ggstatsplot: ggplot2 Based Plots with Statistical Details

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Contents

Raison d'être

`ggstatsplot` is an extension of `ggplot2` package for creating graphics with details from statistical tests included in the plots themselves and targeted primarily at behavioral sciences community to provide a one-line code to produce information-rich plots. In a typical exploratory data analysis workflow, data visualization and statistical modeling are two different phases: visualization informs modeling, and modeling in its turn can suggest a different visualization method, and so on and so forth. The central idea of `ggstatsplot` is simple: combine these two phases into one in the form of graphics with statistical details, which makes data exploration simpler and faster.

But why would combining statistical analysis with data visualization be helpful? We list few reasons below-

- A recent survey (Nuijten, Hartgerink, van Assen, Epskamp, & Wicherts, 2016) revealed that one in eight papers in major psychology journals contained a grossly inconsistent p-value that may have affected the statistical conclusion. `ggstatsplot` helps avoid such reporting errors: Since the plot and the statistical analysis are yoked together, the chances of making an error in reporting the results are minimized. You never have to write the results manually or copy-paste them from someplace else.

Summary of available plots

It, therefore, produces a limited kinds of plots for the supported analyses:

Function	Plot	Description
`ggbetweenstats`	**violin plots**	for comparisons *between* groups/conditions
`ggwithinstats`	**violin plots**	for comparisons *within* groups/conditions
`gghistostats`	**histograms**	for distribution about numeric variable
`ggdotplotstats`	**dot plots/charts**	for distribution about labeled numeric variable
`ggpiestats`	**pie charts**	for categorical data
`ggbarstats`	**bar charts**	for categorical data
`ggscatterstats`	**scatterplots**	for correlations between two variables
`ggcorrmat`	**correlation matrices**	for correlations between multiple variables
`ggcoefstats`	**dot-and-whisker plots**	for regression models

In addition to these basic plots, `ggstatsplot` also provides **`grouped_`** versions (see below) that makes it easy to repeat the same analysis for any grouping variable.

Summary of types of statistical analyses

Most functions share a `type` (of test) argument that is helpful to specify the type of statistical analysis:

- `"parametric"` (for **parametric**)
- `"nonparametric"` (for **non-parametric**)
- `"robust"` (for **robust**)
- `"bayes"` (for **Bayes Factor**)

Currently, it supports only the most common types of statistical tests: **correlation** analyses, **contingency table** analysis, and **regression** analyses. The table below summarizes all the different types of analyses currently supported in this package-

Functions	Description	Parametric	Non-parametric	Robust	Bayes Factor
`ggbetweenstats`	Between group/condition comparisons	Yes	Yes	Yes	Yes

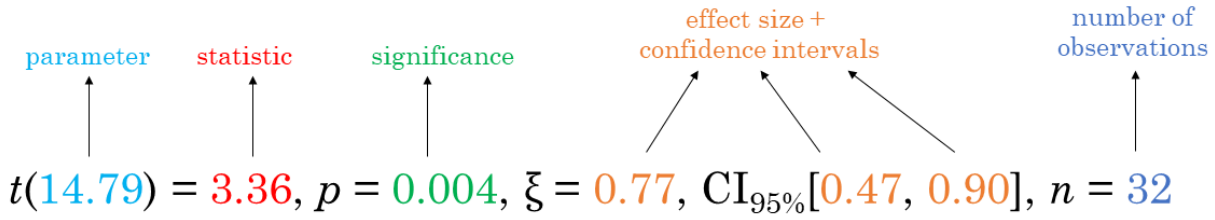


Figure 1: Template for reporting statistical details

Functions	Description	Parametric	Non-parametric	Robust	Bayes Factor
`ggwithinstats`	Within group/condition comparisons	Yes	Yes	Yes	Yes
`gghistostats`, `ggdotplotstats`	Distribution of a numeric variable	Yes	Yes	Yes	Yes
`ggcorrmat`	Correlation matrix	Yes	Yes	Yes	No
`ggscatterstats`	Correlation between two variables	Yes	Yes	Yes	Yes
`ggpiestats`, `ggbarstats`	Association between categorical variables	Yes	`NA`	`NA`	Yes
`ggpiestats`, `ggbarstats`	Equal proportions for categorical variable levels	Yes	`NA`	`NA`	Yes
`ggcoefstats`	Regression model coefficients	Yes	No	Yes	No

Statistical reporting

For **all** statistical tests reported in the plots, the default template abides by the APA gold standard for statistical reporting. For example, here are results from Yuen's test for trimmed means (robust t-test):

Summary of statistical tests and effect sizes

Here is a summary table of all the statistical tests currently supported across various functions:

Functions	Type	Test	Effect size	95% CI available?
`ggbetweenstats`	Parametric	Student's and Welch's t-test	Cohen's d, Hedge's g	✓
`ggbetweenstats`	Parametric	Fisher's and Welch's one-way ANOVA	$\eta^2, \eta_p^2, \omega^2, \omega_p^2$	✓
`ggbetweenstats`	Non-parametric	Mann-Whitney U-test	r	✓
`ggbetweenstats`	Non-parametric	Kruskal-Wallis Rank Sum Test	ϵ^2	✓
`ggbetweenstats`	Robust	Yuen's test for trimmed means	ξ	✓

Functions	Type	Test	Effect size	95% CI available?
`ggbetweenstats`	Robust	Heteroscedastic one-way ANOVA for trimmed means	ξ	✓
`ggwithinstats`	Parametric	Student's t-test	Cohen's d, Hedge's g	✓
`ggwithinstats`	Parametric	Fisher's one-way repeated measures ANOVA	η_p^2, ω^2	✓
`ggwithinstats`	Non-parametric	Wilcoxon signed-rank test	r	✓
`ggwithinstats`	Non-parametric	Friedman test	$W_{Kendall}$	✓
`ggwithinstats`	Robust	Yuen's test on trimmed means for dependent samples	ξ	✓
`ggwithinstats`	Robust	Heteroscedastic one-way repeated measures ANOVA for trimmed means	×	×
`ggpiestats`	Parametric	Pearson's χ^2 test	Cramér's V	✓
`ggpiestats`	Parametric	McNemar's test	Cohen's g	✓
`ggpiestats`	Parametric	One-sample proportion test	Cramér's V	✓
`ggscatterstats` and `ggcorrmat`	Parametric	Pearson's r	r	✓
`ggscatterstats` and `ggcorrmat`	Non-parametric	Spearman's ρ	ρ	✓
`ggscatterstats`and `ggcorrmat`	Robust	Percentage bend correlation	r	✓
`gghistostats` and `ggdotplotstats`	Parametric	One-sample t-test	Cohen's d, Hedge's g	✓
`gghistostats`	Non-parametric	One-sample Wilcoxon signed rank test	r	✓
`gghistostats` and `ggdotplotstats`	Robust	One-sample percentile bootstrap	robust estimator	✓
`gghistostats` and `ggdotplotstats`	Parametric	Regression models	β	✓

Work is in progress to add some of the currently missing functionality.

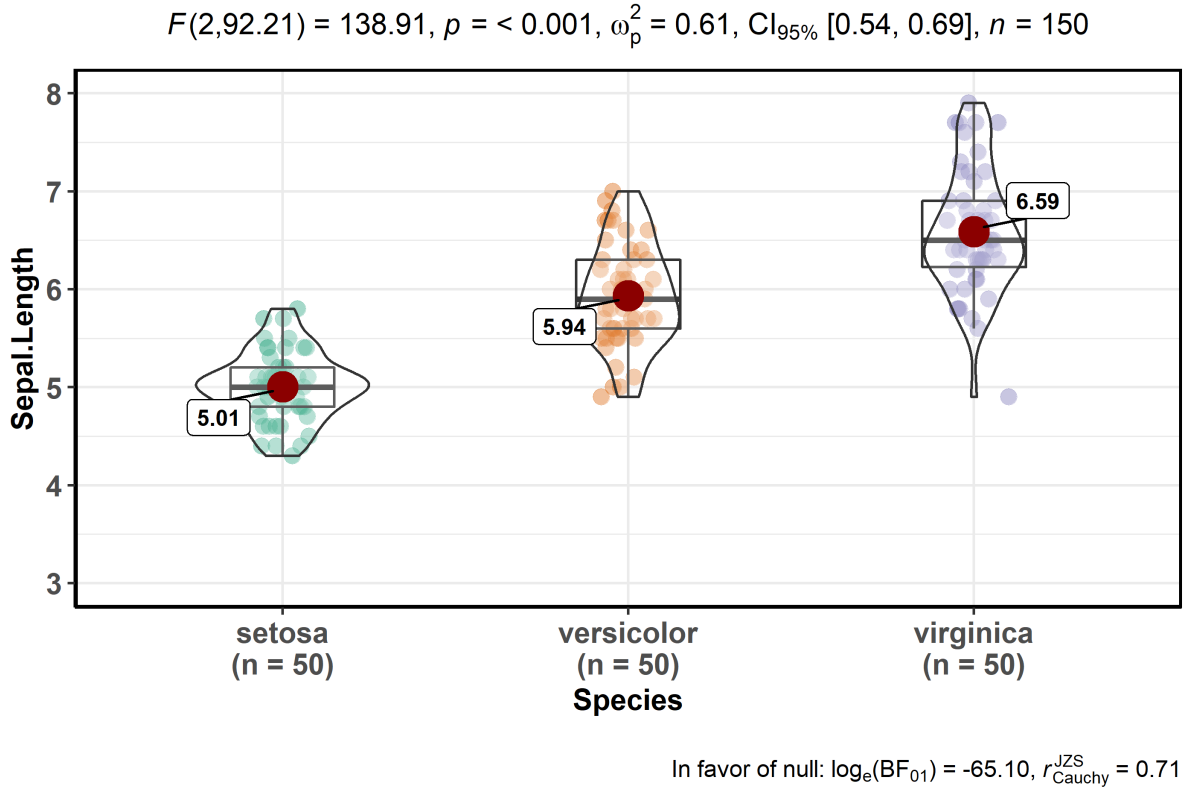
Primary functions

Here are examples of the main functions currently supported in `ggstatsplot`.

