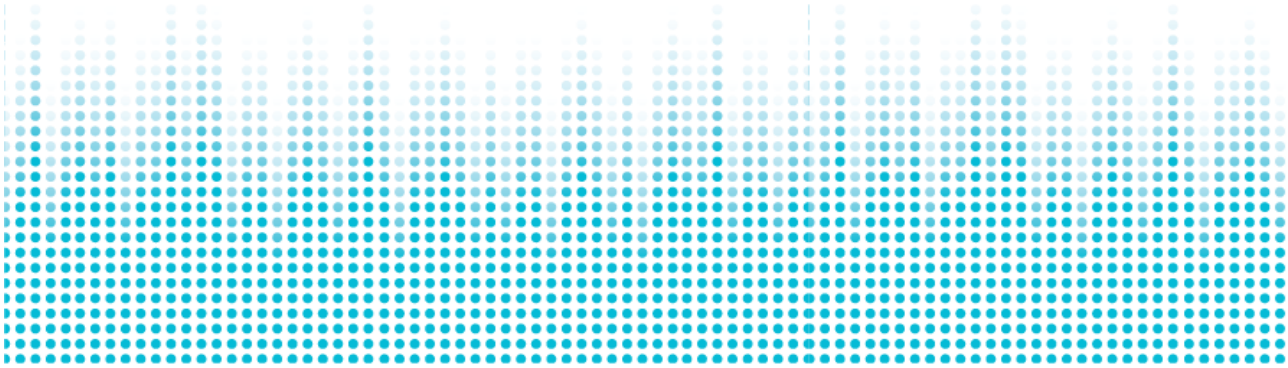
STAR watch™

Professional sleep and activity tracking system

User Manual

Model: STAR WATCH – BD1

Rev 0.10



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Important Information

FCC

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

FCC Caution: Any changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate this equipment.

Industry Canada

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Cet appareil est conforme aux normes d'exemption de licence RSS d'Industry Canada. Son fonctionnement est soumis aux deux conditions suivantes : (1) cet appareil ne doit pas causer d'interférence et (2) cet appareil doit accepter toute interférence, notamment les interférences qui peuvent affecter son fonctionnement.

Introduction to STARwatch

Overview

STARwatch is a professional sleep and activity tracking system that includes three components:

STARwatch Band
Unobtrusive wrist-worn band with integrated motion, light, and wear-detection sensors.

STARwatch Dock
USB docking station for charging the band batteries and providing connectivity to the STAR software.

STAR Software
Windows software application for configuring bands, and managing and analyzing data.

Getting started

The following steps will quickly get you started with your STARwatch system:

1. **Download and install STAR software**
   A link to download STAR software will have been provided to you by Pulsar after your purchase. Run the installation program on a computer that meets the minimum requirements. Start the software after installation is complete.

2. **Connect a dock and band to your computer**
   Plug a dock into a USB port on the computer you have installed the STAR software onto. Place a band onto the dock, and you will see a device appear in the Device tab in the software.

3. **Start a recording**
   Enter a subject name into the device recording screen in the STAR software, and click the Start Recording button. Remove the band from the dock and start wearing it.

4. **Review the User Manual**
   Learn about the complete details on the operation and maintenance of the hardware components and use of the software for device configuration, data management, and sleep scoring analysis.

Hardware Components

Band

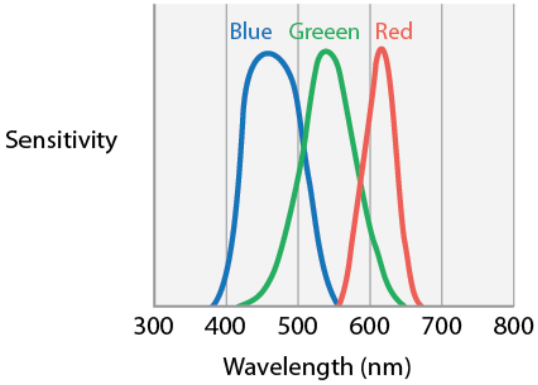
Sensors

Light

The STARwatch has a four channel, RGB-W (Red, Green, Blue, & White) light sensor. The lens is on the front face of the band and receives ambient light. The Red, Green, and Blue channels measure irradiance, the light power, within each of the spectral ranges. The white channel measures overall illuminance, which is an indicator of human brightness perception.

Light channel	Description
Red Irradiance	Red power level in uW/cm^2
Green Irradiance	Green power level in uW/cm^2
Blue Irradiance	Blue power level in uW/cm^2
White Illuminance	White level in lux

The approximate relative sensitivity curves for the Red, Green, and Blue channels are shown in the figure below.

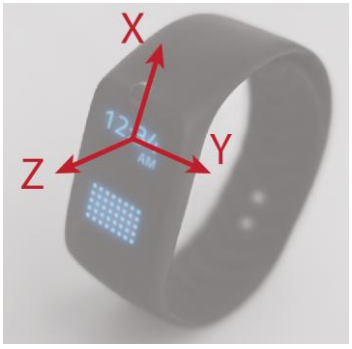


On-wrist

The band detects whether it is being worn using a proximity sensor embedded on the inside surface of the band. When the band is being worn, the presence of the wrist close to the band is measured. The on-wrist sensor uses a capacitive proximity field and does not require the wrist to be in direct contact with the surface of the band, but if the band is worn loosely it may result in intermittent spuriuous off-wrist measurements.

Accelerometer

A three axis accelerometer measures motion of the band along the X, Y, and Z axes as shown in the figure below. The raw acceleration signals are measured at a sampling rate of 50Hz or above, and later processed to generate derived activity count metrics. The sampling rate and range setting of the accelerometer are selected at the time a recording is started. The default settings are 50Hz, and ±4g.



Setting	Values	Description
Frequency	50Hz, 100Hz, 200Hz	Rate at which raw acceleration values are measured. Higher rates reduce battery life.

Range	±4g, ±8g, ±16g	Maximum acceleration range. Higher ranges allows faster movements to be detected. Lower ranges provider greater sensitivity for slower movements.

Display

The STARwatch band has an illuminated display that provides status indicators to both device administrators and subjects. When the band is docked the display has a landscape orientation and off the dock it has a portrait orientation.

Touch

Users can toggle display modes of the STARwatch band using the touch interface on the front face. A long press on the face will awaken the screen. Subsequent short presses will toggle the display page.

