

¹ **nocturn: an online tool and R package for sleep data visualisation**

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Software

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⁶ **Summary**

⁷ Both researchers and self-trackers commonly record sleep times, using various methods. **nocturn** was designed to enable rapid and easy exploration of sleep data, regardless of the data collection method used. It provides a graphical user interface using R shiny, as well as functions that can be imported as an R package. **nocturn** is particularly suited to the visualisation of large longitudinal sleep datasets, e.g. ranging over several months. It allows filtering data, and generating visualisations and metrics to assess sleep regularity. The graphical interface makes the app easily usable without any programming experience, while the functions available in the R package are aimed at power-users who wish to produce their own automated workflows.



Figure 1: Hex logo for the **nocturn** package

¹⁵ **Glossary**

Table 1: Glossary of terms used in the **nocturn** app.

Term	Definition
User	The person using the nocturn app or R package
Subject	The person whose sleep has been recorded
Night	The date of a sleep session, calculated from 12pm to 12pm. For example, all sessions between 2025-01-01 12:00 noon and 2025-01-02 12:00 noon will be part of night “2025-01-01”
Session	A long sleep interval, typically an entire night, defined by its start and end time, and optionally some additional metrics such as the number of awakenings, breathing rate, or ambient temperature

Term	Definition
Epoch	A timestamped interval (typically 30sec) during a sleep session, annotated to indicate if the subject is asleep, and optionally which stage of sleep they are in

16 Statement of need

17 Advances in Open Science and data sharing have lead to the publication of a large number of
 18 sleep monitoring datasets, as can be found on the [National Sleep Research Resource](#) (NSRR),
 19 or on general repositories such as [Zenodo](#). While Polysomnography (PSG) remains the gold
 20 standard for sleep monitoring, other methods such as actigraphy and radar-sensing are being
 21 used for longitudinal studies, and to study people's sleep in their home environment. The
 22 increasing availability of these data makes it essential to have tools that allow rapid, high-level
 23 exploration of sleep data recorded through different modalities.

24 `nocturn` was developed to be used by researchers studying sleep, to enable them to:

- 25 ▪ Explore sleep data, regardless of their familiarity with programming languages
- 26 ▪ Apply thresholds on key variables (such as time spent in bed) to remove spurious sleep sessions
- 27 ▪ Generate attractive visualisations that can be used in research outputs during and after the project
- 28 ▪ Produce sleep summary reports to be shared with study participants
- 29 ▪ Create automated workflows to quickly produce the outputs listed above for a large number of participants

33 State of the field

34 Current software for sleep data analysis either focuses exclusively on one data type
 35 (e.g. actigraphy ([van Hees et al., 2025](#)) or PSG ([Purcell, 2019](#))), is not always free to use or
 36 open-source ([Muthén, 2025](#)), and is often difficult to integrate with other tools. To avoid
 37 these pitfalls, `nocturn` was designed according to the FAIR principles (making software that is
 38 Findable, Accessible, Interoperable and Reusable), making it easy to integrate into existing
 39 analysis pipelines.

40 Software design

41 An important consideration in the design of `nocturn` was to make it flexible to use for people
 42 with different programming knowledge. Therefore, it was essential for the software to have a
 43 graphical user interface. We decided to use R shiny, for the following reasons:

- 44 ▪ Its rapidity and ease of implementation, to quickly provide a working solution to researchers in our ongoing research projects
- 45 ▪ The availability of a dedicated shiny server at the University of Edinburgh that could host the app - therefore removing any installation work for users who only want to use the graphical interface
- 46 ▪ The "dashboard" interface of R shiny apps, which makes the different menus and software outputs easy for users to access
- 47 ▪ The possibility to expose the main functions underlying the R shiny app as an R package, for users wanting to write their own data analysis scripts
- 48 ▪ R being one of the most widely used programming languages in the field of sleep research

54 The codebase for the `nocturn` R shiny app is organised into modules, for clarity and to facilitate
 55 ongoing maintenance and development. Finally, `nocturn` development has been open on github from its onset, and the software uses an MIT license in order to maximise its reusability.

