earliest weekly commitments), followed by 4 wk habitual sleep at home (irregular condition) [26]. They found that the average body temperature was lower during regular versus irregular conditions, but participants did not have significantly different mood, cognitive performance, or sleep architecture [26]. In the late 1990s, Manber and colleagues conducted a home-based experiment on a selected sample of 39 university students who were irregular sleepers and had self-reported daytime sleepiness [27]. After 12 d baseline, participants were randomized into either regular sleep condition (i.e., sleep timing to remain within 1 h of habitual sleep timing) or sleep only condition (i.e., natural sleep timing without specific instruction); both groups were instructed to sleep for $\geq$7.5 h to avoid sleep deprivation [27]. The authors reported that based on sleep diary, SEm increased and SOLm decreased in the regular sleep but not sleep only condition, and that compared to the sleep only group, the regular sleep group had greater and longer lasting reduction in daytime sleepiness [27]. More recently, Shen and colleagues [28] experimentally enforced regular RT, BT, and other routines in university students with irregular sleep patterns and at risk for bipolar spectrum disorders. Despite significantly greater reduction in self-report TSTv in the experimental versus control group, increased lifestyle regularity did not result in changes in mood lability or manic/depressive symptoms [28].

Discussion

Summary of findings

To the best of our knowledge, this is the first systematic review on the correlates of sleep/wake IIV. Compared to the literature on the mean levels of sleep/wake patterns, the literature on IIV appeared small, unsystematic, and post hoc, with under-developed theoretical frameworks and inconsistent methodologies. There are two areas of research on sleep/wake IIV that are more developed: one is focused on bipolar symptomatology, and the other on insomnia. Other correlates were typically examined by a single study without replication, or were based on samples that differed in important characteristics (e.g., age, mental/physical health status), limiting conclusions that can be drawn.

Nevertheless, the following correlates were identified as sharing more consistent relationships with one or more aspects of sleep/wake IIV: age (younger age with more variable sleep timing), race/ethnicity (non-White with more variable sleep duration and quality), cohabitation (cohabitation with less variable sleep timing), physical health conditions (health conditions with more variable sleep duration), body weight (higher BMI or weight gain associated with more variable sleep timing), psychopathology (the presence of bipolar and depression symptomatology with more variable sleep duration and quality, insomnia with more variable sleep quality), chronotype (eveningness with more variable sleep timing), and stress (stressful life events with more variable sleep duration). There is some evidence that daytime consequences of, and the recovery from, sleep deprivation/disruption might be related to habitual sleep/wake IIV. Cognitive behavioral therapy for insomnia consistently reduces most aspects of self-report sleep/wake IIV. Whilst it was possible to significantly reduce sleep/wake timing and duration IIV through experimental manipulation both in the laboratory [26] and in participants' own home [27,28], the effects of such reduction on daytime functioning were variable and inconclusive, and likely due to different sample characteristics.

Some correlates showed more consistent associations with some but not other aspects of sleep/wake IIV (e.g., greater insomnia severity was consistently associated with more variable subjective sleep quality but not subjective or objective timing or duration, eveningness with more variable self-report sleep timing but not quality). Given some aspects of sleep (e.g., BT, RT) are more directly susceptible to behavioral and environmental influences than others

(e.g., SOL, WASO), such differential associations could shed light on potentially diverse etiology and mechanisms of sleep IIV. In addition, different associations between some correlates and sleep diary versus actigraphy measured sleep IIV were noted (e.g., individuals with insomnia symptoms having greater SOL IIV on sleep diary but not actigraphy). This is consistent with the notion that although the two measures typically correlate well, their subjective versus objective natures could contribute to some discrepancies in both the values of sleep parameters derived [66] and the strengths of their associations with correlates [67]. This is particularly the case for studies on samples with insomnia (i.e., theme D), a condition in which misperception of sleep is well established concept in the literature [68].

Gaps and opportunities

Theoretical perspectives

First, there is a lack of existing framework for understanding the etiology of sleep/wake IIV, as well as the mechanisms through which it could be associated with physical and mental health outcomes. Second, it is not clear whether the correlates identified in this review are causes or consequences of sleep/wake IIV, or if they share a bidirectional relationship. For example, whilst daily variation in sleep quality might be a clinical feature of insomnia, it could also perpetuate unhelpful beliefs such as "my sleep is unpredictable" and sleep anxiety, which further aggravate insomnia symptoms [69]. It is also possible that the associations between sleep/wake IIV can be explained by unexamined common causes. For example, the association between younger age and higher sleep timing IIV might be due to greater eveningness as a potential common cause, as eveningness has been associated with both younger age [70] and more variable sleep timing [5,33,40]; similarly, some personality traits reported to be associated with irregular sleep patterns (e.g., lower sociability, self-acceptance, self-control) [6] might underlie both high sleep/wake IIV and the presence of depressive symptoms. Further, despite more variable sleep/wake patterns being associated with a range of adverse outcomes, it is not clear that greater sleep/wake IIV is always related to deleterious outcomes, or whether such associations are linear. In different contexts, greater IIV can be theorized as being both non-adaptive and adaptive [71]. For example, much has been said about irregular sleep as a non-adaptive behavior in the context of insomnia, with the implication that regular sleep is adaptive. However, very low variability in sleep timing among patients with insomnia sometimes stems from rigid rules about sleep timing that are anchored in a general maladaptive belief that sleep is fragile or there is a critical window for sleep. Moreover, a finding that healthy irregular sleepers were less prone to microsleep after sleep deprivation [57] suggests that these individuals might adapt better to changing sleep durations.