ggbetweenstats

This function creates either a violin plot, a box plot, or a mix of two for **between**-group or **between**-condition comparisons with results from statistical tests in the subtitle. The simplest function call looks like this-

```
# loading needed libraries
library(ggstatsplot)

# for reproducibility
set.seed(123)

# plot
ggstatsplot::ggbetweenstats(
  data = iris,
  x = Species,
  y = Sepal.Length,
  messages = FALSE
) + # further modification outside of ggstatsplot
  ggplot2::coord_cartesian(ylim = c(3, 8)) +
  ggplot2::scale_y_continuous(breaks = seq(3, 8, by = 1))
```



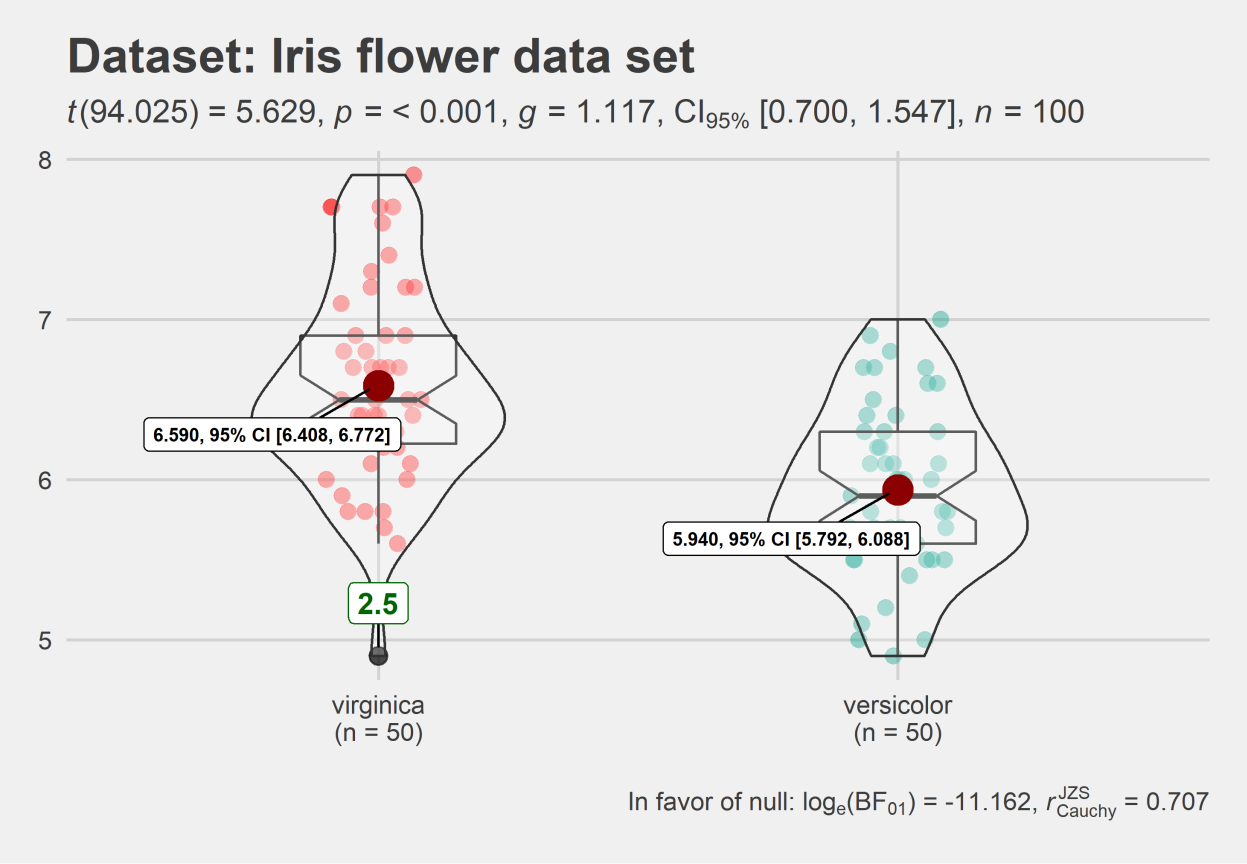
Note that this function returns a `ggplot2` object and thus any of the graphics layers can be further modified.

The `type` (of test) argument also accepts the following abbreviations: `"p"` (for *parametric*) or `"np"` (for

nonparametric) or `"r"` (for *robust*) or `"bf"` (for *Bayes Factor*). Additionally, the type of plot to be displayed can also be modified (`"box"`, `"violin"`, or `"boxviolin"`).

A number of other arguments can be specified to make this plot even more informative or change some of the default options.

```
library(ggplot2)

# for reproducibility
set.seed(123)

# let's leave out one of the factor levels and see if instead of anova, a t-test will be run
iris2 <- dplyr::filter(.data = iris, Species != "setosa")

# let's change the levels of our factors, a common routine in data analysis
# pipeline, to see if this function respects the new factor levels
iris2$Species <- factor(x = iris2$Species, levels = c("virginica", "versicolor"))

# plot
ggstatsplot::ggbetweenstats(
  data = iris2,
  x = Species,
  y = Sepal.Length,
  notch = TRUE, # show notched box plot
  mean.plotting = TRUE, # whether mean for each group is to be displayed
  mean.ci = TRUE, # whether to display confidence interval for means
  mean.label.size = 2.5, # size of the label for mean
  type = "parametric", # which type of test is to be run
  k = 3, # number of decimal places for statistical results
  outlier.tagging = TRUE, # whether outliers need to be tagged
  outlier.label = Sepal.Width, # variable to be used for the outlier tag
  outlier.label.color = "darkgreen", # changing the color for the text label
  xlab = "Type of Species", # label for the x-axis variable
  ylab = "Attribute: Sepal Length", # label for the y-axis variable
  title = "Dataset: Iris flower data set", # title text for the plot
  ggtheme = ggthemes::theme_fivethirtyeight(), # choosing a different theme
  ggstatsplot.layer = FALSE, # turn off ggstatsplot theme layer
  package = "wesanderson", # package from which color palette is to be taken
  palette = "Darjeeling1", # choosing a different color palette
  messages = FALSE
)
```



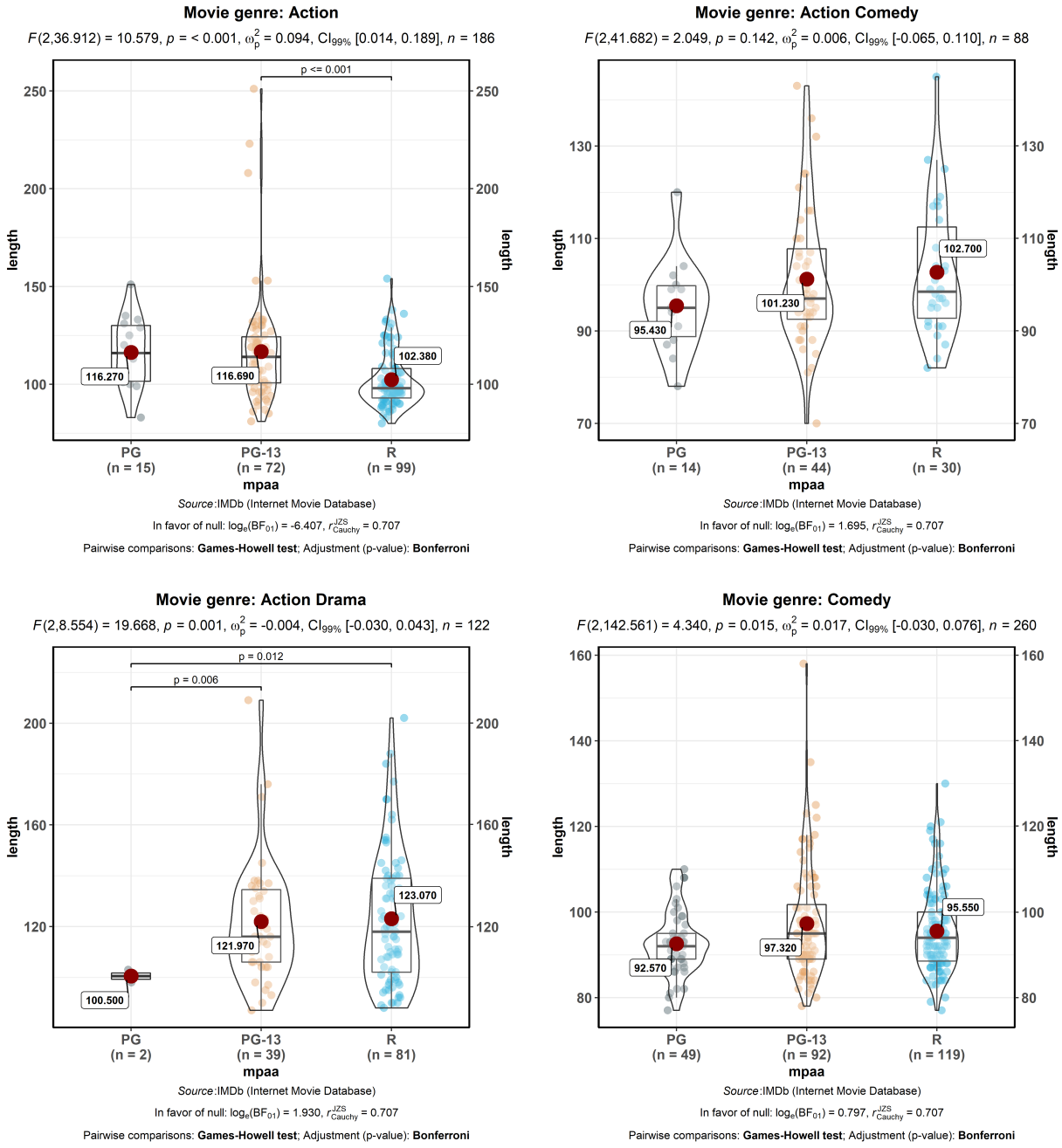
As can be seen from the plot, the function by default returns Bayes Factor for the test (here, Student's t-test). If the null hypothesis can't be rejected with the null hypothesis significance testing (NHST) approach, the Bayesian approach can help index evidence in favor of the null hypothesis (i.e., BF_{01}).