57 Research impact statement

58 nocturn is currently used for data analysis in the Ambient-BD project, which studies sleep and
 59 circadian rhythm in 180 participants diagnosed with Bipolar Disorder over 18 months ([Manrai
 60 et al., 2025](#)). It was previously used by the Ambient-Teens project, which used radar-sensing,
 61 actigraphy and sleep diaries to perform longitudinal sleep monitoring in adolescents ([Caddick
 62 et al., 2024](#)).

63 Main functionalities

64 Graphical interface

65 The nocturn graphical interface features three main menus, which can be accessed using the
 66 top navigation bar, and are displayed in the app's sidebar ([Figure 2](#)). **Import Data** allows
 67 importing Session and Epoch data (more on data types below), and setting column names,
 68 i.e. specifying which columns in the data contain information such as start of the sleep session,
 69 time at sleep onset, or time at wakeup. **Filtering** lets the user select sleep sessions by date
 70 range, subject ID, sleep onset time, as well as minimum time spent in bed or spent asleep.
 71 **Export data** allows exporting the pre-processed data as csv, and generating a summary “sleep
 72 report” (currently only available for data generated from the Somnofy radar device).

73 The main app panel displays several summary data tables (top), and data visualisations
 74 (bottom). Both are updated reactively when the input data or the filters change.

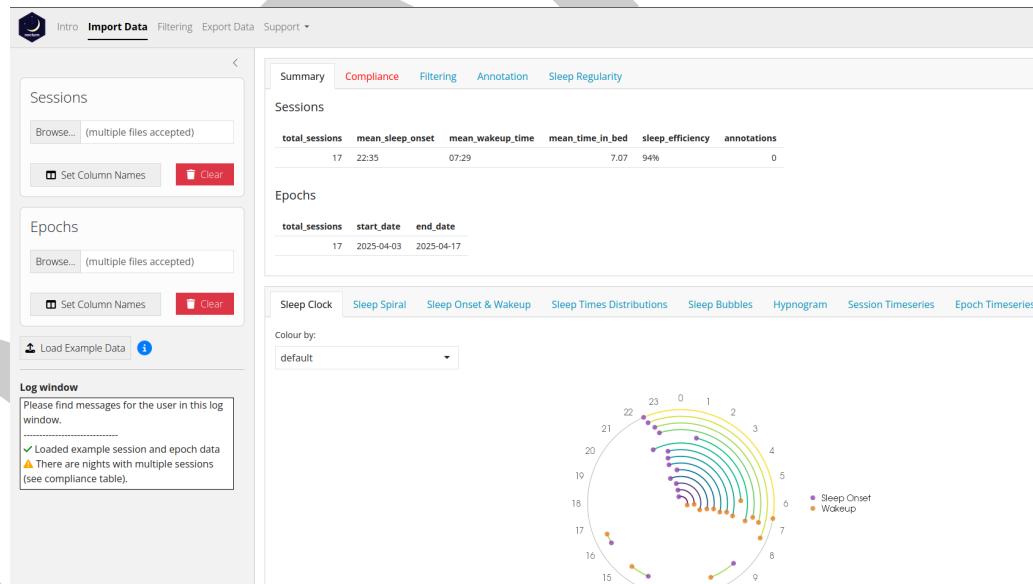


Figure 2: View of the nocturn graphical interface after loading example data.