Battery

Power is provided by an internally-sealed rechargeable Lithium-Ion battery. The battery charges when placed on the dock. Recharge time will vary based on the level of battery, but a full charge from empty to full will complete within 1.5h. A battery full indicator is shown on the band display, and within the software when a full charge has been achieved.

Dock

Charge-only use

The dock can be used just to charge bands, by connecting the USB cable to any USB port that can provide power. The USB port may be a USB wall-adapter, a computer (with or without the STAR software), or on a USB hub.

Charge and data connectivity use

When the dock's USB cable is connected to a computer that is running the STAR software, it provides both battery charging and data connectivity. When a band is connected to the dock its battery will charge automatically if it is not full, and the band will appear in the STAR software.

Software

Overview

The STAR software is a Windows application that serves two purposes: a) communication with the STARwatch band **devices**, b) organization and analysis of the **data**.

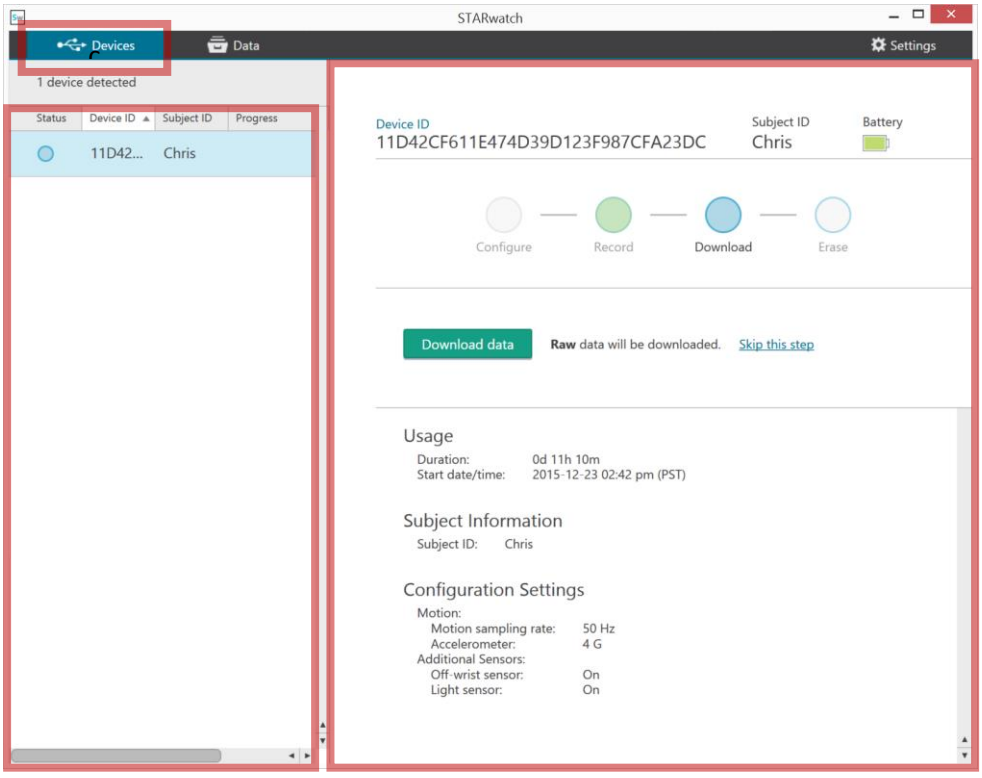
Installation

Running the STAR software requires a computer that meets the following requirements:

Requirement	Description
Operating system	Windows 7, 8, 8.1
RAM	4 GB
Disk space	100GB recommended for initial use.

Device management

The Devices tab view has two panels: 1) a connected devices list that shows all bands currently connected to the computer, and 2) a device detail that shows information about any device that is selected in connected devices list.

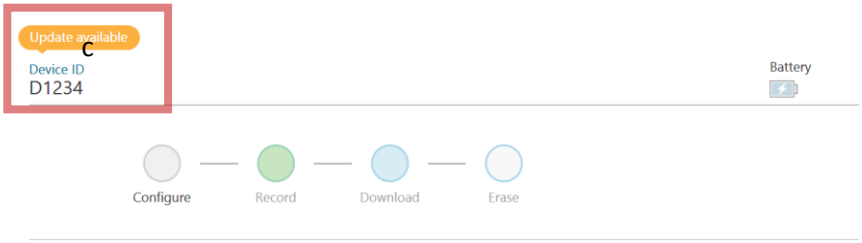


1. Connected devices list 2. Device detail

Firmware updates

The STAR software automatically checks over the internet for new firmware updates that are available for the STARwatch. These updates contain performance enhancements or additional features and should always be updated if they're available.

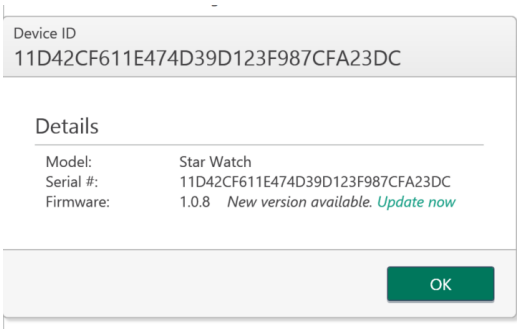
In the device detail panel, the availability of an update is shown by an alert above the device ID:



Apply an update

If an update available alert is visible, follow these steps to apply an update:

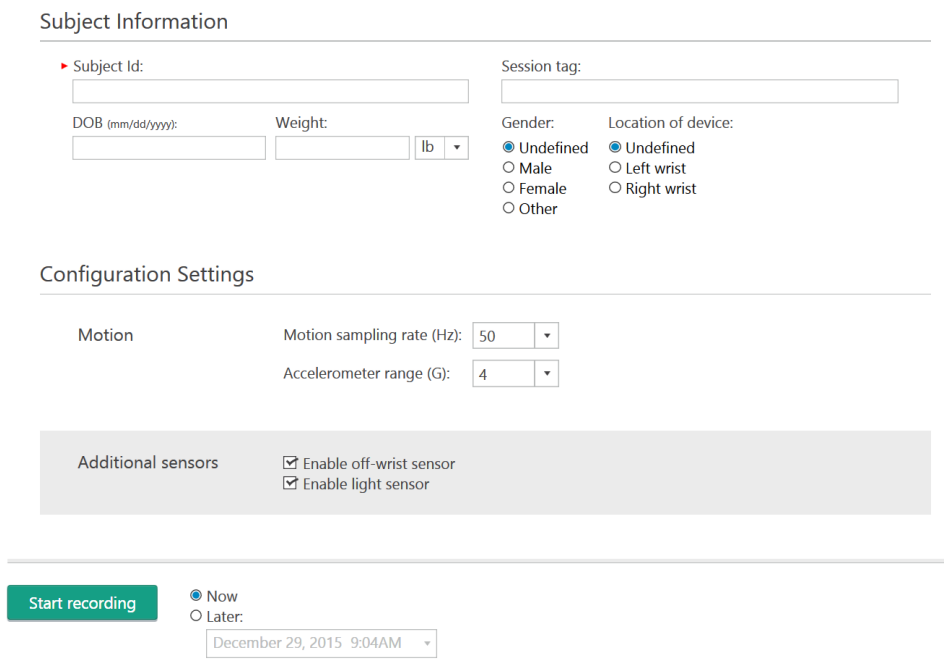
1. Check that a good internet connection is available
2. Ensure the device is in Configure mode (data has been erased, and it is not currently recording)
3. Click on the **Update Available** alert
4. On the device information pop-up window, click **Update Now**