By default, natural logarithms are shown because Bayes Factor values can sometimes be pretty large. Having values on logarithmic scale also makes it easy to compare evidence in favor alternative (BF_{10}) versus null (BF_{01}) hypotheses (since $log_e(BF_{01}) = -log_e(BF_{01})$).

Additionally, there is also a `grouped_` variant of this function that makes it easy to repeat the same operation across a **single** grouping variable:

```
# for reproducibility
set.seed(123)

# plot
ggstatsplot::grouped_ggbetweenstats(
  data = dplyr::filter(
    .data = ggstatsplot::movies_long,
    genre %in% c("Action", "Action Comedy", "Action Drama", "Comedy")
  ),
  x = mpaa,
  y = length,
  grouping.var = genre, # grouping variable
  pairwise.comparisons = TRUE, # display significant pairwise comparisons
  pairwise.annotation = "p.value", # how do you want to annotate the pairwise comparisons
  p.adjust.method = "bonferroni", # method for adjusting p-values for multiple comparisons
  conf.level = 0.99, # changing confidence level to 99%
  ggplot.component = list( # adding new components to `ggstatsplot` default
```

```
    ggplot2::scale_y_continuous(sec.axis = ggplot2::dup_axis())
  ),
  k = 3,
  title.prefix = "Movie genre",
  caption = substitute(paste(
    italic("Source"),
    ":IMDb (Internet Movie Database)"
  )),
  palette = "default_jama",
  package = "ggsci",
  messages = FALSE,
  nrow = 2,
  title.text = "Differences in movie length by mpaa ratings for different genres"
)
```



Summary of tests

Following (between-subjects) tests are carried out for each type of analyses-

Type	No. of groups	Test
Parametric	> 2	Student's or Welch's one-way ANOVA
Non-parametric	> 2	Kruskal–Wallis one-way ANOVA

Type	No. of groups	Test
Robust	> 2	Heteroscedastic one-way ANOVA for trimmed means
Bayes Factor	> 2	Student's ANOVA
Parametric	2	Student's or Welch's t-test
Non-parametric	2	Mann–Whitney U test
Robust	2	Yuen's test for trimmed means
Bayes Factor	2	Student's t-test

The omnibus effect in one-way ANOVA design can also be followed up with more focal pairwise comparison tests. Here is a summary of *multiple pairwise comparison* tests supported in *ggbetweenstats*-

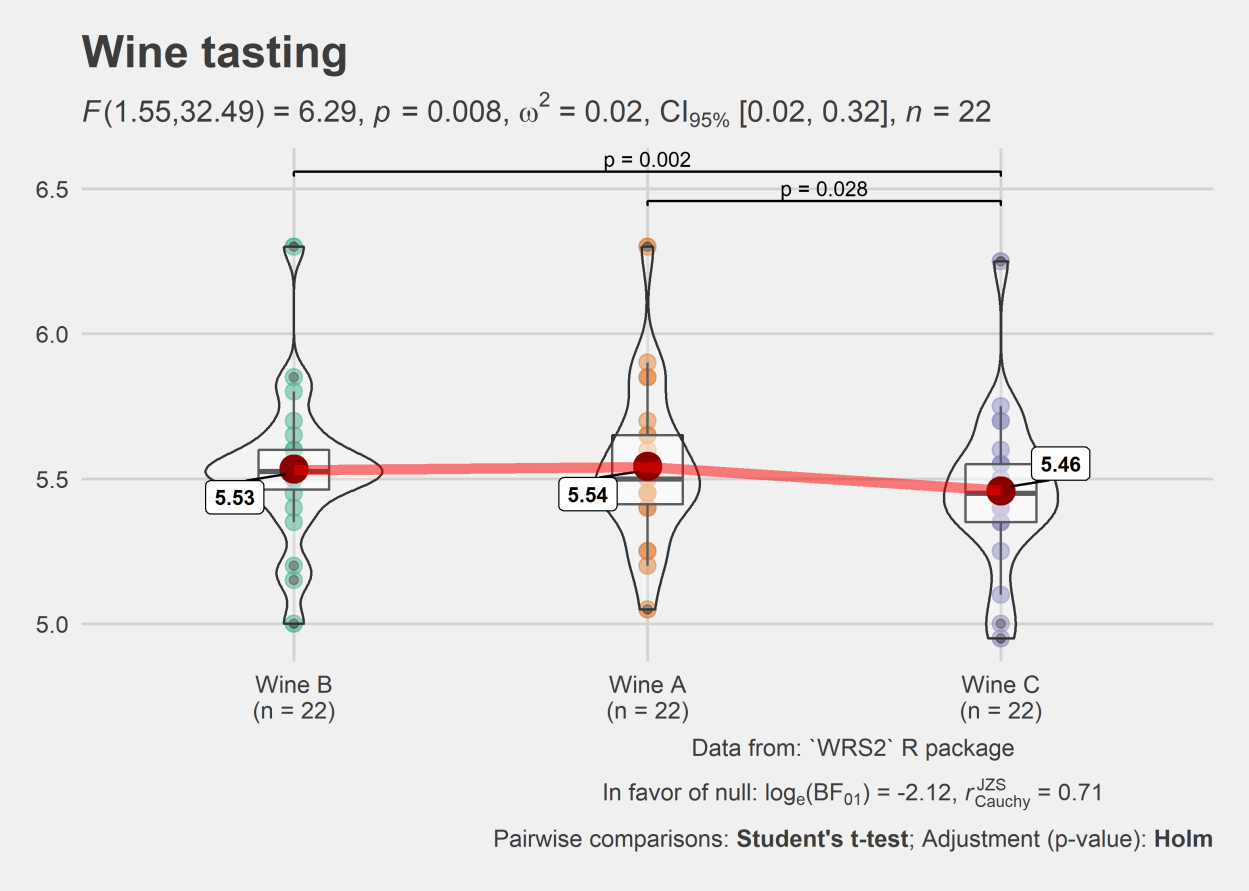
Type	Equal variance?	Test	p-value adjustment?
Parametric	No	Games-Howell test	Yes
Parametric	Yes	Student's t-test	Yes
Non-parametric	No	Dwass-Steel-Crichtlow-Fligner test	Yes
Robust	No	Yuen's trimmed means test	Yes
Bayes Factor	No	No	No
Bayes Factor	Yes	No	No