75 Programmatic interface

76 The nocturn R package supports custom data processing workflows:

- 77 ■ The data are stored as DataFrames, which allows easy integration with tidyverse
 78 ([Wickham et al., 2019](#)) or custom functions
- 79 ■ Plotting functions all return ggplot2 objects ([Wickham, 2016](#)), allowing for further
 80 editing of figures
- 81 ■ All functionalities available via the graphical interface can easily be reproduced in code

82 This makes it straightforward to integrate nocturn functions into existing data analysis pipelines.

83 **Input data**

84 Two main types of sleep data can be imported into nocturn. **Sessions** are the main data type
 85 used in nocturn. They are data tables where each row represents a different “sleep session”,
 86 from the time the subject went to bed (or started sleeping) to the time they got out of bed
 87 (or woke up). This could be for example the “night summary” output from part 4 of the
 88 **GGIR** pipeline (actigraphy data), the “sleep sessions” from a Somnofy device (VitalThings -
 89 Trondheim, Norway), or entries from a sleep diary. **Epochs** are timestamped data (at any
 90 resolution), where each data point is annotated to indicate if the subject is asleep or awake.
 91 Supported data formats are .csv, .xls, .xlsx, and .edf.

92 **Data compliance and data pre-processing**

93 **Compliance**

94 A common occurrence in sleep data is spurious sleep sessions, where the subject is incorrectly
 95 reported as being asleep. Spurious sleep sessions are typically short (a few minutes to hours),
 96 occur during the day, and can be due to:

- 97 ■ Pets lying on the bed (radar devices)
- 98 ■ The subject lying still in bed, e.g. reading or watching TV (radar devices, actigraphy)
- 99 ■ Movement in the room, such as curtains blowing in the wind (radar devices)
- 100 ■ The subject taking a nap during the day, which might not be of interest in the context
 of a particular study

102 The **Compliance tab** (main app panel) highlights days where multiple sleep sessions took
 103 place, as well as some characteristics of these sessions. This can help quickly identify spurious
 104 sleep sessions, as well as days with multiple sleep sessions which could affect sleep regularity
 105 measurements.

106 **Filtering**

107 The following filters are available in the nocturn filtering menu:

Table 2: List of filters available in nocturn.

Filter name	Description
Date	Restricts the data to a particular date range
Subjects	Select one or several subjects in the data, identified by the “subject ID” column
Age	Select a range of subject ages, calculated as the difference between session start time and birth year
Sex	Select subjects by sex (multiple choices possible)
Sleep onset	Only keep sleep sessions where the sleep onset is in the specified range
Time in bed	Minimum time spent in bed (interval between session start and session end), in hours
Time asleep	Minimum time spent asleep (interval between sleep onset and wakeup), in hours

108 Note that filters will only appear in the menu if the necessary information is available. For
 109 example the “sex” filter will not appear if the data does not have a column indicating the sex
 110 of the subject.

111 All filters work at the Sessions level. To filter Epoch data, make sure it has a column selected
 112 for “Session ID” (Import Data, Epochs, Set Column Names), which links to the IDs in the
 113 Sessions table. Any filters applied to Sessions will automatically remove the corresponding
 114 epochs.

115 The **Filtering tab** displays all sleep sessions that were removed by filtering. The last column of
116 the table ("filters") shows which filter(s) caused the session to be excluded from the data.

117 The pre-processed data can be downloaded from the **Export data** menu. The sessions highlighted
118 in the compliance and filtering tables can be downloaded by clicking the "download" button in
119 their respective tabs.

120 Annotations

121 The **Annotation tab** allows users to manually add tags to sleep sessions. This can be useful to:

- 122 ▪ Highlight specific sessions in figures
- 123 ▪ Display information from other sources, for example health questionnaires completed by
124 participants

125 To add an annotation, write it in the "Annotation" text box, select sessions by clicking on the
126 table (shift + click to select a range of sessions), and click on "Apply".

127 Tip: use the search box above the Annotation table to select specific sessions: for example,
128 searching for "2024-01" will show all sessions that started or ended in January 2024.

129 Sleep regularity

130 The **Sleep Regularity tab** contains two tables displaying sleep regularity metrics ([Fischer et al.,
131 2021](#)) based on either session or epoch data. Clicking on the name of the metrics will display
132 a help page with a definition, how to interpret the values, and any relevant references.