5. Wait for the firmware to complete the automatic update. Do not disconnect the device from the dock while the upload is in progress.

Configuring a device for recording

When a device is in ready state to start a new recording (data has been erased, and it is not currently recording), the Recording Configuration page will show in the device detail panel when the device is connected:

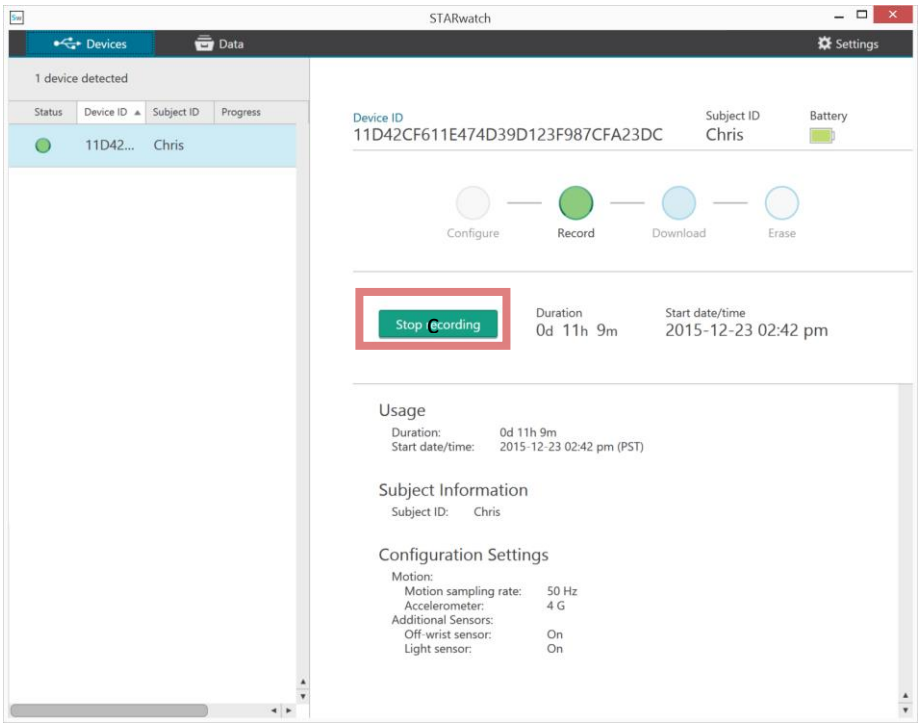


Set the subject identification, sensor configuration settings, and recording start time to the desired values then select **Start recording** to put the device into recording mode.

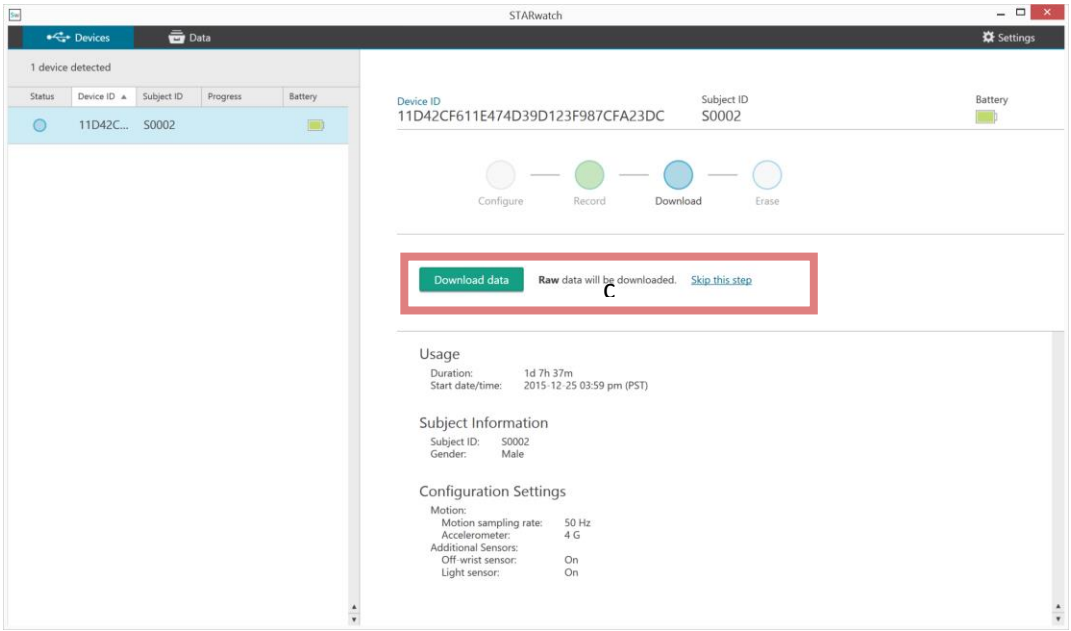
Stopping a Recoding and Downloading data

When a device that is recording is placed on the dock information about the device's current recording session is shown in the device detail panel. The device can be removed from the dock it will continue its recording session uninterrupted.

