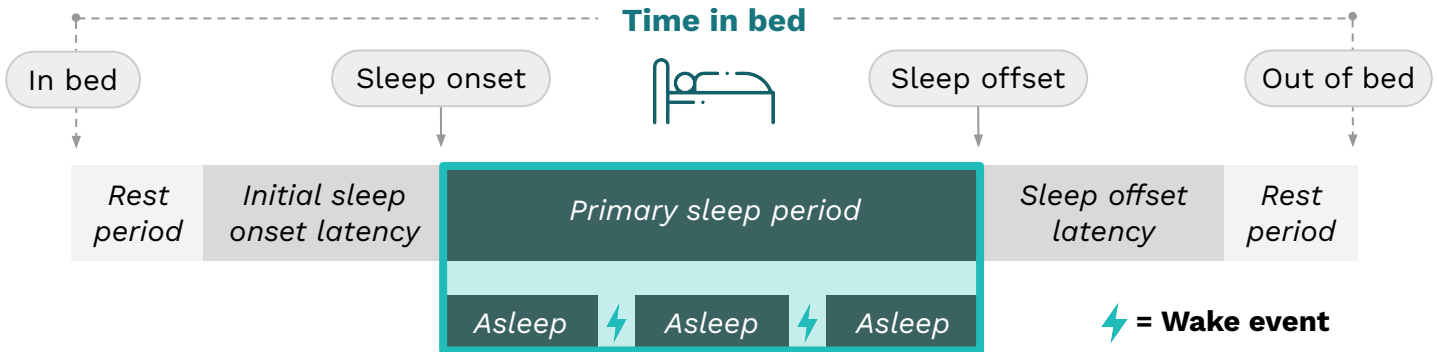




Core Digital Measure of Sleep: Total sleep time (Duration)

Also known as: true sleep time, time spent sleeping
Type: Duration of time

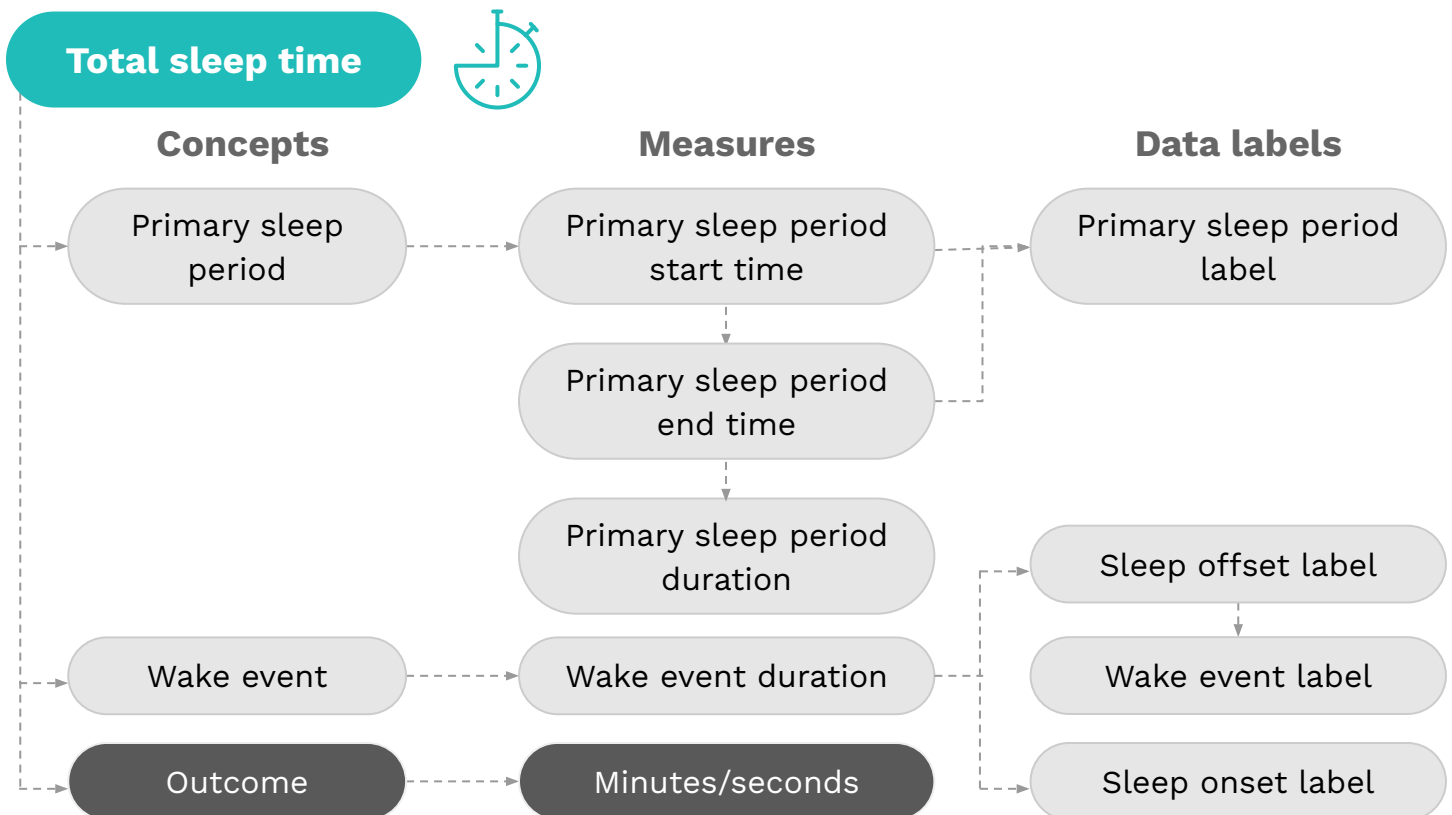
Definition: The duration of time spent sleeping in the primary sleep period



Total sleep time = (Primary sleep period) - (WASO)

WASO* = Σ (⚡ Duration)

*Wake after sleep onset



Measure considerations

Importance: Total sleep time is an important indicator of health and mortality.^{1,2,3}

Measure derivation: The difference between the primary sleep period duration and the sum of all wake events in the primary sleep period (i.e., wake after sleep onset).