For more, see the `ggbetweenstats` vignette: https://indrajeetpatil.github.io/ggstatsplot/articles/web_only/ggbetweenstats.html

ggwithinstats

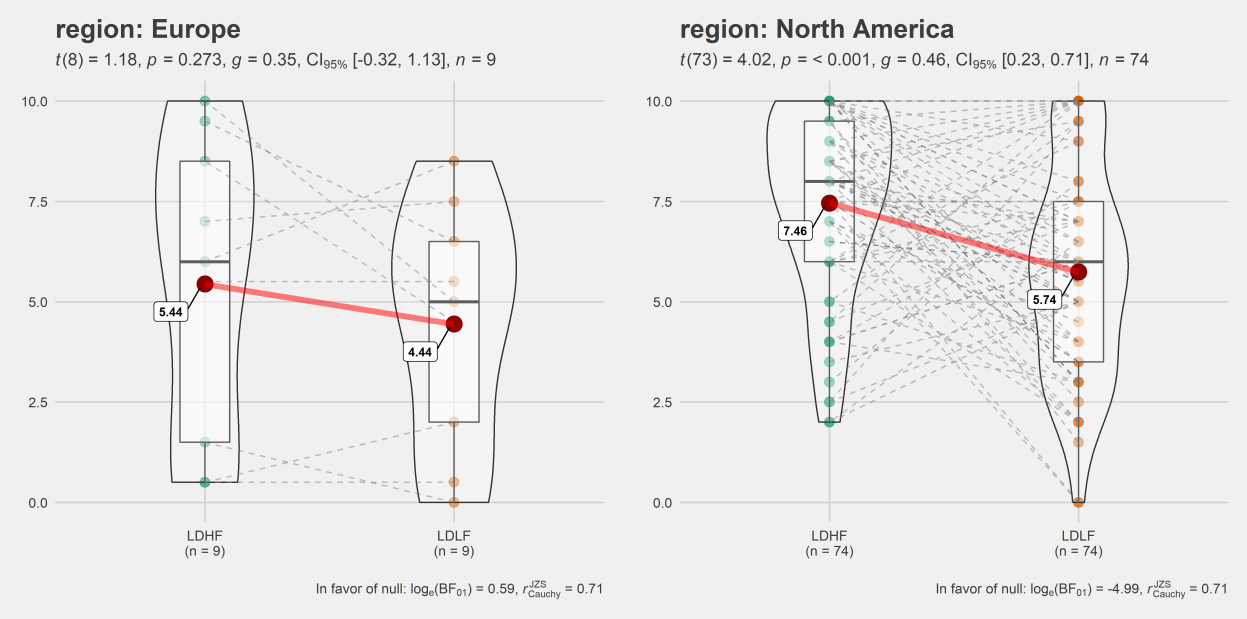
`ggbetweenstats` function has an identical twin function `ggwithinstats` for repeated measures designs that behaves in the same fashion with a few minor tweaks introduced to properly visualize the repeated measures design. As can be seen from an example below, the only difference between the plot structure is that now the group means are connected by paths to highlight the fact that these data are paired with each other.

```
# for reproducibility and data
set.seed(123)
library(WRS2)

# plot
ggstatsplot::ggwithinstats(
  data = WRS2::WineTasting,
  x = Wine,
  y = Taste,
  sort = "descending", # ordering groups along the x-axis based on
  sort.fun = median, # values of `y` variable
  pairwise.comparisons = TRUE,
  pairwise.display = "s",
  pairwise.annotation = "p",
  title = "Wine tasting",
  caption = "Data from: `WRS2` R package",
  ggtheme = ggthemes::theme_fivethirtyeight(),
  ggstatsplot.layer = FALSE,
  messages = FALSE
)
```



As with the `ggbetweenstats`, this function also has a `grouped_` variant that makes repeating the same analysis across a single grouping variable quicker. We will see an example with only repeated measurements-

```
# common setup
set.seed(123)

# getting data in tidy format
data_bugs <- ggstatsplot::bugs_long %>%
  dplyr::filter(.data = ., region %in% c("Europe", "North America"))

# plot
ggstatsplot::grouped_ggwithinstats(
  data = dplyr::filter(data_bugs, condition %in% c("LDLF", "LDHF")),
  x = condition,
  y = desire,
  xlab = "Condition",
  ylab = "Desire to kill an artrhopod",
  grouping.var = region,
  outlier.tagging = TRUE,
  outlier.label = education,
  ggtheme = ggthemes::theme_fivethirtyeight(),
  ggstatsplot.layer = FALSE,
  messages = FALSE
)
```



Summary of tests

Following (within-subjects) tests are carried out for each type of analyses-

Type	No. of groups	Test
Parametric	> 2	One-way repeated measures ANOVA
Non-parametric	> 2	Friedman test
Robust	> 2	Heteroscedastic one-way repeated measures ANOVA for trimmed means
Bayes Factor	> 2	One-way repeated measures ANOVA
Parametric	2	Student's *t*-test
Non-parametric	2	Wilcoxon signed-rank test
Robust	2	Yuen's test on trimmed means for dependent samples
Bayes Factor	2	Student's *t*-test

The omnibus effect in one-way ANOVA design can also be followed up with more focal pairwise comparison tests. Here is a summary of *multiple pairwise comparison* tests supported in *ggwithinstats*-

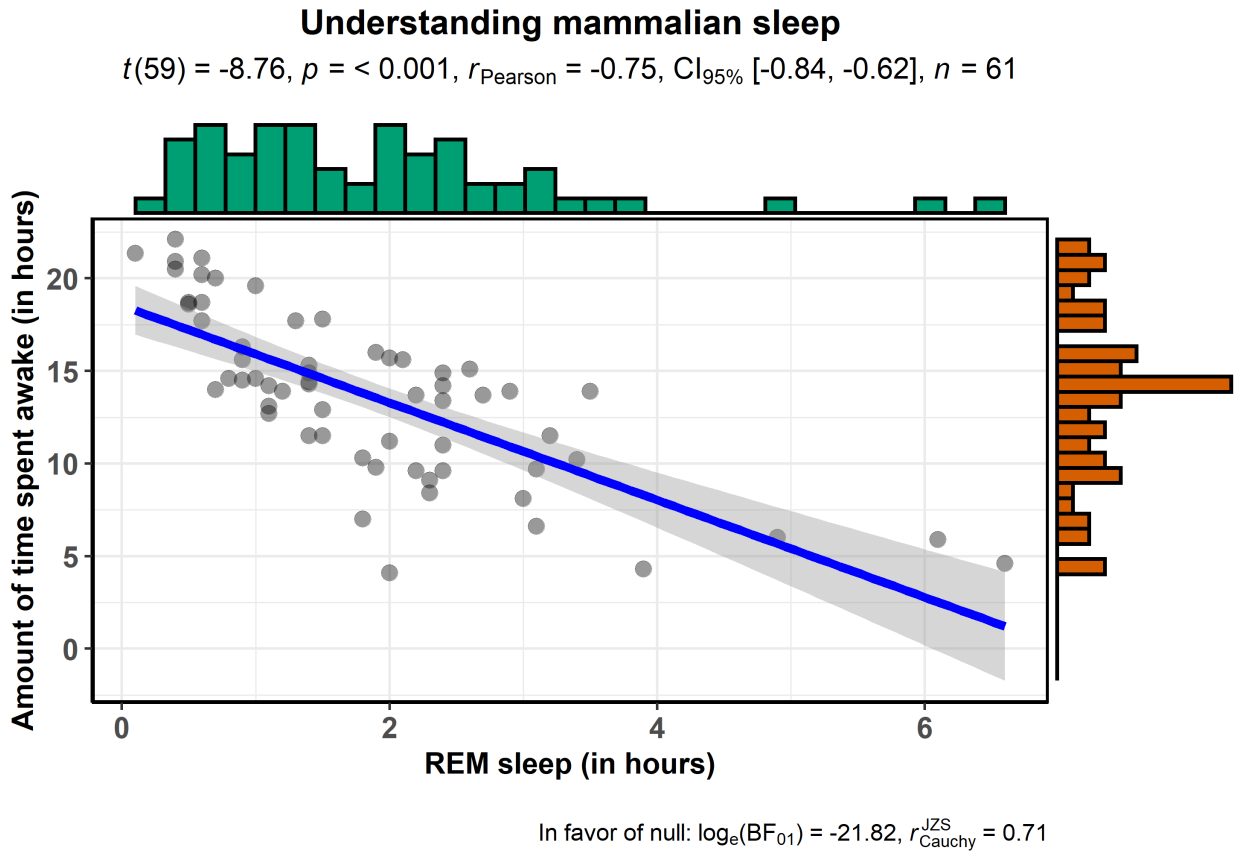
Type	Test	*p*-value adjustment?
Parametric	Student's *t*-test	Yes
Non-parametric	Durbin-Conover test	Yes
Robust	Yuen's trimmed means test	Yes
Bayes Factor	No	No

For more, see the `ggwithinstats` vignette: https://indrajeetpatil.github.io/ggstatsplot/articles/web_only/ggwithinstats.html

ggscatterstats

This function creates a scatterplot with marginal distributions overlaid on the axes (from `ggExtra::ggMarginal`) and results from statistical tests in the subtitle:

```
ggstatsplot::ggscatterstats(
  data = ggplot2::msleep,
  x = sleep_rem,
  y = awake,
  xlab = "REM sleep (in hours)",
  ylab = "Amount of time spent awake (in hours)",
  title = "Understanding mammalian sleep",
  messages = FALSE
)
```