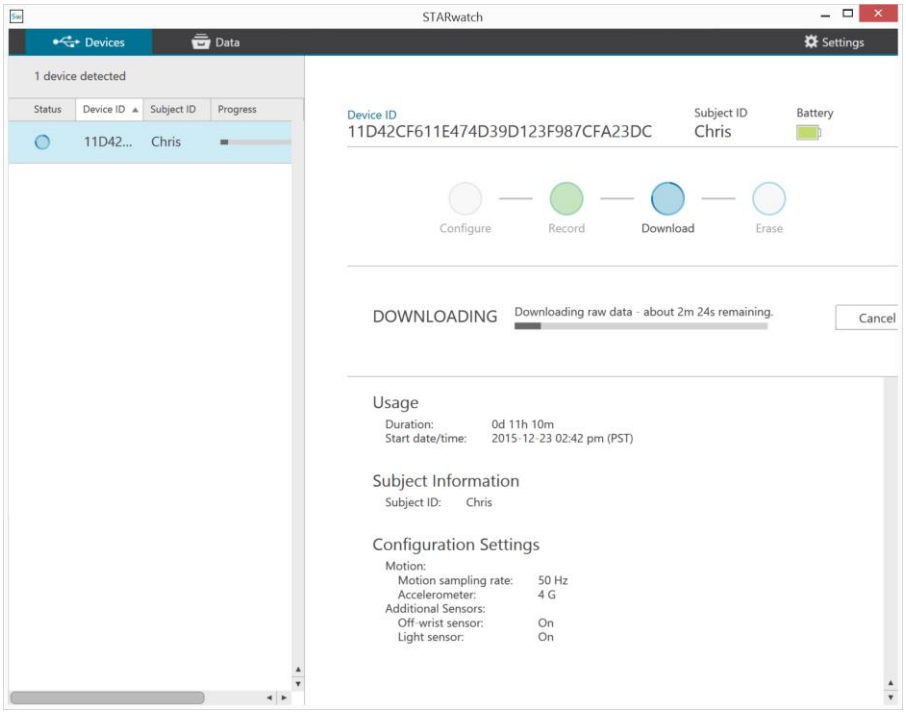
To end the recording session, click the **Stop recording** button.



The download screen will then show an option to **Download Now** or **Skip and Erase**. The Skip and Erase option will bypass the download step and permanently delete the data on the device.

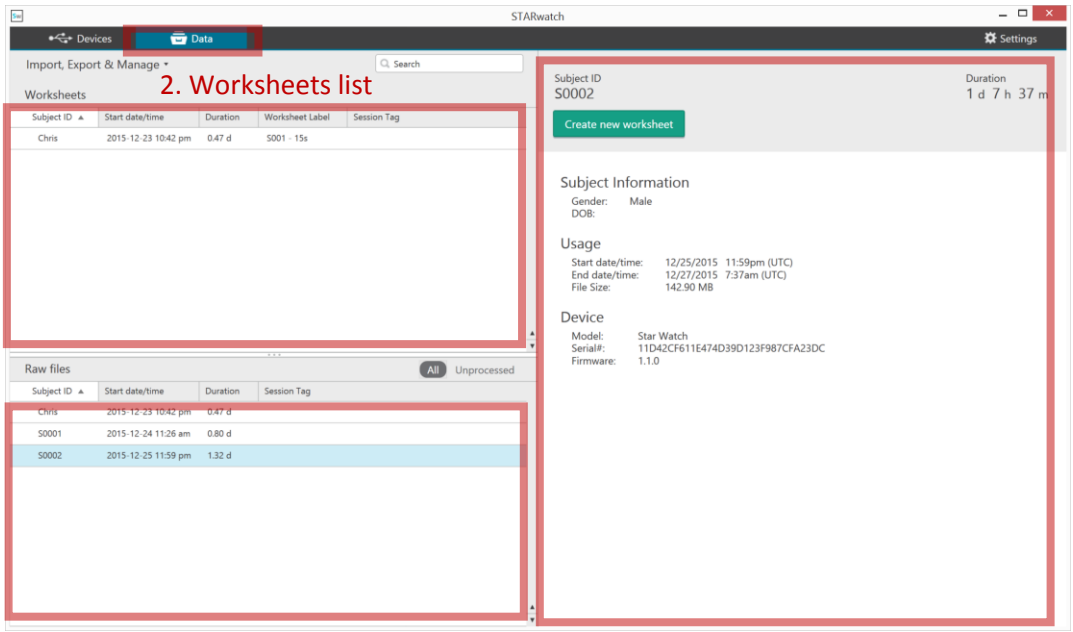


Initiating the Download process will show a download progress bar. Once the download is complete a new raw data file is available in the Data tab.



Data management

The Data tab view has three panels: 1) Raw data file list with original downloaded data files, 2) Worksheets list with each of the epoch-sampled worksheets that have been created, and 3) detail view of the data file or worksheet that is selected.



Raw files

Raw files contain the STARwatch sensor measurements at the full sampling rates that were selected during recording. The sampling rates may vary between channels, so the raw files contain data streams at variable sampling rates. Each time a download from a device is completed a new Raw file is created, and cannot be modified after it has been created.

The fields in the raw files include the following:

Raw file field	Description
Off-Wrist	Numeric value indicating wrist proximity. Values > 0 are off-wrist, values < 0 are on-wrist.
White Light (lux)	White light illuminance measurement
Red Light (uW/cm^2)	Red light irradiance measurement
Green Light (uW/cm^2)	Green light irradiance measurement
Blue Light (uW/cm^2)	Blue light irradiance measurement
Accel X (g)	Acceleration in the x-axis
Accel Y (g)	Acceleration in the y-axis

Accel Z (g)	Acceleration in the z-axis

Worksheets

Worksheets are summary data files, in which all channels have been resampled into consistently sized epochs. The multi-axis, high-frequency motion data from the Raw files is aggregated into a single Activity Count field that is used as the input for actigraphy sleep scoring.

The fields in the worksheets, and the epoch binning method is as follows:

Worksheet data field	Description
Off-Wrist	True or false value indicating wear or non-wear. Median value of all raw off-wrist measurements in the epoch
White Light (lux)	Mean value of all raw white-light measurements in the epoch
Red Light (uW/cm^2)	Mean value of all raw red-light measurements in the epoch
Green Light (uW/cm^2)	Mean value of all raw green-light measurements in the epoch
Blue Light (uW/cm^2)	Mean value of all raw blue-light measurements in the epoch
Activity Count	Numeric value indicative of the overall level of motion during the epoch. Raw X, Y, Z acceleration values are filtered and integrated.

