Core Measures: Sleep Measurement System

Variables for creating the core digital measures of sleep

Last updated March 27th, 2024

CORE MEASURES *of* SLEEP

Digital Measures Development

https://datacc.dimesociety.org/core-measures-sleep/

DATAcc by DiME
Digital Health Measurement Collaborative Community

DIGITAL MEDICINE SOCIETY

Variables

Variables are specific aspects of sleep measurement that can be used to create higher order measures, such as the core measures.

Variables consist of epoch level timestamps, epoch level labels, and derived variables.

Core Measures: Sleep Measurement System definitions

Epoch

The core measures: Sleep Measurement System uses an epoch-based paradigm.*
An epoch is a fixed-length period of time over which a phenomenon is measured.
    The measurement(s) data come from one or multiple sensor inputs.
    The interpretation of epoch data can be made from human scoring of the data, or from the output of an algorithm applied to the data.
In typical polysomnography (PSG), epochs are 30-second windows of data from multiple channels.
Different technologies will use different epoch lengths. It is crucial to report the epoch length of any selected technology.

* Other paradigms exist, and solutions based on other systems are also valid.

Epoch timestamps

Each epoch will have one or more associated timestamps.
    The timestamp will typically represent the start time and date of the epoch.
        Additional timestamps could represent the end of the epoch.

When a timestamp is referred to in this measurement system, it is intended to be the epoch start time.
    This timestamp can be used and manipulated to create derived variables for sleep measurement.
        Timestamps should ideally use the form year:month:day:hh:min:sec.

Epoch labels

The interpretation of each epoch leads to one or more associated labels.
These labels are additional variables that contain the interpretation of that epoch or denote important information about that epoch.
A label typically contains a 1 (true) or a 0 (false) to indicate the presence or absence of a given status or event.

Although some systems allow for just a single interpretation variable per epoch, this measurement system requires a **long-format** dataset with multiple labels to allow for later derivation of the core measures of sleep.

Epoch label types

Status label

Status labels are used over multiple epochs to denote an individual's ongoing state. For example, an individual will have many Asleep Labels in succession, showing a period of sleep.

Event label

Event labels denote a given epoch where an event occured. For example, although there may be multiple sleep onsets in a 24-hour period, a sleep onset Label would denote the epoch where sustained sleep initially occurred in each sleeping bout.

Derived variables

Epoch labels can be used to select one or more epochs. The epoch label or the corresponding epoch timestamps can be used to derive meaningful information.
    A single epoch timestamp can be selected to represent the start or end of a given period (e.g., the beginning of the primary sleep period).
    Multiple epoch timestamps can be selected and used in a mathematical operation to create a duration variable (e.g., the duration of the primary sleep period).
    A count of multiple epoch labels can be used to derive the frequency of events (e.g., the frequency of wake events).
These variables can be further used in the specification of the Core Digital Measures of Sleep, or for creating new measures outside of the Core Digital Measures of Sleep.

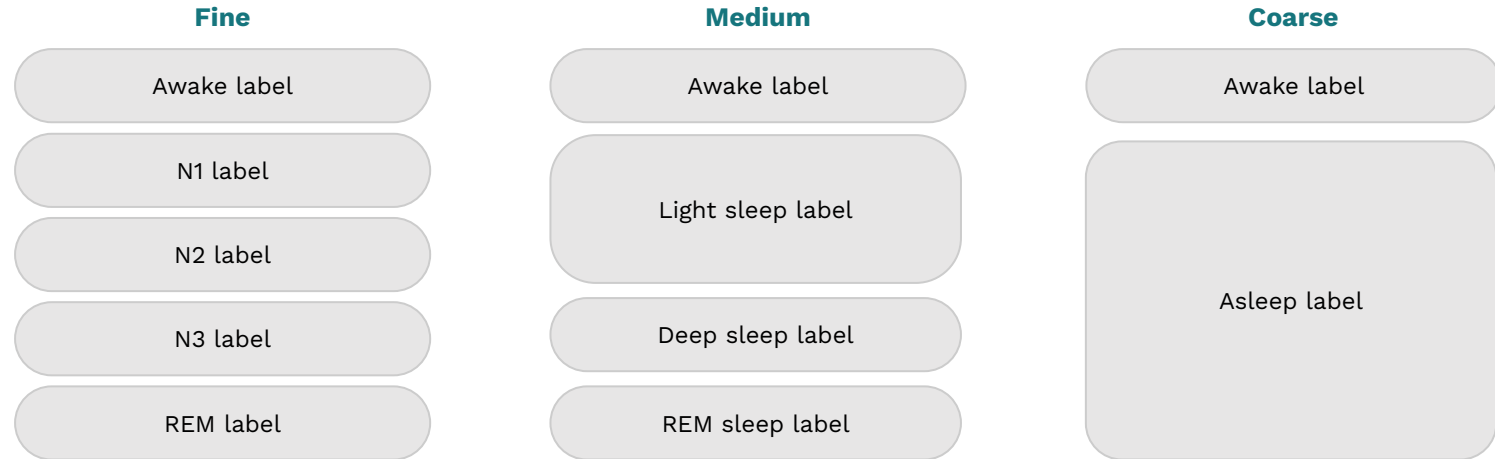# Core Measures: Sleep Measurement System definitions

