

Package ‘spiro’

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Title Manage Data from Cardiopulmonary Exercise Testing

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Description Import, process, summarize and visualize raw data from metabolic carts. See Robergs, Dwyer, and Astorino (2010) <[doi:10.2165/11319670-000000000-00000](https://doi.org/10.2165/11319670-000000000-00000)> for more details on data processing.

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URL <https://github.com/ropensci/spiro>,
<https://docs.ropensci.org/spiro/>

BugReports <https://github.com/ropensci/spiro/issues>

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spiro-package	<i>spiro: Work with data from cardiopulmonary exercise testing</i>
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Description

The spiro package enables a fast workflow with raw files from metabolic carts/spiroergometry systems. It provides simple tools for data import, processing, summary and visualization.

Main functions

- Use [spiro](#) for import and processing of cardiopulmonary exercise testing data.
- Use [spiro_summary](#) and [spiro_max](#) for a stepwise summary or the maximum parameter values of the imported data.
- Use [spiro_plot](#) to visualize the data.

add_bodymass	<i>Calculate additional variables related to body mass for cardiopulmonary exercise testing data</i>
--------------	--

Description

add_bodymass() amplifies existing spiroergometric data by the calculation of body mass-related variables.

Usage

```
add_bodymass(data, bodymass = NULL)
```

Arguments

data	A data.frame of the class <code>spiro</code> containing the gas exchange data. Usually the output of a <code>spiro</code> call.
bodymass	A numeric value to manually set the participant's body mass.

Details

Based on the participant's body mass relative oxygen uptake (`VO2_rel`) and carbon dioxide (`VCO2_rel`) output are calculated. `bodymass` will be received from the original file's meta data, but can be manually overridden, e.g. if the value in the meta data is incorrect or rounded.

For running protocols, running economy (RE) is calculated.

Value

A data.frame of the class `spiro` containing the cardiopulmonary exercise testing data including variables relative to body mass.

Examples

```
# get example file
file <- spiro_example("zan_gxt")

s <- spiro(file)
out <- add_bodymass(s, bodymass = 65.3)
head(out)
```

add_hr	<i>Import and apply heart rate data to cardiopulmonary exercise testing data</i>
--------	--

Description

`add_hr()` imports an additional file containing heart rate data and adds it to an existing spiroergometric data file.

Usage

```
add_hr(data, hr_file, hr_offset = 0)
```

Arguments

data	A data.frame of the class <code>spiro</code> containing the gas exchange data. Usually the output of a <code>spiro</code> call.
hr_file	The absolute or relative path of a <code>*tcx</code> file that contains additional heart rate data.
hr_offset	An integer, corresponding to the temporal offset of the heart-rate file. By default the start of the heart rate measurement is linked to the start of the gas exchange measurement.

Details

Heart rate data will be imported from a .tcx file. After interpolating the data to full seconds, it is then matched to the imported data.

Value

A data.frame containing the spirometric and heart rate data.

Examples

```
# Get example data
oxy_file <- spiro_example("zan_ramp")
hr_file <- spiro_example("hr_ramp.tcx")

# Import and process spiro data
oxy_data <- spiro(oxy_file)

# Add heart rate data
out <- add_hr(oxy_data, hr_file)
head(out)
```

add_protocol	<i>Add a test protocol to an exercise testing dataset</i>
--------------	---

Description

add_protocol() adds a predefined test protocol to an existing set of data from an exercise test.

Usage

```
add_protocol(data, protocol)
```

Arguments

data	A spiro data.frame containing the exercise testing data.
protocol	A data.frame containing the test protocol, as created by set_protocol , set_protocol_manual or get_protocol .

Value

A data.frame of the class spiro with cardiopulmonary parameters and the corresponding load data.

See Also

[set_protocol](#) for protocol setting with helper functions.
[set_protocol_manual](#) for manual protocol design.
[get_protocol](#) For automated extracting of protocols from raw data.

Examples

```
# Get example data
file <- spiro_example("zan_gxt")

s <- spiro(file)
out <- add_protocol(
  s,
  set_protocol(pt_pre(60), pt_steps(300, 50, 50, 7, 30))
)
head(out)
```

bw_filter

Smooth data with a (zero-phase) Butterworth filter

Description

Internal function for [spiro_smooth](#).