There are a number of opportunities for future studies in addressing these gaps. First, there is a need for theory development that could guide more systematic research in better understanding sleep/wake IIV. Correlates identified in this review could provide a starting point in hypothesizing potential contributing factors to, and consequences of sleep/wake IIV for the development of theories and models that can be tested empirically in future studies. Such theories and models need to consider: 1) potentially differential associations between correlates and sleep timing, duration, and quality IIV; 2) complexity in the causal relationships between correlates and sleep/wake IIV; 3) the possibility that greater sleep/wake IIV could be both non-adaptive and adaptive, and 4) the possibility of non-linear associations between sleep/wake IIV and outcomes of interest.

Second, to better understand sleep/wake IIV, both hypothesis-driven and exploratory approaches are needed. On one hand, studies with a priori aims/hypotheses that focus specifically on sleep/wake IIV are essential. On the other hand, this body of literature is still at its infancy, and explorative studies could help identify potential correlates that have not yet been examined. Initially, re-examination of existing datasets can be an option for such explorative purpose. Perhaps a significant step in extending current understanding of sleep/wake patterns beyond their mean levels, is the conceptual integration of IIV as a second dimension along with individual means. Whenever possible, future studies with daily measurements of sleep/wake patterns should incorporate the examination of IIV of sleep variables when their individual means are examined.

Finally, the diverse nature of correlates identified in this review suggests that to further our understanding of sleep/wake IIV, interdisciplinary collaboration with combined efforts from more than one field (e.g., sleep, circadian, psychological, physical health sciences) is essential. In other fields of research (e.g., affect and aging), IIV has been identified as a construct of theoretical and clinical significance [71–73], and the study of IIV has gained momentum. For example, research in a large cohort demonstrated that beyond the mean, IIV in life satisfaction predicts decreased survival over nine years [74]. Such literature provide valuable food for thought in the development of theories, methods, and research agendas when studying sleep/wake IIV.

Methodological perspectives

First, most (81.1%) identified studies were of observational design, and only three studies examined the effects of experimentally manipulated IIV on outcomes of interest. More observational studies are certainly needed to 1) replicate/clarify findings on known correlates, 2) explore unexamined correlates, and 3) establish normative range of daily sleep/wake IIV in naturalistic settings. Prospective, longitudinal studies and experimental studies are particularly needed as they hold the potentials of 1) studying sleep/wake IIV with its correlates and/or itself systematically manipulated to represent wider range of levels than what is seen in naturalistic settings, 2) clarifying causal directions of IIV and their correlates, and 3) uncovering potential mechanisms underlying identified associations.

Second, existing studies largely relied on methods such as ISD (66%) and CV (9.4%). Both methods quantify net IIV [72] and incorporate systematic time effects (e.g., therapeutic effects of a sleep intervention, effects of seasonal variation in daylight on sleep timing), which if not of direct relevance to the hypothesis, may inflate the estimation of IIV. Some studies reduced systematic time effects by detrending before calculating ISD [34], or by using methods (e.g., MSSD) that are less sensitive to such effects [5,65]. All above mentioned approaches, however, do not account for measurement error and are susceptible to low reliability, particularly when the number of repeated observations and/or individual differences in IIV is small [75]. Unlike means, which have good reliability with a few repeated measures, if IIV were to be estimated using ISD, as many as 50 repeated observations would be required for a reliable instrument (reliability .9) to achieve reasonable reliability (reliability .8) [76]. None of the included studies reported considerations or justifications for sample size or the number of repeated measures required for IIV to be reliably quantified (two provided sample size justifications for analyses relating IIV to correlates). In addition, missing data are common in daily repeated measures, but existing literature predominantly relied on methods that do not address missing data (e.g., ISD, CV, MSSD), resulting in compromises, such as reduction in usable sample sizes (in cases of listwise deletion) and biases towards days with no missing data (in

cases of omission). Recent methodological advances in modeling IIV [77–79] overcome the aforementioned limitations of traditional methods. Pertinent to sleep/wake IIV, a flexible approach that can be applied in relatively small samples, few repeated measures, and allow quantification of time-structured IIV [72] such as that described in Wiley et al. (2014) [77] could provide essential tools for future studies.