133 Currently available sleep regularity metrics are:

- 134 ▪ **Mid-sleep standard deviation**: a measure of the variation in sleep pattern
- 135 ▪ **Social Jet-Lag**: the mismatch in midsleep time between work days and free days
- 136 ▪ **Chronotype**: the midpoint between sleep onset and wakeup time on work-free days
([Roenneberg et al., 2019](#))
- 137 ▪ **Composite Phase Deviation (CPD)**: uses the chronotype to assess the regularity of sleep
over several days
- 138 ▪ **Interdaily Stability (IS)**: compares sleep-wake patterns (at the epoch level) over multiple
days
- 139 ▪ **Sleep Regularity Index (SRI)**: measures the similarity of sleep-wake patterns from one
day to the next (ranges from 0 to 100)

144 Visualisations

145 nocturn provides a range of different visualisations, which can be accessed by clicking on the
146 different tabs in the main panel. Visualisations use either Session or Epoch data, and can be
147 saved in png, pdf or svg format.

148 For most visualisations, a "Colour by" menu allows changing the colour scale depending on
149 variables contained in the data. For example, [Figure 3](#) shows a sleep duration scatterplot
150 ("Sleep Bubbles" in nocturn) coloured by the average temperature recorded during the sleep
151 session.

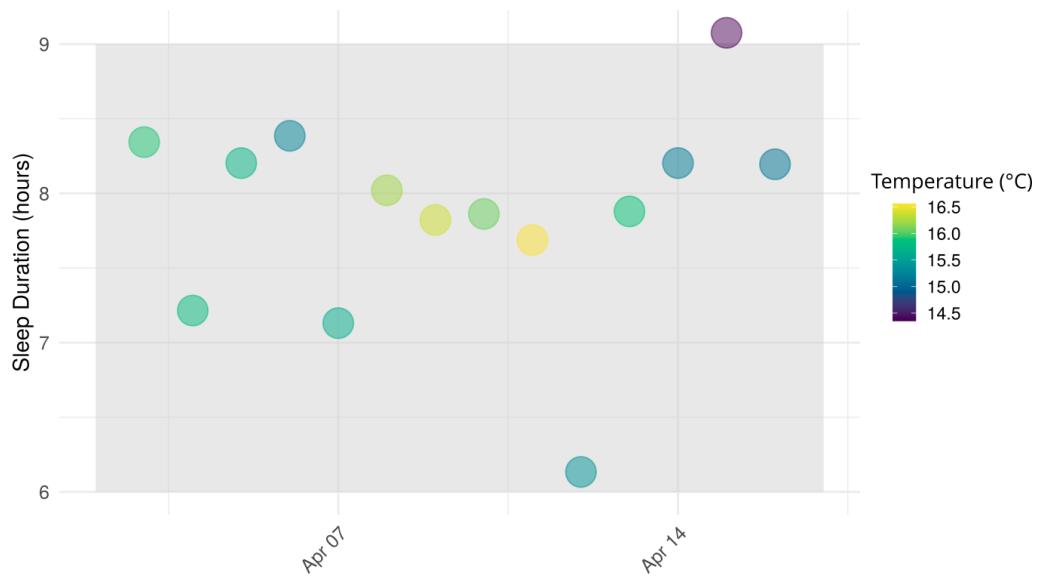


Figure 3: Sleep duration scatterplot with dot colour showing the average temperature during the sleep session.