Sleep Staging Labels

General Description: Sleep staging labels are the fundamental basis for the Core Measures of Sleep System and the resulting Core Digital Measures of Sleep produced by DATAcc.

The choice of sleep staging labels will be dependent on the scientific or clinical question under examination. For some questions, it is necessary to measure fine-grain sleep stages; for other questions, coarse-grain staging (asleep vs. awake) may be appropriate. Medium and coarse-grain staging can either be derived directly from fine grain staging or algorithmically estimated.

The selected measurement technology will depend on the choice of sleep staging measurement required.

Granularity

Fine	Medium	Coarse
Awake label	Awake label	Awake label
N1 label	Light sleep label	Asleep label
N2 label		
N3 label	Deep sleep label	
REM label	REM sleep label	

Sleep staging label descriptions and definitions

Coarse-grain measurement   Medium-grain measurement   Fine-grain measurement

Asleep label

Description

"Asleep" is a state consisting of a union of REM and the N1-N3 stages of sleep. A state of sleep can be detected in multiple ways, through changes in brain activity, body motion, respiration, heart rate, etc.

Label definition

A Label for each epoch denoting when an individual is recorded to be asleep. **The parameters or algorithms for detecting sleep** must be clearly defined or referenced.

Alternatively, the asleep Label can be defined as the presence of any of: light sleep, deep sleep, REM sleep, and N1, N2, N3 and REM labels presented in the Core Measures: Sleep Measurement System, where these are collected by the selected technology.

Awake label

Description

Awake is the absence of sleep and a state of conscious awareness of an individual's surroundings. A state of being awake can be detected in multiple ways: through changes in brain activity, body motion, respiration, heart rate, etc., or through the measurement of actions which indicate consciousness.

Label definition

A label for each epoch denoting when an individual is recorded to be awake. **The parameters or algorithms for detecting and distinguishing awake from asleep must be clearly defined or referenced.**

Alternatively, the awake label can be defined as the absence of any of: light sleep, deep sleep, REM sleep, and N1, N2, N3 and REM labels presented in the Core Measures: Sleep Measurement System, where these are collected by the selected technology. This definition does not assume that missing data represents a state of being awake.

Sleep staging label descriptions and definitions

| Coarse-grain measurement | Medium-grain measurement | Fine-grain measurement |

Light Sleep label

Description

Light Sleep is an algorithmic estimation of a combination of the N1 and N2 stages. Is typically derived from non-EEG signal data, when brain activity data is not available.

Label definition

A label for each epoch denoting when an individual is recorded to be in light sleep. **The parameters or algorithms for estimating light sleep must be clearly defined or referenced.** Alternatively, the light sleep label can be defined as the presence of any of the N1 or N2 labels, in the case that these are collected by the selected technology.

Deep sleep label

Description

Deep sleep is an algorithmic estimation of slow wave sleep. It is typically derived from non-EEG signal data.