Optional deviations: By specifying what constitutes a confirmed wake event, users can ensure that the outcome of total sleep time is interpretable. With rationale, a confirmed wake event could be more or less conservative to meet the specific research goals.

Primary sleep period label

Description

A sleep period is a duration of time that an individual spends asleep in a single session. It may involve some number of brief awakenings, but the individual returns to sleep rather than terminating their sleep attempt. There could be several sleep periods in a given 24-hour period, but research and clinical practice is often concerned with activity within a primary sleep period, such as going to sleep at night and intending to wake up in the morning.

Label definition

A label for each epoch between:

- The first sleep onset Label=1 with a time attempting to sleep label=1
- The final sleep offset label=1 with a time attempting to sleep label=1

The final sleep offset is not included in the definition.

Where the time attempting to sleep label is not available, the In bed label can be used in its place. This substitution should be clearly noted.

Why is this important?

The primary sleep period label differentiates from the asleep label, as any sleep period can include brief periods of waking, provided the individual falls back asleep.

The primary sleep period label can therefore be used in conjunction with other labels and derived variables to determine, for example, the number of awakenings or the length of awakenings during the sleep period. It also allows the user to derive measures of other sensor-based symptomology or activity occurring during the sleep period.

Derived variables

Primary sleep period start time

Variable definition

The **timestamp** of the first epoch with the primary sleep period label.

Primary sleep period end time

Variable definition

The **timestamp** of of the final epoch with the primary sleep period label.

Primary sleep period duration

Definition: A **time duration (seconds)** calculated as the difference between the primary sleep period start and end times.



Sleep offset label

Description

An epoch where the individual transitions from being asleep to being awake.

Label definition

A label for the first epoch in a series of epochs with an asleep label=0 that follow a series of epochs with asleep label=1 (the opposite of the sleep onset Label). The valid minimum length of each series must be specified.

Why is this important?

The sleep offset label can be used to define when individuals wake up from sleep. This waking may not be the final awakening of a given period of sleep, but could be important for understanding the continuity of an individual's sleep.

For example, the sleep offset label could be used in conjunction with other parameters to understand how many times an individual wakes up during a primary sleep period before their intended wake time.

Sleep offset time

Variable definition

The **timestamp** associated with a sleep offset label.

Wake event label

Variable definition

An epoch with a sleep offset label=1 and primary sleep period=1.

Sleep onset label

Description

An epoch where the individual transitions from being awake to being asleep.

Label definition

A label for the first epoch in a series of epochs with an asleep label=1 that follow a series of epochs with asleep label=0. The valid minimum length of each series must be specified.

For example, a valid minimum length could be ten 30-second epochs of sleep (5 minutes in total). In this case, where sleep is registered for at least ten consecutive epochs, the first epoch in the series would be awarded the sleep onset label. If a series of epochs is registered for less than ten consecutive epochs, no sleep onset Label would be awarded.

Why is this important?

Not all sleep epochs represent a confirmed sleeping bout. Describing, evidencing, and confirming a minimum detected sleep time prior to denoting sleep onset allows for more sensitive sleep measurement.

The sleep onset label can be used to define when individuals achieve sleep and used in conjunction with other parameters to derive important metrics, such as the time it takes for an individual to fall asleep.

Sleep onset time

Variable definition

The **timestamp** associated with a sleep onset label.

Sleep onset time

Sleep offset time

Wake event label

Wake event duration

Variable definition

The **time duration (seconds)** of a wake event that occurs during the primary sleep period and is followed by a further period of sleep.

The duration of each wake event is calculated separately as the difference between:

- The sleep offset time associated with a wake event label=1, and
- The sleep onset time of the following epoch with sleep onset label=1

Why is this important?

By measuring each wake event duration, not only can the sum of all wake event durations be used to measure wake after sleep onset, but individual wake bouts can be assessed if relevant to the research question.

Additionally, wake event durations with outlying duration magnitudes can be individually explored as a data quality assurance step.

References

1. Yin, J., Jin, X., Shan, Z., Li, S., Huang, H., Li, P., ... & Liu, L. (2017). Relationship of sleep duration with all-cause mortality and cardiovascular events: a systematic review and dose-response meta-analysis of prospective cohort studies. *Journal of the American Heart Association*, 6(9), e005947.
2. Lin, Y., Wu, Y., Lin, Q., Wing, Y. K., Xu, L., Ge, J., ... & Wei, S. (2023). Objective Sleep Duration and All-Cause Mortality Among People With Obstructive Sleep Apnea. *JAMA Network Open*, 6(12), e2346085-e2346085.
3. Li, H., Qian, F., Han, L., Feng, W., Zheng, D., Guo, X., & Zhang, H. (2023). Association of healthy sleep patterns with risk of mortality and life expectancy at age of 30 years: a population-based cohort study. *QJM: An International Journal of Medicine*, hcad237.