Usage

```
bw_filter(x, n = 3, W = 0.04, zero_lag = TRUE)
```

Arguments

x	A numeric vector on which the digital filter should be applied
n	Order of the Butterworth filter, defaults to 3
W	Low-pass cut-off frequency of the filter, defaults to 0.04
zero_lag	Whether a zero phase (forwards-backwards) filter should be applied.

Details

Digital filtering might be a preferable processing strategy for smoothing data from gas exchange measures when compared to moving averages. Robergs et al. (2010) proposes a third order Butterworth filter with a low-pass cut-off frequency of 0.04 for filtering VO2 data.

It should be noted that Butterworth filter comprise a time lag. A method to create a data series with zero lag is to subsequently apply two Butterworth filters in forward and reverse direction (forward-backwards filtering). While this procedure removes any time lag it changes the magnitude of the filtering response, i.e. the resulting filter has not the same properties (order and cut-off frequency) as a single filter has.

Value

A numeric vector of the same length as x.

Examples

```
# Get V02 data from example file
vo2_vector <- spiro(spiro_example("zan_gxt"))$V02

out <- bw_filter(vo2_vector)
head(out, n = 20)
```

get_anonid

Get the anonymization id from personal data

Description

get_anonid() returns the anonymization id corresponding to given personal data.

Usage

```
get_anonid(name, surname, birthday = NULL)
```

Arguments

name	A character string, containing the participant's name as present in the raw data file.
surname	A character string, containing the participant's surname as present in the raw data file.
birthday	A character string, containing the participant's birthday as present in the raw data file. If no birthday data is available in the raw data, this is ignored.

Details

By default, the spiro package anonymizes personal information obtained from file meta data. The data are saved to the "info" attribute of a spiro() call. The default anonymization ensures that no personal information is accidentally revealed, e.g. by sharing spiro outputs as .Rda files.

While there is no way to directly deanonymize the data, get_anonid() allows you to recreate the ids, when meta data (name, surname and birthday) are known. Birthday is only used within the id generation if available in the original raw data.

To disable the anonymization process during import use spiro(anonymize = FALSE)

Value

A character string, containing the anonymized id.

Examples

```
get_anonid("Jesse", "Owens", "12.09.1913")
```

get_protocol	<i>Guess a test protocol from a corresponding exercise testing dataset</i>
--------------	--

Description

get_protocol() gets the underlying test protocol based on given load data.

Usage

```
get_protocol(data)
```

Arguments

data	A data.frame containing the exercise testing data. It is highly recommend to parse non-interpolated breath-by-breath data.
------	--

Value

A data.frame with the duration and load of each protocol step.

Examples

```
# Import example data
raw_data <- spiro_import(file = spiro_example("zan_gxt"))

get_protocol(raw_data)
```

knit_print.spiro	<i>Printing spiro data frames in a knitr context</i>
------------------	--

Description

knit_print.spiro() provides a method for printing data.frames from [spiro](#) within knitr.

Usage

```
## S3 method for class 'spiro'
knit_print(x, min = 10, max = 20, digits = 2, ...)
```

Arguments

x	A data.frame of the class spiro to be printed.
min	An integer, which sets the number of rows to which x will be limited in printing if row number exceed max.
max	An integer, setting the maximal number of rows to be not cut to min in printing.
digits	An integer giving the number of decimals to be rounded to.
...	Passing of additional arguments to knit_print.default().

Details

Cardiopulmonary exercise testing data imported by `spiro` will often come in large `data.frames`. When knitting R Markdown documents these will normally be printed in full size.

This function provides a method for `data.frames` of the class `spiro` to limit the number of rows displayed to `min` if it exceeds `max`. The number of hidden data rows will be printed below the `data.frame`.

Value

The function prints its argument and returns it invisibly.

Examples

```
# Get example data
s <- spiro(spiro_example("zan_gxt"))

knitr::knit_print(s)
```

print.spiro

Printing spiro data frames

Description

Printing method for `spiro` objects that rounds output to two decimals.