152 A gallery of nocturn visualisations can be found on the [nocturn wiki](#).

153 **Session-based**

- 154 ■ **Sleep Clock** - A circular plot showing sleep onset and wakeup times. Each night is
- 155 plotted at a different radius on the circle.
- 156 ■ **Sleep Onset & Wakeup** - A horizontal bar graph showing the average times at sleep onset
- 157 and wakeup, grouped either by night, by day of the week, or by work day vs. work-free
- 158 day.
- 159 ■ **Sleep Time Distributions** - A distribution of sleep onset, midsleep and wakeup times,
- 160 taking into account the circularity of time. The distributions can be shown as boxplot,
- 161 histogram or density, and all three types can optionally be shown as circular plots.
- 162 ■ **Sleep bubbles** - A scatterplot showing the sleep duration per session. A grey rectangle
- 163 on the plot emphasises the usual duration of sleep at night (6 to 9 hours). Dots are
- 164 coloured according to sleep duration if they are within the 6-9 hour range, and grey
- 165 otherwise.
- 166 ■ **Session Timeseries** - A scatter plot showing the evolution of any variable in the Session
- 167 data over time.

168 **Epoch-based**

- 169 ■ **Sleep Spiral** - A spiral where each turn represents a 24h day, showing when the subject
- 170 was asleep or awake.
- 171 ■ **Hypnogram** - A bar graph showing the transition times between the different stages of
- 172 sleep, if available in the Epoch data.
- 173 ■ **Epoch Timeseries** - A scatter plot showing the evolution of any variable in the Epoch
- 174 data over time.

175 Examples of use

176 App

177 In a web browser, navigate to nocturn.bio.ed.ac.uk

178 Load and inspect the data

- 179 ▪ Under Import Data, click on Load Example Data to use the example dataset
- 180 ▪ Once the data has loaded, the Sleep Clock will be displayed in the main panel, showing
- 181 that most sleep sessions range from ~ 22:30 to ~ 07:00, while three short sessions were
- 182 recorded during the day
- 183 ▪ Click on the Compliance tab (main panel, highlighted in red) to see nights where multiple
- 184 sleep sessions were recorded

185 Filter out short sleep sessions

- 186 ▪ Under Filtering, set the Sleep filter “Minimum Time Asleep” to 2 hours
- 187 ▪ Note that the shorter sleep sessions have been removed from the Sleep Clock, and from
- 188 the Compliance tab

189 Explore the data

- 190 ▪ Browse the different visualisations in the main panel
- 191 ▪ Have a look at the sleep regularity metrics (Sleep Regularity tab)

192 R package

193 The script below imports session and epoch data, applies filtering (minimum time asleep) and
194 saves the sleep clock figure in png format.

```
library(nocturn)

# Load the data
sessions <- load_sessions("path/to/sessions_reports.csv")

# Filter the sessions
filtered_sessions <- sessions |>
  set_min_time_asleep(2)

# Print the number of duplicate sessions
print(paste0(
  "There are ",
  nrow(get_non_complying_sessions(filtered_sessions)),
  " duplicate sessions."
))

# Make a sleep clock plot
clock_plot <- plot_sleep_clock(filtered_sessions)

# Save plots as png
ggplot2::ggsave(
  filename = "clock.png",
  plot = clock_plot,
  device = "png",
  bg = "white"
)
```

195 If you do not have data available, you can use the script with pre-loaded example data. To do

196 so, replace the line under # Load the data by:

```
sessions <- example_sessions
```

197 AI usage disclosure

198 Github Copilot with ChatGPT 4.1 was used to assist with writing the code for nocturn, through
199 line completion and generating short code snippets (less than 10 lines of code). All AI outputs
200 were reviewed and edited by the authors, and validated through tests and comparison to
201 expected results. AI was not used for software design, or to generate large amounts of code.

202 AI was not used in the writing of this article, or the writing of software documentation.

203 Author contributions

204 Conceptualisation: DT and AJM; Software: DT; Supervision: AJM; Funding acquisition: AJM;
205 Writing - original draft: DT; Writing - review & editing: DT and AJM.

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212 For the purpose of open access, the author has applied a Creative Commons Attribution (CC
213 BY) license to any Author Accepted Manuscript version arising from this submission.

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