Label definition

A label for each epoch denoting when an individual is recorded to be in Deep Sleep. **The parameters or algorithms for estimating deep sleep must be clearly defined or referenced.**

REM sleep label

Description

REM sleep is an algorithmic estimation of the REM stage of the sleep cycle. It is typically derived from non-EEG signal data.

Label definition

A label for each epoch denoting when an individual is recorded to be in REM Sleep. **The parameters or algorithms for estimating REM Sleep must be clearly defined or referenced.**

Sleep staging label descriptions and definitions

Coarse-grain measurement	Medium-grain measurement	Fine-grain measurement

N1 label

Description

The N1 stage of sleep is a short transitional stage at the beginning of the sleep cycle. It typically needs brain activity data to be estimated.

Label definition

A label for each epoch denoting when an individual is recorded to be in N1 sleep. **The algorithm for detecting N1 sleep must be evidenced.**

N2 label

Description

The N2 stage of sleep represents the majority of non-REM sleep. It typically needs brain activity data to be estimated.

Label definition

A label for each epoch denoting when an individual is recorded to be in N2 sleep. **The algorithm for detecting N2 sleep must be evidenced.**

N3 label

Description

The N3 stage of sleep represents slow wave sleep. It typically needs brain activity data to be estimated.

Label definition

A label for each epoch denoting when an individual is recorded to be in N3 sleep. **The algorithm for detecting N3 sleep must be evidenced.**

REM label

Description

The REM stage of sleep represents a state with rapid eye movements alongside changes in the respiration pattern, and a pattern of brain activity similar to the awake state. It needs brain activity data to be estimated.

Label definition

A label for each epoch denoting when an individual is recorded to be in REM sleep. **The algorithm for detecting REM sleep must be evidenced.**

Specific epoch label and derived variable descriptions and definitions

Contextual data labels and derived variables

General description: Epoch labels allow epochs to be designated as representing different states or events. For example, having a label that represents an individual being in bed can be used alongside the sleep staging labels to understand whether an epoch labeled as sleep occurred while the individual was in bed or not. Similarly, by using a label for the primary sleep period, the user can distinguish between sleeping inside the main rest period of the day, and napping outside of that period.

It is unlikely that these epoch labels and derived variables are of primary interest to the researcher, but in combination with each other and the sleep staging labels, the Core Digital Measures of Sleep and other associated measures can be derived.

Sleep onset label	*Type: Event 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 offset label	*Type: Event 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 awakening 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.
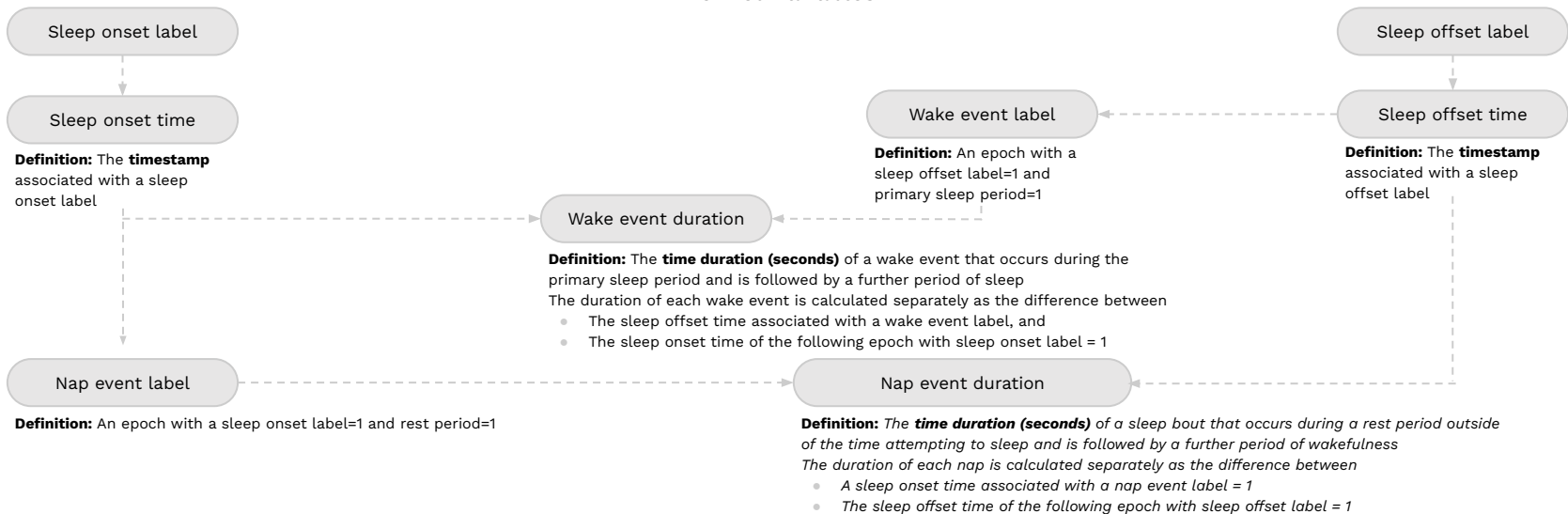
Specific epoch label and derived variable descriptions and definitions