Usage

```
## S3 method for class 'spiro'
print(x, digits = 2, ...)
```

Arguments

<code>x</code>	A <code>data.frame</code> of the class <code>spiro</code> to be printed.
<code>digits</code>	An integer giving the number of decimals to be rounded to.
<code>...</code>	Passing of additional arguments to <code>print.data.frame()</code> .

Value

The function prints its argument and returns it invisibly.

Examples

```
# Get example data
s <- spiro(spiro_example("zan_gxt"))

out <- print(s)
head(out)
```

set_protocol	<i>Setting an exercise testing profile</i>
--------------	--

Description

set_protocol() allows to set an load profile for an exercise test based on profile sections.

Usage

```
set_protocol(...)
```

```
pt_pre(duration)
```

```
pt_wu(duration, load, rest.duration = 0)
```

```
pt_steps(duration, load, increment, count, rest.duration = 0)
```

```
pt_const(duration, load, count, rest.duration = 0)
```

Arguments

...	Functions related to sections of the load profile, such as pt_pre, pt_wu, pt_const or pt_step. Sections will be evaluated in the order they are entered.
duration	A number, giving the duration of the test section or a single load within the test section (in seconds).
load	A number, giving the (initial) load of a section.
rest.duration	A number, specifying the duration of (each) rest (in seconds).
increment	A number, giving the difference in load between the current and the following load step.
count	An integer for the number of load sections.

Value

A data.frame with the duration and load of each protocol step.

Functions

- pt_pre(): Add pre-measures to a load protocol
- pt_wu(): Add a warm up to a load protocol
- pt_steps(): Add a stepwise load protocol
- pt_const(): Add a constant load protocol

See Also

[set_protocol_manual](#) For manual protocol design.

[get_protocol](#) For automated extracting of protocols from raw data.

Examples

```
set_protocol(pt_pre(60), pt_wu(300, 100), pt_steps(180, 150, 25, 8, 30))
```

set_protocol_manual *Manually setting a testing profile*

Description

set_protocol_manual() allows to set any user-defined load profile for an exercise test.

Usage

```
set_protocol_manual(duration, load = NULL)

## Default S3 method:
set_protocol_manual(duration, load)

## S3 method for class 'data.frame'
set_protocol_manual(duration, load = NULL)
```

Arguments

duration	Either a numeric vector containing the duration (in seconds) load each load step, or a data.frame containing columns for duration and load.
load	A numeric vector of the same length as duration containing the corresponding load of each step.

Value

A data.frame with the duration and load of each protocol step.

Methods (by class)

- set_protocol_manual(default): Default method when duration and load are given separately
- set_protocol_manual(data.frame): Method for data frames with a duration and a load column

See Also

[set_protocol](#) for protocol setting with helper functions.

[get_protocol](#) For automated extracting of protocols from raw data.

Examples

```

set_protocol_manual(
  duration = c(300, 120, 300, 60, 300),
  load = c(3, 5, 3, 6, 3)
)

# using a data.frame as input
pt_data <- data.frame(
  duration = c(180, 150, 120, 90, 60, 30),
  load = c(200, 250, 300, 350, 400, 450)
)
set_protocol_manual(pt_data)

```

 spiro

Process raw data from metabolic carts/spiroergometric measures

Description

spiro() wraps multiple functions to import and process raw data from metabolic carts into a data.frame.

Usage

```

spiro(
  file,
  device = NULL,
  bodymass = NULL,
  hr_file = NULL,
  hr_offset = 0,
  protocol = NULL,
  anonymize = TRUE
)

```

Arguments

file	The absolute or relative path of the file that contains the gas exchange data.
device	A character string, specifying the device for measurement. By default the device type is guessed by the characteristics of the file. This can be overridden by setting the argument to "cortex", "cosmed", "vyntus" or "zan".
bodymass	Numeric value for participant's body mass, if the default value saved in the file should be overridden.
hr_file	The absolute or relative path of a *tcx file that contains additional heart rate data.
hr_offset	An integer, corresponding to the temporal offset of the heart-rate file. By default the start of the heart rate measurement is linked to the start of the gas exchange measurement.

protocol	A data.frame by set_protocol or set_protocol_manual containing the test protocol. This is automatically guessed by default. Set to NA to skip protocol guessing.
anonymize	Whether meta data should be anonymized during import. Defaults to TRUE. See get_anonid for more information.