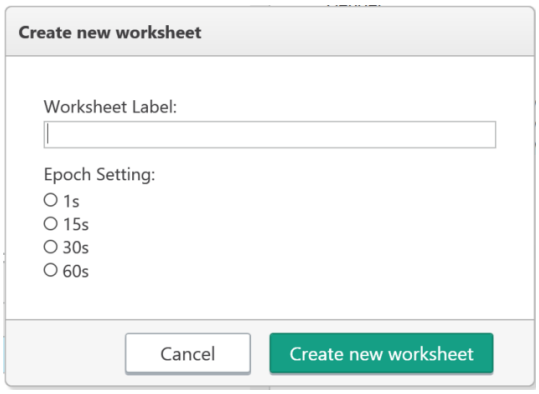
Creating worksheets

Worksheet from raw file

Raw files contain the high resolution measurements that are processed to create new worksheet with fixed duration epochs. When creating a worksheet an epoch duration is selected, and the raw file measurements are aggregated into bins of the selected epoch duration.

To process a raw data file into a new worksheet:

1) Select a raw data file
2) Click ‘Create new worksheet’ button
3) Select a label, and epoch setting

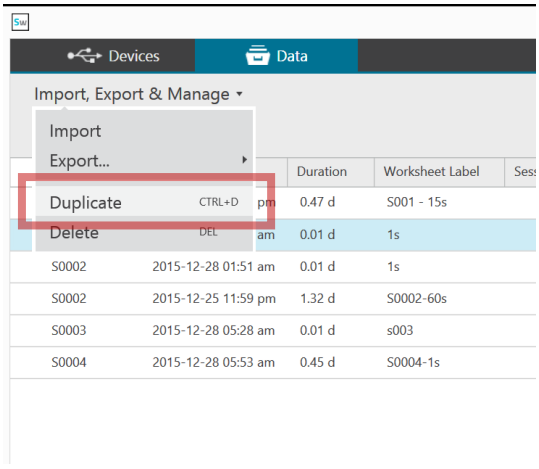


Worksheet from another worksheet

An existing worksheet can be duplicated to create a new worksheet. This approach does not require the associated Raw file, but does not allow the selection of a different epoch setting than the one used in the existing worksheet. Duplicating a worksheet will also copy over all in-bed and sleep estimates that have been added to the existing worksheet.

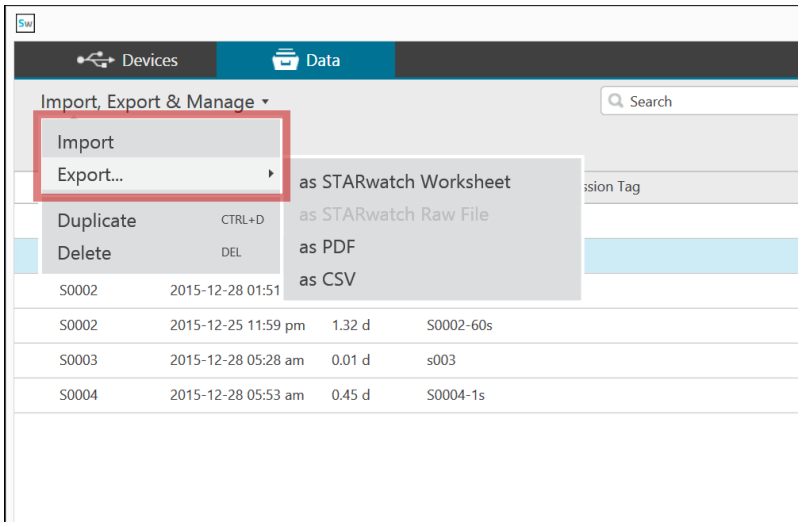
To process a duplicate an existing worksheet:

1) Select a worksheet
2) Select the menu option **Import, Export & Manage** > **Duplicate**



Import & Export

STAR software provides various options for exporting data for analysis in other scientific computing applications, exporting summary reports, and archiving and transporting data. These options are found in the **Import** and **Export** options under the **Import, Export & Manage** menu.



Worksheet CSV Export

A CSV (Comma Separated Values) worksheet export contains multiple sections of analytical data intended for detailed human review or for import into another scientific computing tool. The sections include:

- Subject – subject identification
- Recording Session – session start and end times
- Device – model and identification
- Recording Settings – sensor configuration parameters set when recording started.
- Analysis Settings – analysis parameters set when editing the worksheet
- InBed Interval Sleep Statistics – summary statistics about the measurements during each contiguous in-bed interval
- Active Interval Statistics – summary statistics about the measurements during each contiguous active interval
- Daily Interval Statistics – summary statistics about the amount of time spent in each classification state grouped by day
- Off-Wrist Interval Statistics – summary statistics about the measurements during each contiguous off-wrist interval
- Sleep Report – sleep quality and quantity metrics for each day
- Eport Data – complete list of values for each epoch in the data set

Worksheet PDF Export

A PDF worksheet export includes a visual raster plot for each day of data, and a summary sleep report statistics table. The PDF is convenient for quickly presenting or sharing data with others outside of the STAR software.

Worksheet STARwatch (*.wstar) Export & Import

The **STARwatch Worksheet** (***.wstar**) file format is a compressed binary format used exclusively for archiving data or transporting data between two STAR software

applications. When you export a worksheet in this format you will create a ***.wstar** file. This file can be imported back into a STAR application.

Common uses for the *.wstar Export/Import include exporting a worksheet so that it can be sent to another computer running the STAR application, and exporting a worksheet for archiving in a backup.

Raw File CSV Export

A CSV (Comma Separated Values) raw file export provides complete sensor measurements recorded by the device, and is designed for machine-readability. The sections include:

- Subject – subject identification
- Recording Session – session start and end times
- Device – model and identification
- Recording Settings – sensor configuration parameters set when recording started.
- Analysis Settings – analysis parameters set when editing the worksheet
- Raw Data – complete list of measurement values for each sample in the data set. Fields that are sampled more infrequently that others are shown with blank values when no measurement was taken at a particular time instant.

Raw File Export and Import options

The **STARwatch Raw** (***.rstar**) file format is a compressed binary format used exclusively for archiving data or transporting data between two STAR software applications. When you export a raw file in this format you will create a ***.rstar** file. This file can be imported back into a STAR application.