Contextual data labels and derived variables

General description: Epoch labels allow epochs to be designated as representing different states or events. For example, having a label that represents an individual being in bed can be used alongside the sleep staging labels to understand whether an epoch labeled as sleep occurred while the individual was in bed or not. Similarly, by using a label for the primary sleep period, the user can distinguish between sleeping inside the main rest period of the day, and napping outside of that period.

It is unlikely that these epoch labels and derived variables are of primary interest to the researcher, but in combination with each other and the sleep staging labels, the Core Digital Measures of Sleep and other associated measures can be derived.

Derived variables

Sleep onset label

Sleep onset time

Definition: The **timestamp** associated with a sleep onset label

Wake event label

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

Sleep offset label

Sleep offset time

Definition: The **timestamp** associated with a sleep offset label

Wake event duration

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, and
- The sleep onset time of the following epoch with sleep onset label = 1

Nap event label

Definition: An epoch with a sleep onset label=1 and rest period=1

Nap event duration

Definition: The **time duration (seconds)** of a sleep bout that occurs during a rest period outside of the time attempting to sleep and is followed by a further period of wakefulness
The duration of each nap is calculated separately as the difference between
- A sleep onset time associated with a nap event label = 1
- The sleep offset time of the following epoch with sleep offset label = 1

Specific epoch label and derived variable descriptions and definitions

Contextual data labels and derived variables

General description: Epoch labels allow epochs to be designated as representing different states or events. For example, having a label that represents an individual being in bed can be used alongside the sleep staging labels to understand whether an epoch labeled as sleep occurred while the individual was in bed or not. Similarly, by using a label for the primary sleep period, the user can distinguish between sleeping inside the main rest period of the day, and napping outside of that period.

It is unlikely that these epoch labels and derived variables are of primary interest to the researcher, but in combination with each other and the sleep staging labels, the Core Digital Measures of Sleep and other associated measures can be derived.

| In bed label | *Type: Status label* |

Description

Epochs covering all periods where the individual is in bed.

Label definition

A label for each epoch denoting when an individual is recorded to be in bed. The state of being in bed could be provided by user input, but is likely detected by an algorithm. **The parameters or algorithms for detecting that the individual is in bed should be clearly defined or referenced.**

Why is this important?

Being in bed does not necessarily mean that the individual has the intention to sleep (see time attempting to sleep label) or is asleep (see sleep staging labels). However, in cases where the intention to sleep is not collected, the In bed label can be used as a less precise default or proxy.

The in bed label also records instances of leaving bed during the **primary sleep period**, which could be useful for some research questions.

| Time attempting to sleep label | *Type: Status label* |

Description

Epochs covering the primary period of time where the individual intends to sleep.

Label definition

A label for each epoch between the point at which the individual intends to start sleeping to the point which the individual intends to stop sleeping.

The intention to start and end sleep could be provided by user input or detected by an algorithm. **The parameters or algorithms for detecting the individuals intention to sleep should be clearly defined or referenced.**

Why is this important?

The inclusion of intention is difficult for measurement, as it is non-observable and must be inferred or reported. However, intention is important for distinguishing between epochs that record quiet restfulness (e.g., lying in bed reading) from the active process of trying to achieve sleep. Distinguishing between the two will lead to more sensitive measurement of sleep parameters.