Details

This function performs multiple operations on raw data from metabolic carts. It imports the raw data from a file, which might be complemented by an additional .tcx file with heart rate data. For details of data import and supported file types visit [spiro_import](#).

Breath-by-breath data is linearly interpolated to get data points for every second. Based on the given load data, the underlying exercise protocol is guessed and applied to the data. If no load data is available or the protocol guess turns wrong, you can manually specify the exercise protocol by using [set_protocol](#) or [set_protocol_manual](#). If you want to skip the automated protocol guessing without providing an alternative, set protocol = NA. Note that in this case, some functions relying on load data (such as [spiro_summary](#)) will not work.

Additional variables of gas exchange are calculated for further analysis. Per default the body mass saved in the file's metadata is used for calculating relative measures. It is possible to supply bodymass manually to the function, overriding that value.

Protocols, heart rate data and body mass information can also be given in a piping coding style using the functions [add_protocol](#), [add_hr](#) and [add_bodymass](#) (see examples).

After processing, you may summarize the resulting data frame with [spiro_summary](#) and [spiro_max](#), or plot it with [spiro_plot](#).

Value

A data.frame of the class `spiro` with cardiopulmonary parameters interpolated to seconds and the corresponding load data.

The attribute "protocol" provides additional information on the underlying testing protocol. The attribute "info" contains additional meta-data from the original raw file. The attribute "raw" gives the imported raw data (without interpolation).

Examples

```
# get example file
file <- spiro_example("zan_gxt")

out <- spiro(file)
head(out)

# import with user-defined test profile
p <- set_protocol(pt_pre(60), pt_steps(300, 2, 0.4, 9, 30))
out2 <- spiro(file, protocol = p)
head(out2)

# import with additional heart rate data
oxy_file <- spiro_example("zan_ramp")
```

```
hr_file <- spiro_example("hr_ramp.tcx")

out3 <- spiro(oxy_file, hr_file = hr_file)
head(out3)

# use the add_* functions in a pipe
# Note: base R pipe requires R version 4.1 or greater)
## Not run:
spiro(file) |>
  add_hr(hr_file = hr_file, hr_offset = 0) |>
  add_bodymass(68.2)

## End(Not run)
```

spiro_example

Get path to spiro example

Description

spiro_example returns the file path for example data files within the spiro package.

Usage

```
spiro_example(file = NULL)
```

Arguments

file	Name of the file, either "zan_gxt", "zan_ramp" or "hr_ramp.tcx". Leave the argument empty to get a vector with the paths of all three example files. Note that the package contains more example data, which is used for internal testing.
------	--

Value

A character vector with the absolute file path of the example file(s).

Examples

```
# get path of a specific example data file
spiro_example("zan_gxt")

# get all paths of example data files
spiro_example()
```

spiro_import	<i>Import raw data from spiroergometric devices</i>
--------------	---

Description

spiro_import() retrieves cardiopulmonary data from various types of metabolic cart files.

Usage

```
spiro_import(file, device = NULL, anonymize = TRUE)
```

Arguments

file	The absolute or relative path of the file that contains the gas exchange data.
device	A character string, specifying the device for measurement. By default the device type is guessed by the characteristics of the file. This can be overridden by setting the argument to "cortex", "cosmed", "vyntus" or "zan".
anonymize	Whether meta data should be anonymized during import. Defaults to TRUE. See get_anonid for more information.

Details

Different metabolic carts yield different output formats for their data. By default, this function will guess the used device based on the characteristics of the given file. This behavior can be overridden by explicitly stating device.

The currently supported metabolic carts are:

- **CORTEX** (.xlsx, .xls or files .xml in English or German language)
- **COSMED** (.xlsx or .xls files, in English or German language)
- **Vyntus** (.txt files in German language)
- **ZAN** (.dat files in German language, usually with names in the form of "EXEDxxx")

Value

A data.frame with data. The attribute info contains addition meta-data retrieved from the original file.