One use for the *.**rstar** Export/Import is to export a raw file so that it can be sent to another computer running the STAR application (e.g. field study sending data to a central repository)

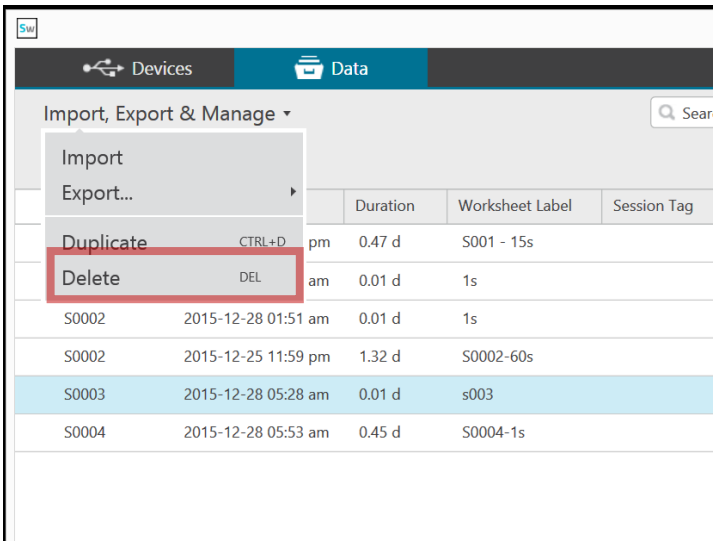
The *.rstar Export/Import may also be used to archive data into a long-term backup. As the number of raw files increases, the amount of disk space occupied by the Raw files may grow substantially. If the Raw file data is not going to be accessed frequently again, it may be helpful to export the Raw files into separate storage, and delete the Raw Files in the the application.

Deleting

A worksheet can be deleted by selecting one in the Worksheet list, and then selectiong the menu item **Import, Export & Managed** > **Delete.**

A Raw File can also be deleted, however to reduce the chance of accidental data deletion there is no menu command. To delete a Raw File, select a Raw File in the

Raw File List and then press the <DEL> button. A commond prompt will ask for a confirmation before permanently deleting the data.



Worksheet editing

The worksheet editing view allows detailed navigation of the timines, reviews of summary statistics, and editing of sleep scoring. The view includes: 1) View mode selection options, 2) Worksheet visualization, and 3) Sleep score configuration.

1. View mode selection

2. Worksheet visualization (raster, timeline or summary)

3. Sleep score configuration

The view modes supported in the Worksheet editor view are:

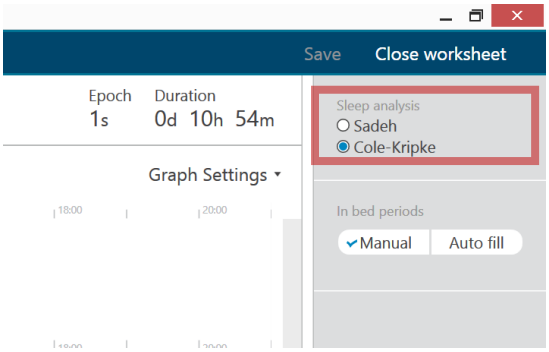
- **Raster** – twenty-four hour timelines stacked vertically, useful for viewing day-by-day patterns
- **Timeline** – horizontal scrolling timeline, allowing zooming into detailed timeline segments
- **Summary** – numeric sleep and activity statistics for the data set

Sleep scoring a worksheet classifies segments of time in which the subject was Active, or In-Bed, and for the In-Bed intervals estimates the times the subject was actually asleep. Scoring is performed as a two step process: 1) Run a sleep analysis to classify each epoch as ACTIVE or INACTIVE, 2) Determine In-Bed intervals and classify epochs within the In-Bed intervals as either Sleep or Wake

Sleep scoring step 1: Sleep analysis for Active/Inactive epoch classification

In the top section of the Sleep Score Configuration panel, select one of the two algorithms that are available as options for the sleep analysis: Sadeh[1] or Cole[2]. Both generally apply a window function to the activity count values, then compare the resulting values to a threshold to classify each epoch as Active or Inactive.

The Active/Inactive classification of each epoch is not shown immediately in the Worksheet visualizer, but can be viewed in a CSV export.

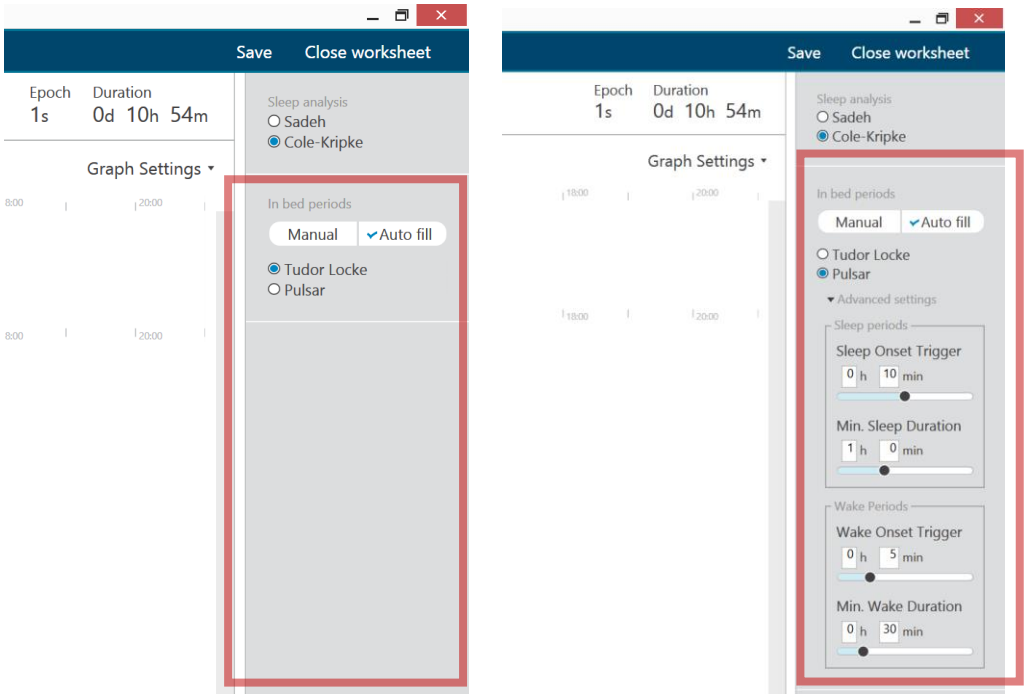


Sleep scoring step 2: Identify In Bed Periods either manually or automatically

The In-Bed period identification can be performed with a combination of automated algorithms and/or manual edits. The second section in the Sleep Score Configuration panel presents two options for identifying In-Bed periods: Manual or Auto-fill. Selecting Auto-Fill triggers an in-bed detection algorithm to run over the entire timeline, whereas Manual indicates that in-bed intervals have been manually edited on the timeline. Once an In-Bed interval is created, the epochs within the In-Bed interval are classified Wake/Sleep based on the Active/Inactive classification from Step 1.