Specific epoch label and derived variable descriptions and definitions

Contextual data labels and derived variables

General description: Epoch labels allow epochs to be designated as representing different states or events. For example, having a label that represents an individual being in bed can be used alongside the sleep staging labels to understand whether an epoch labeled as sleep occurred while the individual was in bed or not. Similarly, by using a label for the primary sleep period, the user can distinguish between sleeping inside the main rest period of the day, and napping outside of that period.

It is unlikely that these epoch labels and derived variables are of primary interest to the researcher, but in combination with each other and the sleep staging labels, the Core Digital Measures of Sleep and other associated measures can be derived.

In bed label

Derived variables

Primary in bed start time

Definition: The **timestamp** of the first epoch with the first In bed label.

Primary in bed end time

Definition: The **timestamp** of the first epoch with the final in bed label.

Primary in bed duration

Definition: A **time duration (seconds)** calculated as the difference between the In bed start and end times.

NB: Variables derived from the in bed label must be in line with user-provided parameters for defining which epoch represents the primary in bed start time and In bed end time, accounting for the individual potentially entering and leaving bed multiple times.

Time attempting to sleep label

Derived variables

Time attempting to sleep start time

Definition: The **timestamp** of the first epoch with the time attempting to sleep label.

Time attempting to sleep end time

Definition: The **timestamp** of the final epoch with the time attempting to sleep label.

Time attempting to sleep duration

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

Specific epoch label and derived variable descriptions and definitions

Contextual data labels and derived variables

General description: Epoch labels allow epochs to be designated as representing different states or events. For example, having a label that represents an individual being in bed can be used alongside the sleep staging labels to understand whether an epoch labeled as sleep occurred while the individual was in bed or not. Similarly, by using a label for the primary sleep period, the user can distinguish between sleeping inside the main rest period of the day, and napping outside of that period.

It is unlikely that these epoch labels and derived variables are of primary interest to the researcher, but in combination with each other and the sleep staging labels, the Core Digital Measures of Sleep and other associated measures can be derived.

Primary sleep period label — *Type: Status 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

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 goes back to sleep.

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 that happens during the sleep period.

Rest period label — *Type: Status label*

Description

Epochs covering the primary period of time where the individual is in a resting state that specifically occurs outside of the time attempting to sleep.

It involves and is often detected through a change in physiological metrics, such as reduced activity.

Label definition

A label for each epoch denoting when an individual is recorded to be resting and the time attempting to sleep label=0.

The Core Measures/; Sleep Measurement System **does not define rest**. The parameters or algorithms for detecting rest should be clearly defined or referenced.

Why is this important?

The rest period label differentiates from the primary sleep period label in that it occurs outside of time attempting to sleep for the primary sleep event of the day. This difference suggests that it is a period of restfulness where the individual did not intend to start their primary sleep event for the day.

This specification allows for the detection of minor sleep events, or naps, to be measured outside of the time attempting to sleep.

Specific epoch label and derived variable descriptions and definitions

Contextual data labels and derived variables

General description: Epoch labels allow epochs to be designated as representing different states or events. For example, having a label that represents an individual being in bed can be used alongside the sleep staging labels to understand whether an epoch labeled as sleep occurred while the individual was in bed or not. Similarly, by using a label for the primary sleep period, the user can distinguish between sleeping inside the main rest period of the day, and napping outside of that period.

It is unlikely that these epoch labels and derived variables are of primary interest to the researcher, but in combination with each other and the sleep staging labels, the Core Digital Measures of Sleep and other associated measures can be derived.

Primary sleep period label

Derived variables

Primary sleep period start time

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

Primary sleep period end time

Definition: The **timestamp** 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.

Rest period label

Derived variables

Rest period start time

Definition: The **timestamp** of the first epoch in a series of epochs with a rest period label=1 that follow a series of epochs with rest period label=0. The valid minimum length of each series must be specified.

Rest period end time

Definition: The **timestamp** of the final epoch in a series of epochs with a rest period label=1. The valid minimum length of each series must be specified.

Rest period duration

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

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