Examples

```
# Get example data
file <- spiro_example("zan_gxt")

out <- spiro_import(file)
head(out)
```

spiro_max	<i>Return maximum values from cardiopulmonary exercise tests</i>
-----------	--

Description

`spiro_max()` returns a `data.frame` with the maximum gas exchange parameters of an exercise test.

Usage

```
spiro_max(data, smooth = 30, hr_smooth = FALSE)
```

Arguments

<code>data</code>	A <code>data.frame</code> of the class <code>spiro</code> containing the gas exchange data. Usually the output of a <code>spiro</code> call.
<code>smooth</code>	Parameter giving the filter methods for smoothing the data. Default is 30 for a 30-second moving average. "20b" will apply a 20-breath averaging for example. See <code>spiro_smooth</code> for further details and filter methods (e.g. Butterworth filters).
<code>hr_smooth</code>	A logical, whether smoothing should also apply to heart rate data. Default is FALSE, which means that the absolute maximum heart rate value is taken without smoothing.

Details

Before calculating the maximum values, the raw data is smoothed. Default smoothing method is a 30-second rolling average. See the `smooth` argument in `spiro_smooth` for more options, such as breath-based averages or digital filtering.

Parameters calculated are the maximum oxygen uptake (absolute and relative), carbon dioxide output, minute ventilation, respiratory exchange ratio (RER), and heart rate. The maximum value are defined as the highest single data values after the smoothing. For the maximum RER a different algorithm is used, as the RER during and after rest may exceed the peak value during exercise. Therefore only values during the last ten percent of the exercise time are considered for the RERmax determination. The RERmax calculation works best for data from tests without rest intervals (e.g., ramp tests) and with attached load protocol data.

Value

A `data.frame` with the maximum parameter values of the data.

Examples

```
# Import and process example data sets
gxt_data <- spiro(file = spiro_example("zan_gxt"))

spiro_max(gxt_data)
```

```
# Use an averaging over a time interval of 15 seconds
spiro_max(gxt_data, smooth = 15)

# Use an averaging over an interval of 15 breaths
spiro_max(gxt_data, smooth = "15b")
```

spiro_plot

Plot data from cardiopulmonary exercise data files

Description

spiro_plot() returns a ggplot2 graph visualizing data from cardiopulmonary exercise testing.

Usage

```
spiro_plot(
  data,
  which = 1:9,
  smooth = "fz",
  base_size = 13,
  grid_args = list(),
  ...
)
```

Arguments

data	A data.frame of the class <code>spiro</code> containing the gas exchange data. Usually the output of a <code>spiro</code> call.
which	A numeric integer setting the plot panels to be displayed. The panels are numbered in the order of the traditional Wasserman 9-Panel Plot: <ul style="list-style-type: none"> • 1: VE over time • 2: HR and oxygen pulse over time • 3: VO₂, VCO₂ and load over time • 4: VE over VCO₂ • 5: V-Slope: HR and VCO₂ over VO₂ • 6: EQVO₂ and EQVCO₂ over time • 7: VT over VE • 8: RER over time • 9: PetO₂ and PetCO₂ over time
smooth	Parameter giving the filter methods for smoothing the data. Default is <code>fz</code> for a zero phase Butterworth filter. See <code>spiro_smooth</code> for more details and other filter methods (e.g. time based averages),
base_size	An integer controlling the base size of the plots (in pts).
grid_args	A list of arguments passed to <code>cowplot::plot_grid()</code> to modify the arrangement of the plots
...	Arguments passed to <code>ggplot2::theme()</code> to modify the appearance of the plots.

Details

This function provides a shortcut for visualizing spiroergometric data from `spiro` with the help of `ggplot2`.

Value

A `ggplot` object.