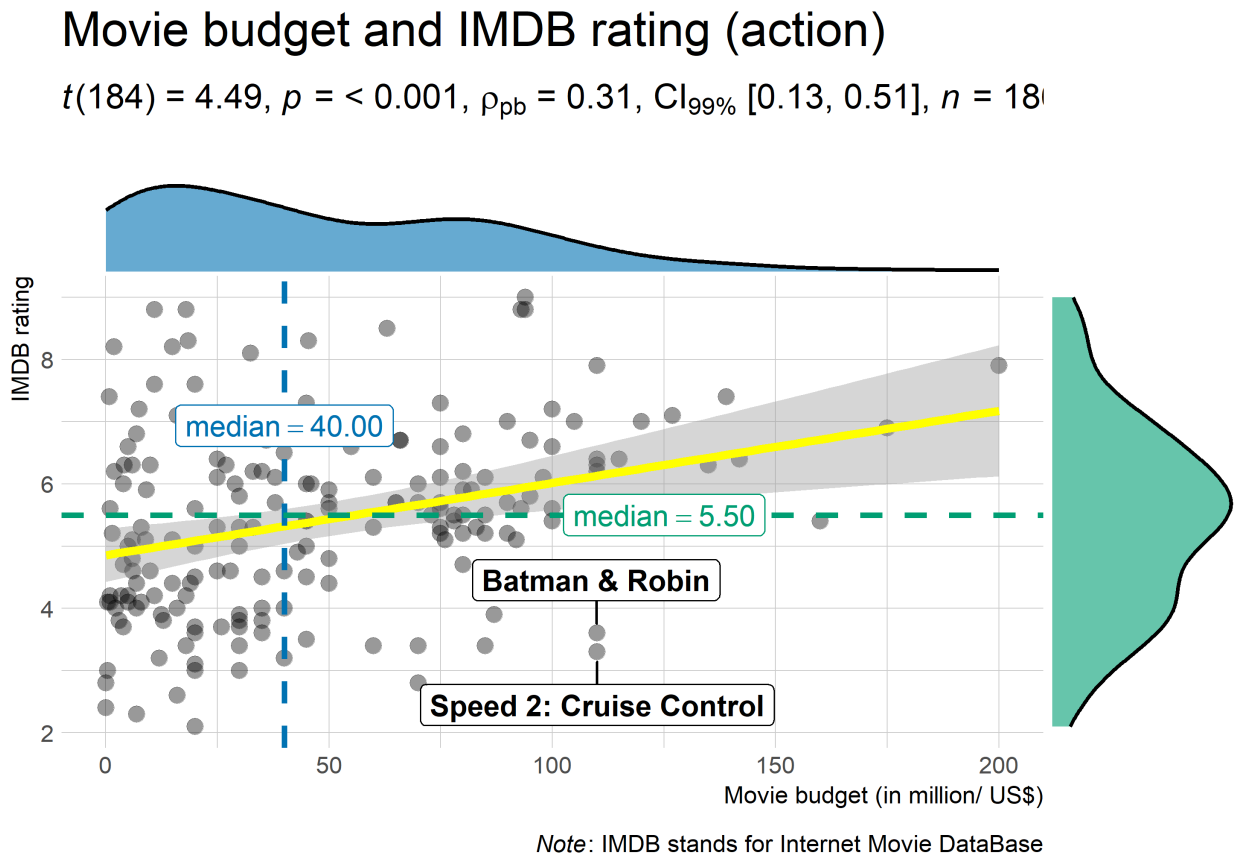
The available marginal distributions are-

- histograms
- boxplots
- density
- violin
- densigram (density + histogram)

Number of other arguments can be specified to modify this basic plot-

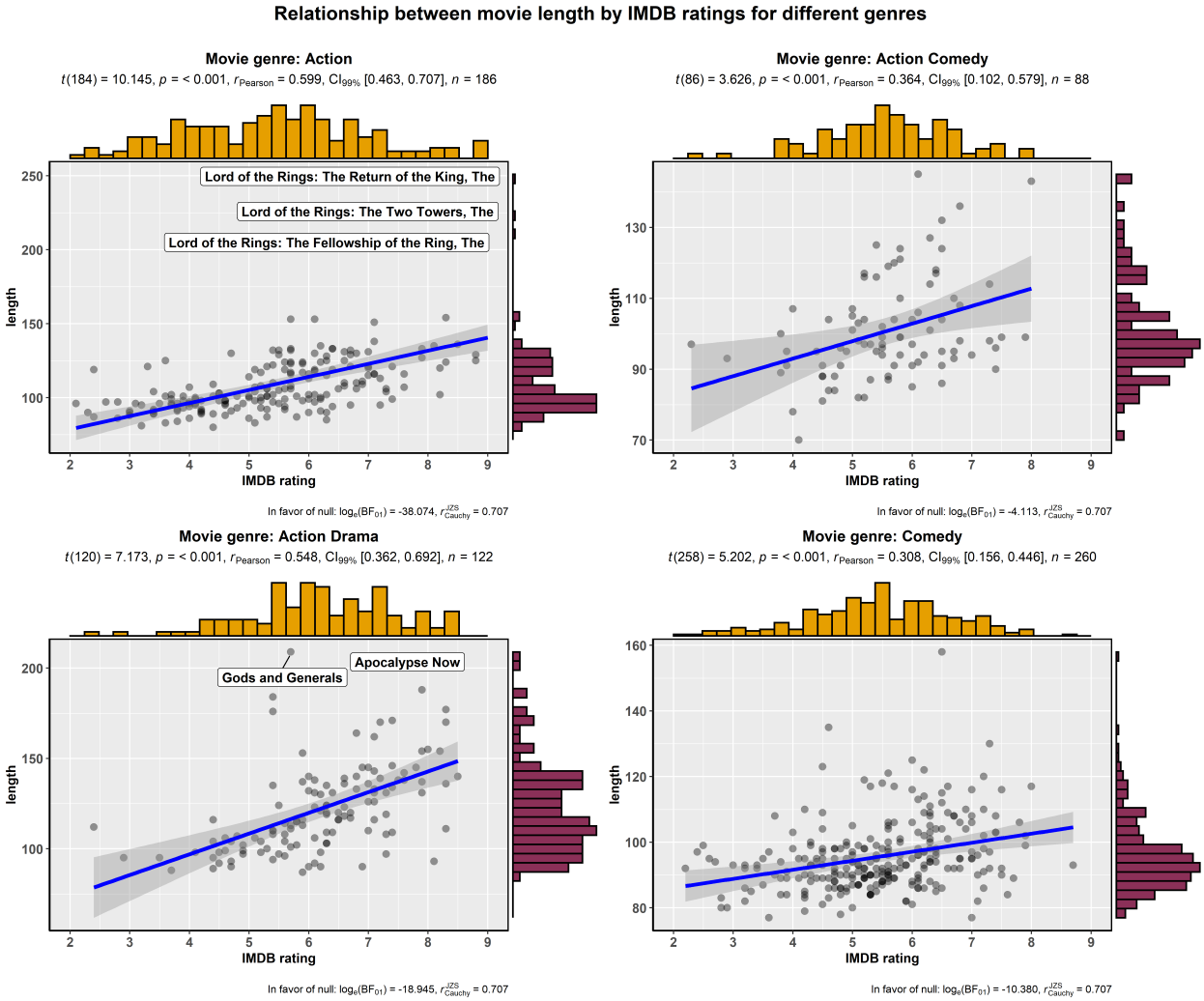
```
# for reproducibility
set.seed(123)

# plot
```

```
ggstatsplot::ggscatterstats(
  data = dplyr::filter(.data = ggstatsplot::movies_long, genre == "Action"),
  x = budget,
  y = rating,
  type = "robust", # type of test that needs to be run
  conf.level = 0.99, # confidence level
  xlab = "Movie budget (in million/ US$)", # label for x axis
  ylab = "IMDB rating", # label for y axis
  label.var = "title", # variable for labeling data points
  label.expression = "rating < 5 & budget > 100", # expression that decides which points to label
  line.color = "yellow", # changing regression line color line
  title = "Movie budget and IMDB rating (action)", # title text for the plot
  caption = expression( # caption text for the plot
    paste(italic("Note"), ": IMDB stands for Internet Movie DataBase")
  ),
  ggtheme = hrbrthemes::theme_ipsum_ps(), # choosing a different theme
  ggstatsplot.layer = FALSE, # turn off ggstatsplot theme layer
  marginal.type = "density", # type of marginal distribution to be displayed
  xfill = "#0072B2", # color fill for x-axis marginal distribution
  yfill = "#009E73", # color fill for y-axis marginal distribution
  xalpha = 0.6, # transparency for x-axis marginal distribution
  yalpha = 0.6, # transparency for y-axis marginal distribution
  centrality.para = "median", # central tendency lines to be displayed
  messages = FALSE # turn off messages and notes
)
```



Additionally, there is also a `grouped_` variant of this function that makes it easy to repeat the same operation across a **single** grouping variable. Also, note that, as opposed to the other functions, this function does not return a `ggplot` object and any modification you want to make can be made in advance using `ggplot.component` argument (available for all functions, but especially useful for this particular function):

```
# for reproducibility
set.seed(123)

# plot
ggstatsplot::grouped_ggscatterstats(
  data = dplyr::filter(
    .data = ggstatsplot::movies_long,
    genre %in% c("Action", "Action Comedy", "Action Drama", "Comedy")
  ),
  x = rating,
  y = length,
  label.var = title,
  label.expression = length > 200,
  conf.level = 0.99,
  k = 3, # no. of decimal places in the results
  xfill = "#E69F00",
  yfill = "#8b3058",
  xlab = "IMDB rating",
  grouping.var = genre, # grouping variable
  title.prefix = "Movie genre",
  ggtheme = ggplot2::theme_grey(),
  ggplot.component = list(
    ggplot2::scale_x_continuous(breaks = seq(2, 9, 1), limits = (c(2, 9)))
  ),
  messages = FALSE,
  nrow = 2,
  title.text = "Relationship between movie length by IMDB ratings for different genres"
)
```



Using `ggscatterstats()` in R Notebooks or R Markdown

If you include a `ggscatterstats()` plot inside an `R Notebook` or `R Markdown` code chunk, you will notice that running the chunk doesn't return any output nor does it give any error. In order to get a `ggscatterstats()` to show up in these contexts, you need to save the `ggscatterstats` plot as a variable in one code chunk, and explicitly print it using the `grid` package in another chunk, like this:

```
# include the following code in your code chunk inside R Notebook or Markdown
grid::grid.newpage()
grid::grid.draw(
  ggstatsplot::ggscatterstats(
    data = ggstatsplot::movies_wide,
    x = budget,
    y = rating,
    marginal = TRUE,
    messages = FALSE
  )
)
```

Another option - or rather a compromise - is not to include marginal distribution at all by setting `marginal = FALSE`.