Auto fill In Bed algorithms

The Auto fill in-bed detection algorithms use the Active/Inactive classification calculated in the Step 1 as an input. The default Auto fill setting is the Tudor-Locke[3] algorithm. Alternatively you can create a custom set of parameters by selecting 'Custom' then adjusting the settings as desired:



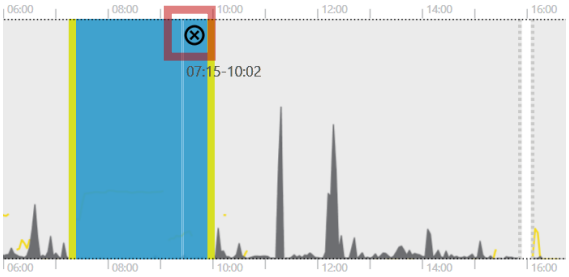
The parameters in the custom in bed algorithm are the following:

Raw file field	Description
In-Bed Onset Trigger (min)	Number of consecutive Inactive epochs that mark the possible beginning of an In Bed period. The In Bed period would start at the first epoch of the consecutive Inactive epochs
Min In-Bed Duration (min)	Minimum duration that an In Bed period must last without a Wake period starting.
Wake Onset Trigger (min)	Number of consecutive Active epochs that mark the possible beginning of a Wake period. The Wake period would start at the first epoch of the consecutive Active epochs
Min In-Bed Duration (min)	Minimum duration that a Wake period must last without an In-Bed period starting.

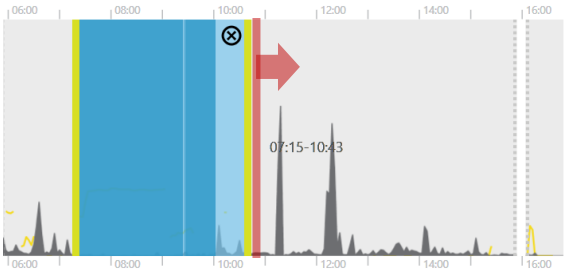
Manually editing In Bed periods

In Bed intervals can be manually edited in either the Raster or Timeline view mode. If the In-Bed settings are set to Auto fill, any manual edits will cause the mode to switch to Manual. There are three ways of editing the In-Bed intervals:

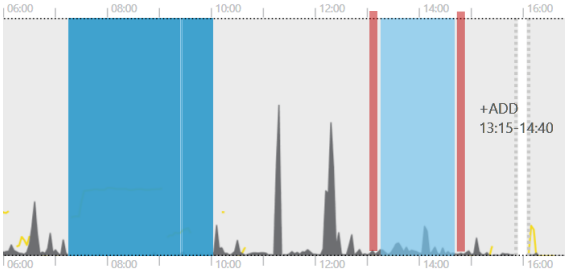
DELETE an In Bed period by hovering over an interval and clicking the X symbol in the upper right corner.



ADJUST START or END of an In Bed period by clicking and dragging an edge.



CREATE a new In Bed period by clicking once on the timeline barto mark a first edge, and clicking a second time to mark the second edge.

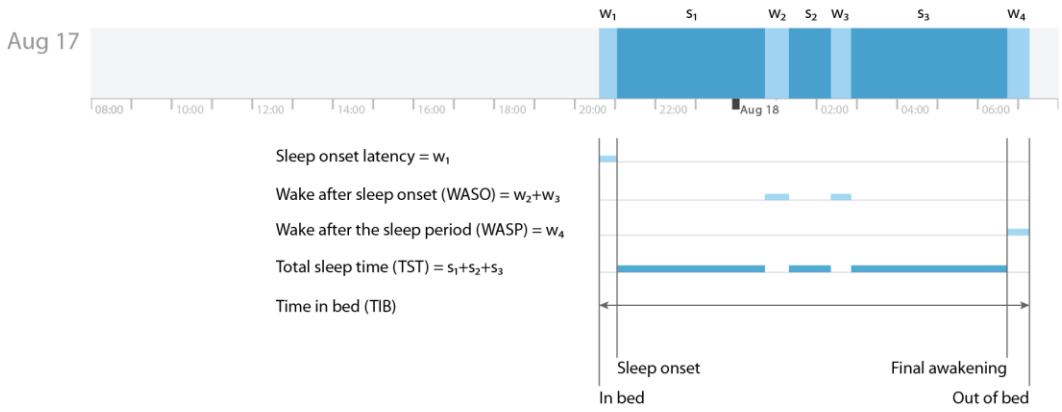


Sleep Statistics Reference

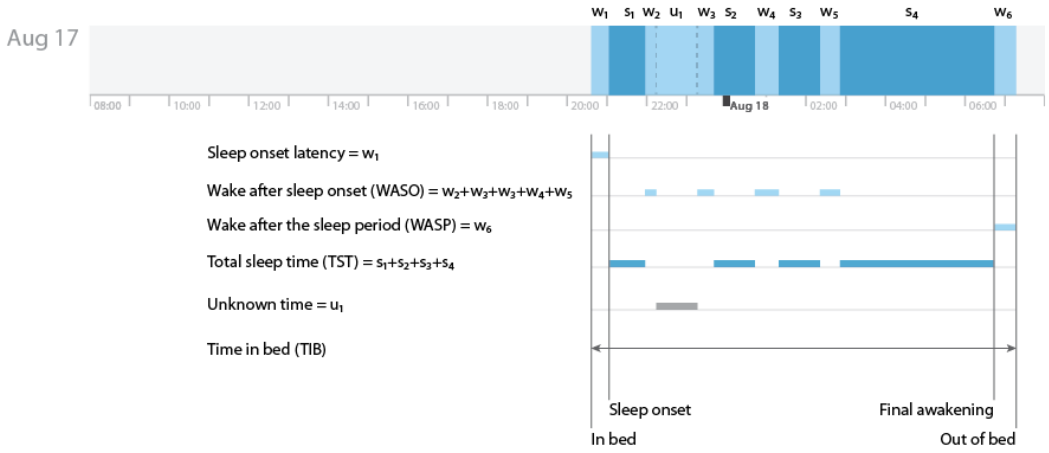
Worksheets export into PDF or CSV formats and include comprehensive sleep statistics based on the In-Bed periods and Sleep/Wake epoch classifications. A reference to the methods and interpretation of the sleep statistic measures is provided below.