Examples

```
# Import and process example data
ramp_data <- spiro(
  file = spiro_example("zan_ramp"),
  hr_file = spiro_example("hr_ramp.tcx")
)

# Display the traditional Wasserman 9-Panel Plot
spiro_plot(ramp_data)

# Display selected panels, here V-Slope
spiro_plot(ramp_data, which = 5)

# Modify the arrangement of plots by passing arguments to
# cowplot::plot_grid() via the grid_args argument
spiro_plot(ramp_data, which = c(4, 5, 6, 8), grid_args = list(nrow = 1))

# Modify the appearance of plots by passing arguments to ggplot2::theme() via
# the ... argument
spiro_plot(ramp_data, axis.title.y = ggplot2::element_text(colour = "green"))
```

spiro_smooth	<i>Apply a smoothing filter to data from cardiopulmonary exercise testing.</i>
--------------	--

Description

Filter vectors and data frames with moving averages and digital filters. Provides the data filtering for `spiro_max` and `spiro_plot`.

Usage

```
spiro_smooth(data, smooth = 30, columns = NULL, quiet = FALSE)
```

Arguments

data	A data frame of the class <code>spiro</code> . Usually the output of the <code>spiro</code> function.
smooth	An integer or character string specifying the smoothing strategy and parameters. Default is 30, which means the applied filter is a 30-second moving average. See the section ' Filtering Methods ' for more details.
columns	A character vector of the data columns that should be filtered. By default the filtering applies to all data column of data (besides load, time and step).
quiet	Whether warning message should be suppressed. Default is FALSE.

Details

Raw data from cardiopulmonary is usually noisy due to measurement errors and biological breath-to-breath variability. When processing or visualizing the gas exchange data, it is often helpful to filter the raw data. This function provides different filtering methods (time average, breath average, digital filters).

Breath-based and digital filters will be applied on the raw breath-by-breath data. Time-based averages will be conducted on the interpolated data.

Value

A data frame

Filtering Methods

Time-Based Average (e.g. `smooth = 30`) A (centered) moving average over a defined timespan. The number can be given as an integer or as a character (e.g. `smooth = "30"`) and defines the length of the calculation interval in seconds.

Breath-Based Average (e.g. `smooth = "15b"`) A (centered) moving average over a defined number of breaths. The integer before the letter 'b' defines the number of breaths for the calculation interval.

Butterworth filter (e.g. `smooth = "0.04f3"`) A digital Butterworth filter (with lag). The number before the letter 'f' defines the low-pass cut-off frequency, the number after gives the order of the filter. See [bw_filter](#) for more details.

Zero-lag Butterworth filter (e.g. `smooth = "0.04fz3"`) A digital forwards-backwards Butterworth filter (without lag). The number before the letter 'f' defines the low-pass cut-off frequency, the number after gives the order of the filter. See [bw_filter](#) for more details.

Examples

```
# Get example data
file <- spiro_example("zan_gxt")
d <- spiro(file)

out <- spiro_smooth(d, 30)
head(out)

# filter only the V02 column with a zero-phase Butterworth filter
```

```
out2 <- spiro_smooth(d, "0.04fz3", columns = "V02")
head(out2)
```

spiro_summary

Stepwise summarize data from cardiopulmonary exercise testing

Description

spiro_summary() returns a data.frame summarizing the main parameters for each step of a spiroergometric test.

Usage

```
spiro_summary(data, interval = 120, quiet = FALSE, exclude = FALSE)
```

Arguments

data	A data.frame of the class spiro_*, as it is generated by spiro .
interval	An integer giving the length of the computational interval in seconds.
quiet	A logical value, whether or not messages should be displayed, for example when intervals were shortened for specific steps.
exclude	A logical value, whether the last step should be excluded from the summary if it was not completely performed.

Details

This function generates mean values of gas exchange and cardiac parameters for all steps of a spiroergometric test. For calculation the given interval before the end of each step is used.

If the interval exceeds the duration of any step, a message will be displayed. If the interval exceeds the duration of all steps, it will be reset to the duration of the longest step. You can silence all messages by setting quiet = TRUE.

When setting exclude = TRUE the function will check whether the last load step was terminated early. If this was the case, the step will not be displayed in the summary.

Value

A data.frame with the mean parameters for each step of the exercise protocol.

Examples

```
# Import and process example data
gxt_data <- spiro(file = spiro_example("zan_gxt"))

spiro_summary(gxt_data)
```

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