Summary of tests

Following tests are carried out for each type of analyses. Additionally, the correlation coefficients (and their confidence intervals) are used as effect sizes-

Type	Test	CI?
Parametric	Pearson's correlation coefficient	Yes
Non-parametric	Spearman's rank correlation coefficient	Yes
Robust	Percentage bend correlation coefficient	Yes
Bayes Factor	Pearson's correlation coefficient	No

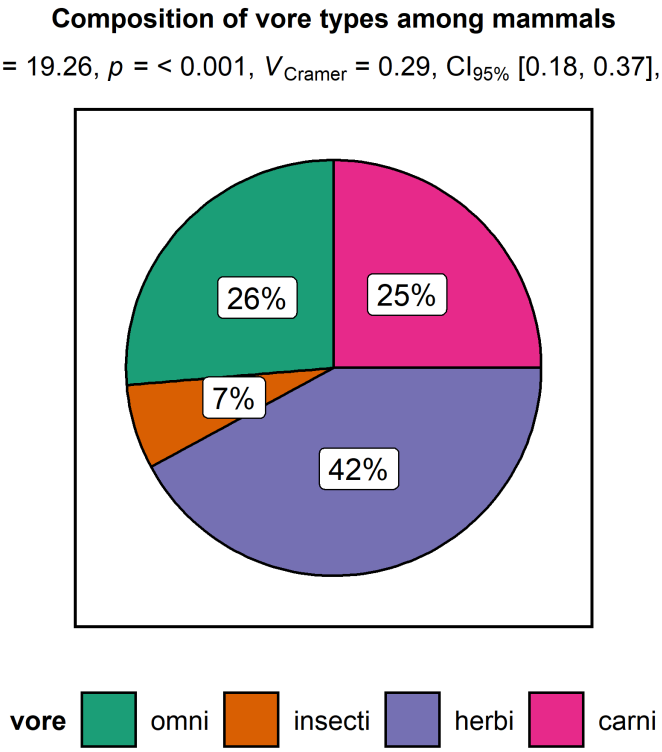
For more, see the `ggscatterstats` vignette: https://indrajeetpatil.github.io/ggstatsplot/articles/web_only/ggscatterstats.html

ggpiestats

This function creates a pie chart for categorical or nominal variables with results from contingency table analysis (Pearson's χ^2 test for between-subjects design and McNemar's χ^2 test for within-subjects design) included in the subtitle of the plot. If only one categorical variable is entered, results from one-sample proportion test (i.e., a χ^2 goodness of fit test) will be displayed as a subtitle.

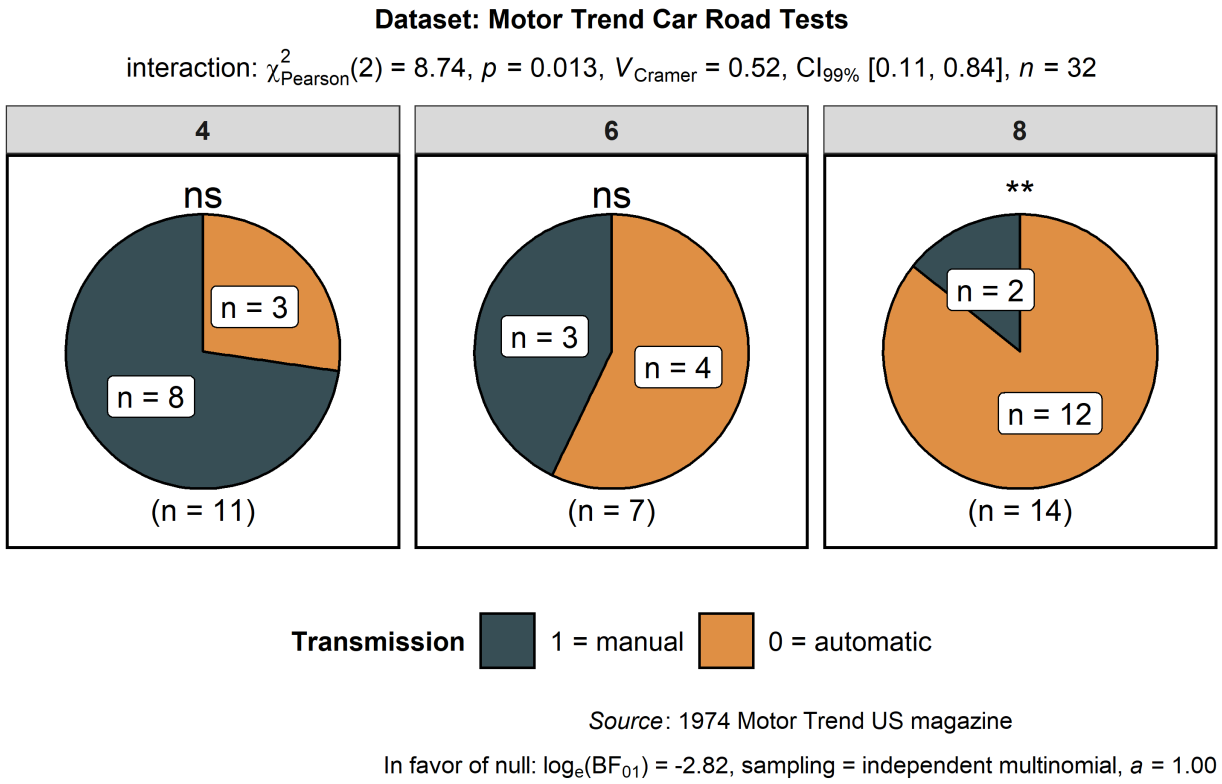
Here is an example of a case where the theoretical question is about proportions for different levels of a single nominal variable:

```
# for reproducibility
set.seed(123)

# plot
ggstatsplot::ggpiestats(
  data = ggplot2::msleep,
  x = vore,
  title = "Composition of vore types among mammals",
  messages = FALSE
)
```



This function can also be used to study an interaction between two categorical variables:

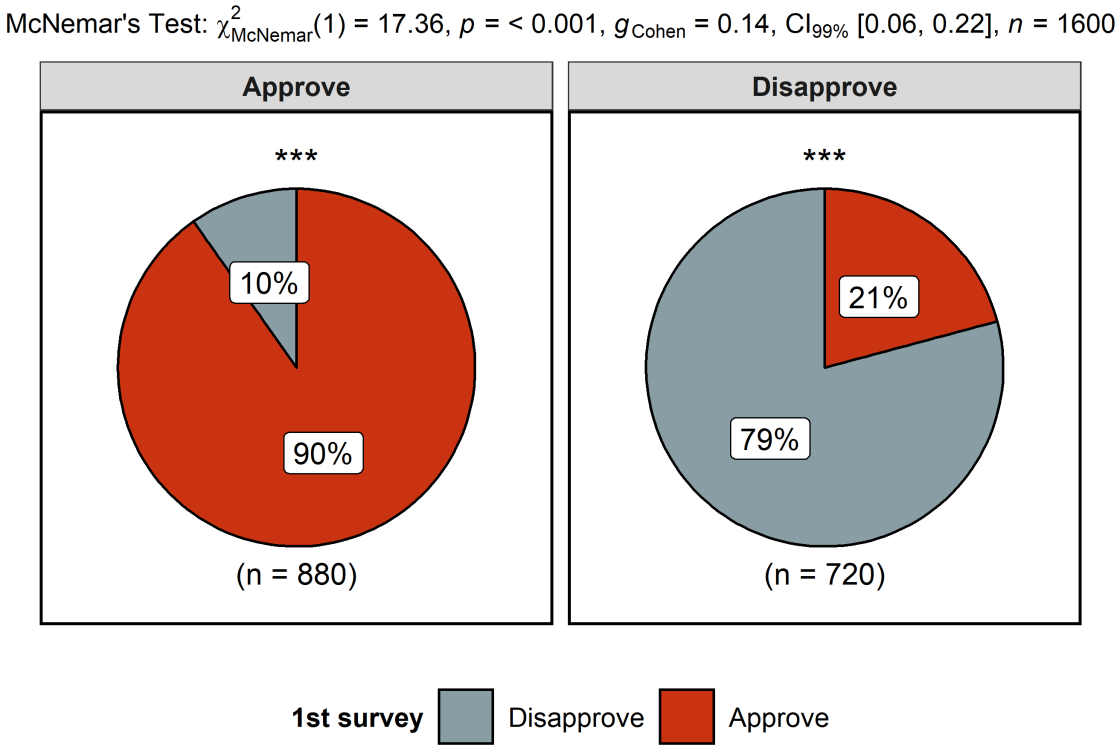
```
# for reproducibility
set.seed(123)

# plot
ggstatsplot::ggpiestats(
  data = mtcars,
  x = am,
  y = cyl,
  conf.level = 0.99, # confidence interval for effect size measure
  title = "Dataset: Motor Trend Car Road Tests", # title for the plot
  stat.title = "interaction: ", # title for the results
  legend.title = "Transmission", # title for the legend
  factor.levels = c("1 = manual", "0 = automatic"), # renaming the factor level names (`x`)
  facet.wrap.name = "No. of cylinders", # name for the facetting variable
  slice.label = "counts", # show counts data instead of percentages
  package = "ggsci", # package from which color palette is to be taken
  palette = "default_jama", # choosing a different color palette
  caption = substitute( # text for the caption
    paste(italic("Source"), ": 1974 Motor Trend US magazine")
  ),
  messages = FALSE # turn off messages and notes
)
```