Sleep metrics for single in-bed intervals

Each epoch within an in bed interval is scored as either Wake or Sleep. Contiguous epochs of the same type are grouped to create Wake and Sleep periods. Metrics for each in bed interval are calculated based on the Wake and Sleep periods as shown in Figure 1.



Sleep and wake metrics for an in bed interval



Sleep and wake metrics for an in bed interval with an unknown period due to the 'off wrist sensor'

Sleep Onset Latency – The length of time between the first attempt to get to sleep and sleep onset.

SleepOnsetLatency = Sum of all epochs scored as wake from the start of the in bed period up to the start of the first epoch scored as Sleep.

Wake after sleep period (WASP) – The length of time spent awake in bed between the final awakening and out of bed. Unknown epochs are not included in the WASP.

WASP = Sum of all epochs scored as wake between the end of the final sleep epoch and the end of the in bed period.

Wake after sleep onset (WASO) – The total length of time spent awake in bed between sleep onset and the final awakening.

WASO = Sum of all epochs scored as wake that are not classified as SleepLatency or WASP.

Unknown Time – The total length of time within the in bed period in which the data in excluded form analysis and the state is unknown.

Total Sleep Time (TST) – The total length of time asleep while in bed, calculated by the sum of all sleep periods.

TST = Sum of all epochs scored as wake within the InBed interval.

Time In Bed (TIB) – The length of time in bed, as calculated.

TIB = Difference between the Out of Bed time and In Bed time.

Sleep Efficiency – The percentage of time spent asleep while in bed.

Sleep efficiency% = TST/(TIB – Unknown) * 100.

Awakenings – The total number of wake periods that interrupted sleep periods, excluding the final awakening.

Avg. Awakening – The average duration of all the wake periods that interrupted sleep periods, excluding the final awakening.

Bed time – The time of the start of the in bed interval. The In Bed time.

Get Up time – The time at which the bed interval ended. The Out of bed time.

The following are some equality conditions that will hold for these variables:

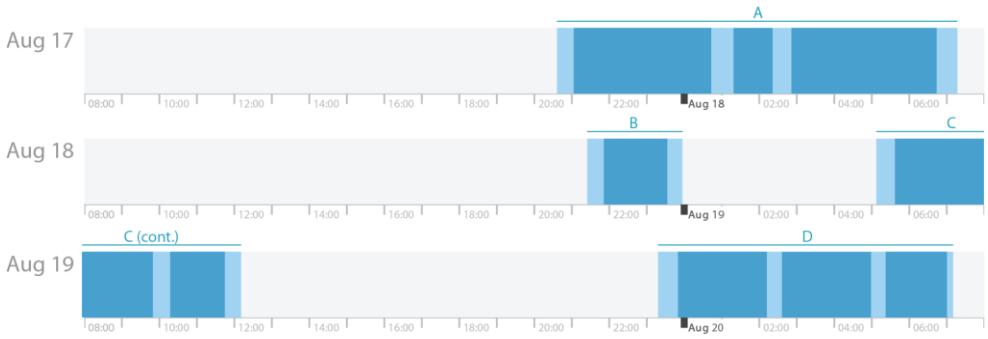
Total time awake in bed = Sleep Latency + WASO + WASP

TIB = SleepLatency + WASO + WASP + TST = Unknown

Daily sleep metrics

For the purpose of visualizing sleep patterns, and calculating daily metrics, a 24-hour day is defined as a 24-hour period starting at a specified hour. The 'day' corresponding to a given date is defined as the period from the Day Start Time on the given date, to the Day Start Time of the next date. For example, with a Day Start Time of 8:00am, the 'day' corresponding to Aug 17 spans from Aug 17, 8:00am to Aug 18, 8:00am, as shown in Figure 2.

Daily sleep metrics are calculated based on the set of In Bed Intervals associated with each day. Each interval is **associated to the day in which the In Bed interval starts.** The interval associations corresponding to Figure 2 are listed in Table 1.



Example in-bed intervals on a 24-hour raster plot with a Day Start Time of 8:00am

Example association of In-bed intervals to days.

Day	Associated intervals
Aug 17	A
Aug 18	B, C
Aug 19	D

The daily metrics are calculated as follows:

Sleep Onset Latency – The sum of sleep onset latency for all intervals associated with the day. A value of NaN if there are no intervals.

Wake after sleep onset (WASO) – The sum of WASO for all intervals associated with the day. A value of NaN if there are no intervals.

Wake after sleep period (WASP) – The sum of WASP for all intervals associated with the day. A value of NaN if there are no intervals.

Total Sleep Time (TST) – The sum of TST for all intervals associated with the day. A value of 0 if there are no intervals.

Time In Bed (TIB) – The sum of TIB for all intervals associated with the day. A value of 0 if there are no intervals.

Sleep Efficiency – The DailyTST/(DailyTIB – DailyUnknown) * 100. A value of NaN if there are no intervals.

Awakenings – The sum of awakenings for all intervals associated with the day. A value of NaN if there are no intervals.

Avg. Awakenings – The average duration of all awakenings for all intervals associated with the day. A value of NaN if there are no intervals.

Bed time – The In Bed time of the *longest* interval associated with the day. In the case where the longest interval occurs in two or more intervals having the same length, the interval occurring first is used. A value of NaN if there are no intervals.

Get Up time – The Out of bed time of the *longest* interval associated with the day. In the case where the longest interval occurs in two or more intervals having the same length, the interval occurring first is used. A value of NaN if there are no intervals.

Note that the method of grouping intervals into days based on the start time makes it possible for values for some of the metrics to have values greater than 24h.

When a day has no sleep intervals, the metrics will either have a value of 0, or be treated as not a number (NaN).

Summary statistics

Summary statistics are calculated for the Min, Average, and Max values of the daily metrics over an entire worksheet data set. The summary values are calculated based on the set of values for each *daily* metric, and are not recalculated using each interval. In cases where the daily metric has a NaN value, it is ignored in the statistical operation.

The Min, Average, and Max statistics for metrics that have time-of-day values (Bed Time and Get Up Time) are calculated based on a linear scale starting from the Day Start Time.

References

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[3] Tudor-Locke, C., et al., Fully automated waist-worn accelerometer algorithm for detecting children's sleep-period time separate from 24-h physical activity or sedentary behaviors. Applied Physiology, Nutrition, and Metabolism, 2013. 39(1): p. 53-57.