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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.