In case of repeated measures designs, setting `paired = TRUE` will produce results from McNemar's χ^2 test-

```
# for reproducibility
set.seed(123)

# data
survey.data <- data.frame(
  `1st survey` = c("Approve", "Approve", "Disapprove", "Disapprove"),
  `2nd survey` = c("Approve", "Disapprove", "Approve", "Disapprove"),
  `Counts` = c(794, 150, 86, 570),
  check.names = FALSE
)

# plot
ggstatsplot::ggpiestats(
  data = survey.data,
  x = `1st survey`,
  y = `2nd survey`,
  counts = Counts,
  paired = TRUE, # within-subjects design
  conf.level = 0.99, # confidence interval for effect size measure
  stat.title = "McNemar's Test: ",
  package = "wesanderson",
  palette = "Royal1"
)
#> Note: 99% CI for effect size estimate was computed with 100 bootstrap samples.
#> Note: Results from one-sample proportion tests for each level of the variable
```

```
#> 2nd survey testing for equal proportions of the variable 1st survey.
#> # A tibble: 2 x 10
#>   `2nd survey` counts  perc N     Approve Disapprove `Chi-squared`    df
#>   <fct>         <int> <dbl> <chr> <chr>   <chr>              <dbl> <dbl>
#> 1 Disapprove      720   45  (n =~ 20.83%  79.17%             245      1
#> 2 Approve         880   55. (n =~ 90.23%  9.77%              570.     1
#> # ... with 2 more variables: `p-value` <dbl>, significance <chr>
```



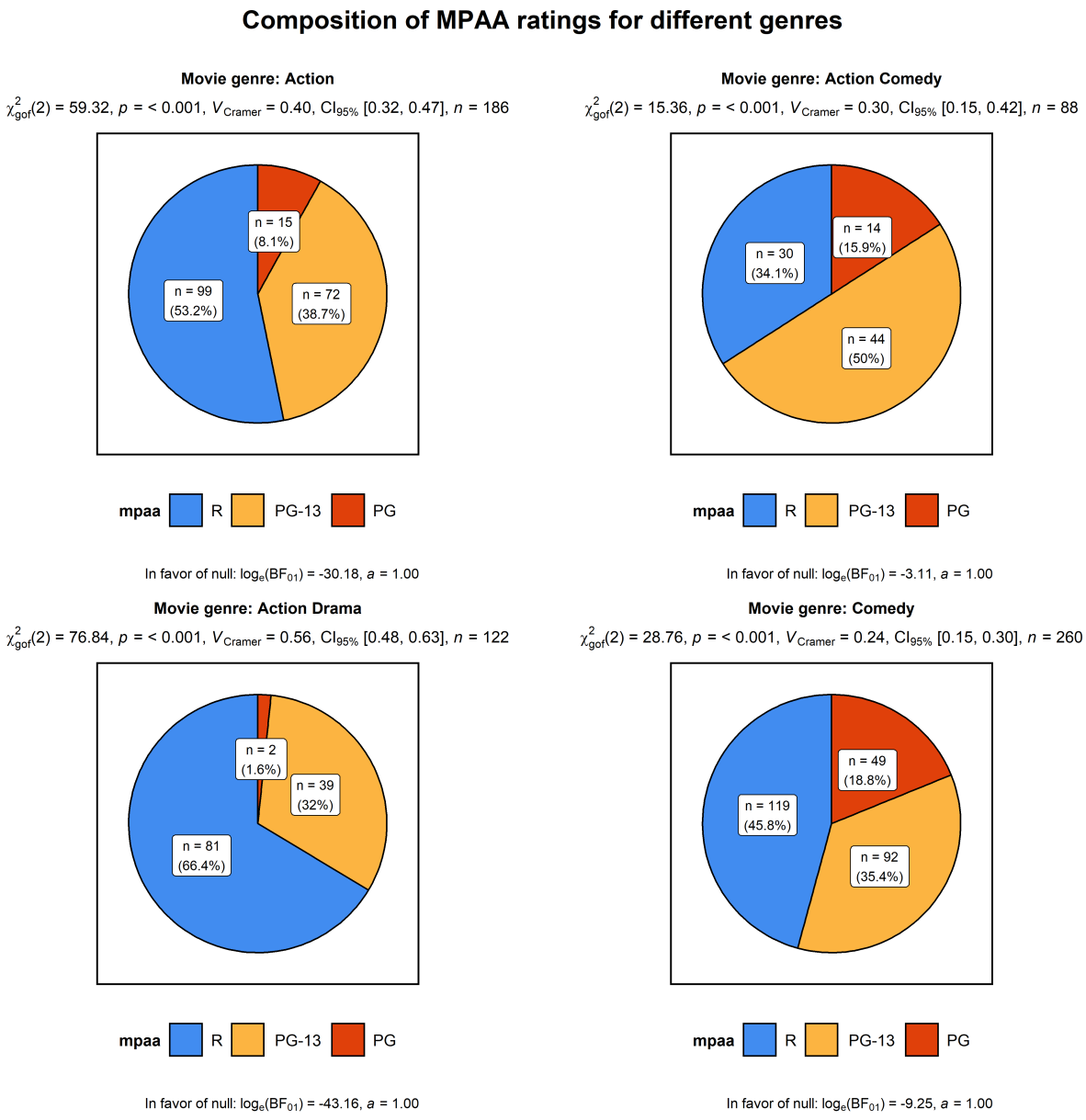
Note that when a two-way table is present (i.e., when both `x` and `y` arguments are specified), p-values for results from one-sample proportion tests are displayed in each facet in the form of asterisks with the following convention:

- $***$: $p < 0.001$
- $**$: $p < 0.01$
- $*$: $p < 0.05$
- ns: $p > 0.05$

Additionally, there is also a `grouped_` variant of this function that makes it easy to repeat the same operation across a **single** grouping variable:

```
# for reproducibility
set.seed(123)

# plot
ggstatsplot::grouped_ggpiestats(
  dplyr::filter(
    .data = ggstatsplot::movies_long,
    genre %in% c("Action", "Action Comedy", "Action Drama", "Comedy")
```

```
  ),
  x = mpaa,
  grouping.var = genre, # grouping variable
  title.prefix = "Movie genre", # prefix for the facetted title
  label.text.size = 3, # text size for slice labels
  slice.label = "both", # show both counts and percentage data
  perc.k = 1, # no. of decimal places for percentages
  palette = "brightPastel",
  package = "quickpalette",
  messages = FALSE,
  nrow = 2,
  title.text = "Composition of MPAA ratings for different genres"
)
```



Summary of tests

Following tests are carried out for each type of analyses-

Type of data	Design	Test
Unpaired	$n \times p$ contingency table	Pearson's χ^2 test
Paired	$n \times p$ contingency table	McNemar's χ^2 test
Frequency	$n \times 1$ contingency table	Goodness of fit (χ^2)

Following effect sizes (and confidence intervals/CI) are available for each type of test-