Third, differences in the covariates included could have contributed to discrepancies in findings across studies. In particular, differences in whether or not the individual means of the sleep variable in question was controlled for made it difficult to conclude whether significant associations between the IIV and correlates were due to the distinctive effects of IIV, or were simply an artefact of its individual means. Compared to sleep variables that are typically normally distributed (e.g., sleep duration and timing), sleep variables with skewed distribution such that individuals with more extreme means have smaller IIV due to floor and ceiling effects [80] (e.g., SOL) are more likely to be affected by this effect as correlations between the individual mean and IIV are likely to be higher in these variables. However, only six of the included studies controlled for corresponding individual mean, and only one in the Insomnia and Sleep Complaints theme, in which SOL, a variable that is often positively skewed, is of key interest. Findings from these six studies suggest that sleep/wake IIV might share meaningful associations with correlates of interests beyond the mean values. Therefore, when examining the relationship between sleep/wake IIV and its correlates, future studies should 1) include the individual mean of the sleep variable as a covariate, and 2) give careful consideration to other confounders to be included as covariates.

Fourth, inconsistent terminologies (e.g., “night-to-night variability”, “daily variation”, “daily instability”, “day-to-day fluctuation”) have been used to describe IIV of sleep/wake patterns. A consistent terminology across future studies will help enhance coherence of this literature and improve the access of relevant findings. For this purpose, we recommend “intraindividual variability (IIV)”.

Finally, given the unsystematic nature of this literature, and that nearly a third of included studies did not have a priori aims or hypotheses related to sleep/wake IIV, there is potential risk for bias towards reporting/publishing positive findings. Going forward, studies of either hypothesis-driven or exploratory natures should report both positive and negative findings.

Limitations

First, due to the heterogeneity of included studies, and the limited number of studies that examined the same correlate, it was not possible to conduct meta-analyses on the strengths of the associations between sleep/wake IIV and its correlates. Whenever available, effect sizes are reported in Table 1. Similarly, it was not possible to systematically assess risk of reporting/publication biases. Second, only studies on adults were included in this review. In children and adolescents, sleep/wake IIV and its correlates might share similarities as well as differences with those reported in adults, and should be further examined. For example, similar to adults, more variable sleep patterns in youths were associated with psychopathology [81] and worse psychological well-being [1], and CBT-I reduced sleep timing IIV [82]; on the other hand age-specific factors such as parental control in children [83] and school-related sleep restriction in adolescents [84] have been reported as correlates of sleep/wake IIV. Finally, this review focuses on identifying and characterizing correlates of sleep/wake IIV, and therefore discussions on findings and potential mechanisms for specific correlates are beyond the scope of this review.

Conclusion

A systematic review of the literature revealed that daily IIV of sleep/wake patterns were associated with important mental and physical health outcomes. Overall, this body of literature is at its infancy. Paucity of the existing literature highlights the need for both hypothesis-driven and exploratory approaches in studying the nature and correlates of sleep/wake IIV. Whenever possible, future studies with daily measurements of sleep/wake patterns should incorporate the examination of IIV as a second dimension along with the means.

Practice points

A systematic review of the correlates of daily sleep/wake IIV revealed the following:

1. This literature appeared small, unsystematic, and post hoc, with under-developed theoretical frameworks and inconsistent methodologies, limiting conclusions that can be drawn on some correlates.
2. The following correlates were most consistently associated with greater IIV in one or more aspects of sleep/wake patterns: younger age, non-White race/ethnicity, living alone, physical health conditions, higher BMI, weight gain, bipolar or depression symptomatology, stress, and evening chronotype; symptoms of insomnia and poor sleep were associated with higher sleep/wake IIV, and sleep interventions reduced such IIV.
3. The effects of experimentally reduced sleep/wake IIV on daytime functioning were variable and inconclusive.
4. Some evidence suggests that daytime consequences of, and the recovery from, sleep deprivation/disruption might be related to habitual sleep/wake IIV.

Research agenda

In studying the nature and correlates of sleep/wake IIV, future studies should address gaps and limitations identified in the existing literature, and more specifically:

1. Development of theories and methodologies is needed to guide more systematic investigations.
2. Both hypothesis-driven and exploratory approaches are needed.
3. Whenever possible, IIV should be conceptually integrated as a second dimension of sleep/wake patterns, and examined along with individual means.
4. Whilst there is a continuing need for observational studies in naturalistic settings, prospective and longitudinal, as well as experimental studies are particularly needed for clarifying causal directions of IIV and their correlates, and uncovering potential mechanisms underneath identified associations.
5. Consideration should be given to the choice of IIV analytic method as they differ in whether they account for systematic trends, measurement error, and whether they

allow missing data. It is also important to consider both the number of participants and the number of repeated measures.
6. The rate of missing data in daily sleep measures should be reported. Analytic approaches that address missing data are more appropriate than listwise deletion or omission.
7. Consideration should be given to the selection of covariates. We recommend that the individual mean of the sleep variable be included as a covariate when examining the relationship between the IIV of the sleep variable and its correlate(s).
8. A consistent terminology across future studies is needed, and we recommend "intraindividual variability (IIV)".
9. Future studies should report both positive and negative findings.

Conflicts of interest

The authors do not have any conflicts of interest to disclose.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.smrv.2015.06.003.

An ongoing systematic review with updated findings on sleep/wake IIV and its correlates can be found here: www.sleepv.org.

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