Assessing sleep regularity: theoretical and practical implications of available metrics

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Background

Irregular sleep, a proxy for circadian disruption in the field, has been associated with adverse health effects1. Sleep regularity has been assessed by focusing on average sleep-wake patterns, using metrics such as standard deviation (StDev), Interdaily Stability (IS), and Social Jet Lag (SJI). Novel metrics have been proposed to instead capture variability between consecutive days: the Composite Phase Deviation (CPD)2 and the Sleep Regularity Index (SRI)3. We systematically compared these metrics across different sources of daily variability (e.g., naps, awakenings), number of days and participants.

Methods

Sleep-wake patterns were synthetically generated over 2-28 days with weekday-weekend differences. Daily sleep variability was introduced by randomly drawing daily mid-sleeps and/or sleep durations from a normal distribution with standard deviation ranging from 0-120 min. Average estimates and 95% confidence intervals (CIs) were calculated for:

- WASO: all-nighters (nights with no sleep); and different study lengths (2-28d).
- Number of days determined for two-group comparisons (i.e. regular vs. irregular sleepers) using Welch’s t-test.

1) Metrics measure on different time scales: global vs. circadian metrics.

2) Metrics integrate different amounts of data: deviation vs. overlap metrics.

3) Overlap, but not deviation, metrics assess fragmented sleep.

Results

1. Scrambling

2. Increasing daily variability

3. Fragmented sleep: naps

4. Interdaily Stability

5. Global metrics require relatively many days for an accurate estimate, whereas circadian metrics require larger samples.

Conclusion

The metrics measure different aspects of sleep regularity and should be seen as complementary rather than competitive. Global metrics require relatively many days for an accurate estimate, whereas circadian metrics require larger samples. Selecting a metric will need to balance study length and sample size. Studies should include more than one metric to capture different aspects of sleep regularity and examine its potential as a proxy for circadian disruption in the field.

References


Figure 1. Sleep regularity metrics. Global metrics SJL (a), StDev (b), and IS (c) quantify overall sleep variability, comparing each day to the average, whereas circadian metrics CPD (d) and SR (e) quantify variability between days, comparing each day to the next.

Figure 2. Global vs. circadian metrics. When sleep episodes were randomly re-ordered, SJL (a) and IS (c) remained identical, whereas CPD (d) and SR (e) were affected, showing that the metrics measure on different time scales. StDev measure on a global scale returning the same values irrespective of day-to-day changes, whereas CPD/SRI measure on a circadian scale capturing changes between consecutive days. Scrambling returned the weekday-weekend difference and thus SJL (d), equaled zero.

Figure 3. Deviation vs. overlap metrics. StDev (a) and CPD (b) use values derived from sleep-wake patterns by measuring the deviation of daily sleep from Reference Sleep (deviation metrics); whereas IS (c) and SR (d) use the entirety of sleep-wake patterns to quantify the overlap between daily patterns and the average pattern, respectively. Between adjacent pattern, SJL (e) is a measure of weekly but not daily sleep regularity (values do not change with increasing daily variability). Variability between consecutive days, comparing each day to the next.

Figure 4. Fragmented sleep: naps. WASO (f). Overlap metrics StDev (g) accurately reflected fragmented sleep (h), while deviation metrics either captured only one dimension, e.g., number of naps (j), or variability in nap timing (j), or could not assess fragmented sleep at all (WASO). For WASO, total duration (not number of wake bouts) determined ISR ‘irregularity’.

Figure 5. Stability vs. regularity. With increasing absent sleep (a), values of StDev (b), CPD (c), and IS (d) returned to a perfectly regular score for constant wakefulness, whereas SRI yielded monotonically lower (‘less regular’) values, suggesting that SRI does not assess the regularity of a sleep-wake pattern without consideration of its ‘stability’: for a sleep-wake rhythm to be regular, both sleep and wakefulness need to be present.

Figure 6. Number of days: Global metrics were less stable over the first 7 days than circadian metrics: all changed up to 33%/98% (a-c) vs. CPD/SRI up to 9%/1% (b-d) (compared with mean at 28d). While 95% CIs narrowed with more days for all metrics, CPD/SRI had generally wider CIs than StDev/SJL, due to circadian metrics measuring on a day-to-day timescale.

Figure 7. Number of participants. Due to their wider CIs, CPD/SRI (e-h) required on average 20% larger sample sizes than StDev/SJL (a-d) but that number decreased with more days (e.g., 12% for 28-d patterns). Sample sizes were not increased for CPD/SRI when comparing groups of very different sleep regularity (dark-blue cells, i.e., regular vs. irregular sleepers).