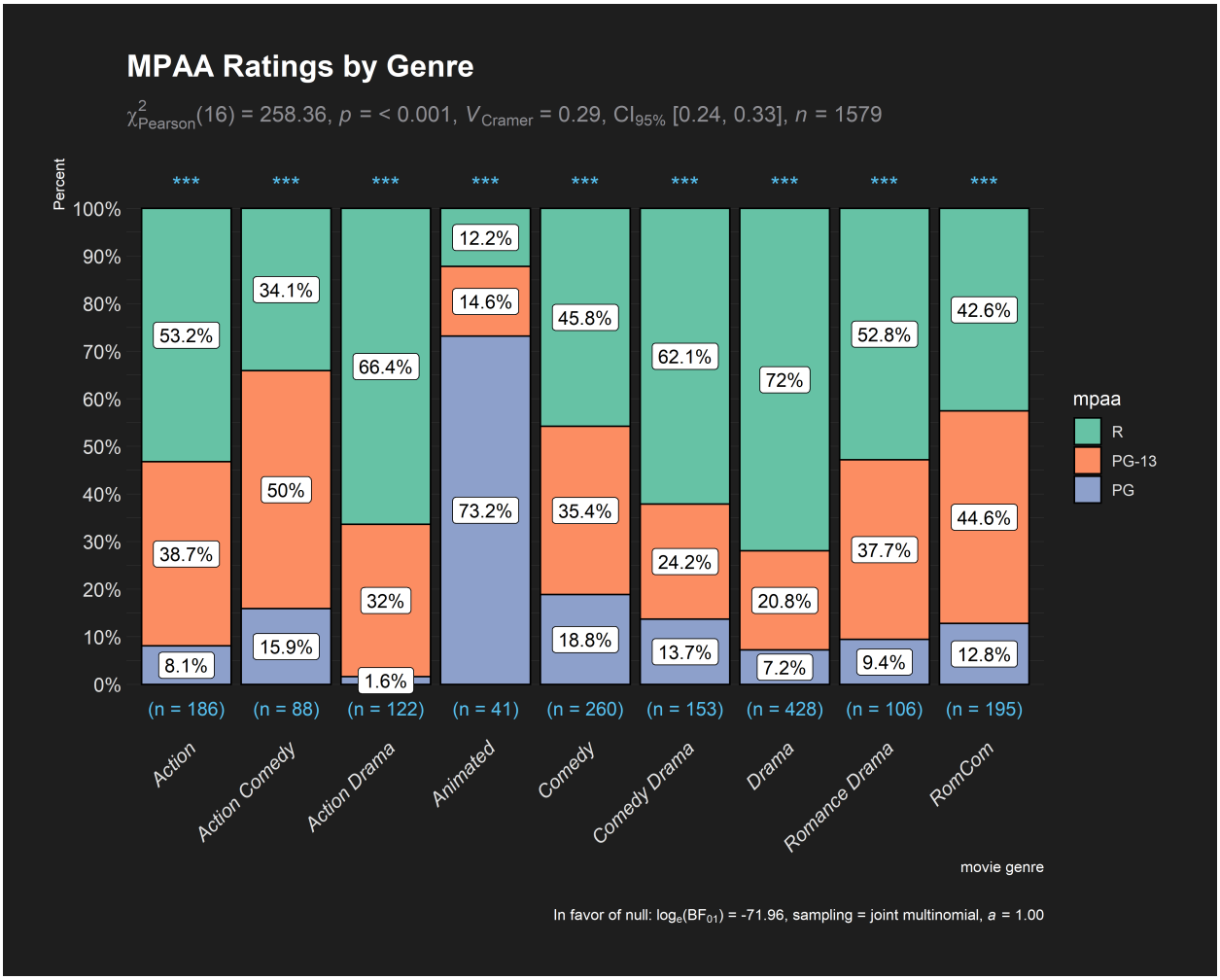
Type	Effect size	CI?
Pearson's chi-squared test	Cramer's V	Yes
McNemar's test	g	Yes
Goodness of fit	V	Yes

For more, see the `ggpiestats` vignette: https://indrajeetpatil.github.io/ggstatsplot/articles/web_only/ggpiestats.html

ggbarstats

In case you are not a fan of pie charts (for very good reasons), you can alternatively use `ggbarstats` function which has a similar syntax-

```
# for reproducibility
set.seed(123)

# plot
ggstatsplot::ggbarstats(
  data = ggstatsplot::movies_long,
  x = mpaa,
  y = genre,
  sampling.plan = "jointMulti",
  title = "MPAA Ratings by Genre",
  xlab = "movie genre",
  perc.k = 1,
  x.axis.orientation = "slant",
  ggtheme = hrbrthemes::theme_modern_rc(),
  ggstatsplot.layer = FALSE,
  ggplot.component = ggplot2::theme(axis.text.x = ggplot2::element_text(face = "italic")),
  palette = "Set2",
  messages = FALSE
)
```



And, needless to say, there is also a `grouped_` variant of this function-

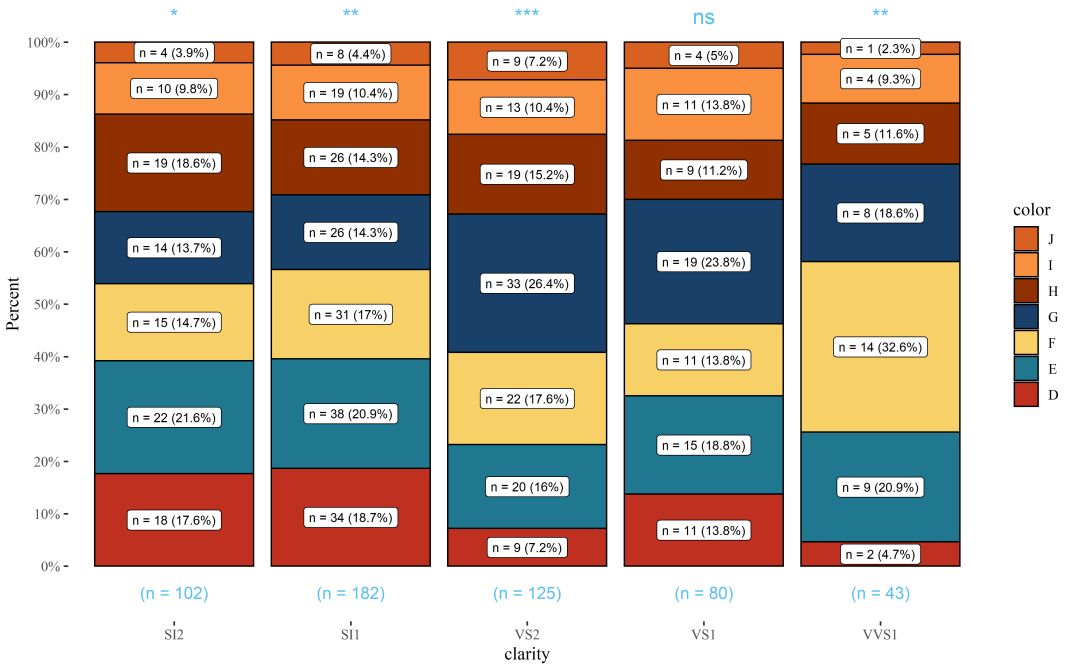
```
# setup
library(ggstatsplot)
set.seed(123)

# let's create a smaller dataframe
diamonds_short <- ggplot2::diamonds %>%
  dplyr::filter(.data = ., cut %in% c("Very Good", "Ideal")) %>%
  dplyr::filter(.data = ., clarity %in% c("SI1", "SI2", "VS1", "VS2", "VVS1")) %>%
  dplyr::sample_frac(tbl = ., size = 0.05)

# plot
ggstatsplot::grouped_ggbarstats(
  data = diamonds_short,
  x = color,
  y = clarity,
  grouping.var = cut,
  sampling.plan = "poisson",
  title.prefix = "Quality",
  data.label = "both",
  label.text.size = 3,
```

```
  perc.k = 1,
  package = "palettetown",
  palette = "charizard",
  ggtheme = ggthemes::theme_tufte(base_size = 12),
  ggstatsplot.layer = FALSE,
  messages = FALSE,
  title.text = "Diamond quality and color combination",
  nrow = 2
)
```

Diamond quality and color combination

Quality: Very Good

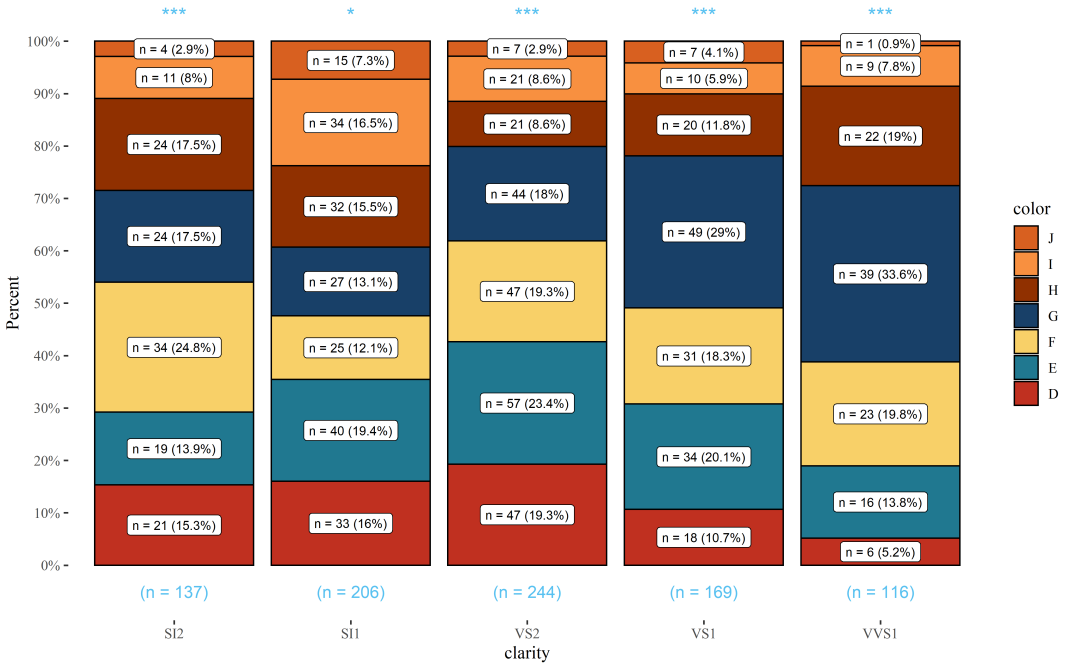
$\chi^2_{Pearson}(24) = 32.05$, $p = 0.126$, $V_{Cramer} = 0.12$, $CI_{95\%}$ [0.05, 0.13], $n = 532$



In favor of null: $\log_e(BF_{01}) = 2.86$, sampling = poisson, $a = 1.00$

Quality: Ideal

$\chi^2_{Pearson}(24) = 81.35$, $p = < 0.001$, $V_{Cramer} = 0.15$, $CI_{95\%}$ [0.10, 0.16], $n = 872$



In favor of null: $\log_e(BF_{01}) = -16.80$, sampling = poisson, $a = 1.00$

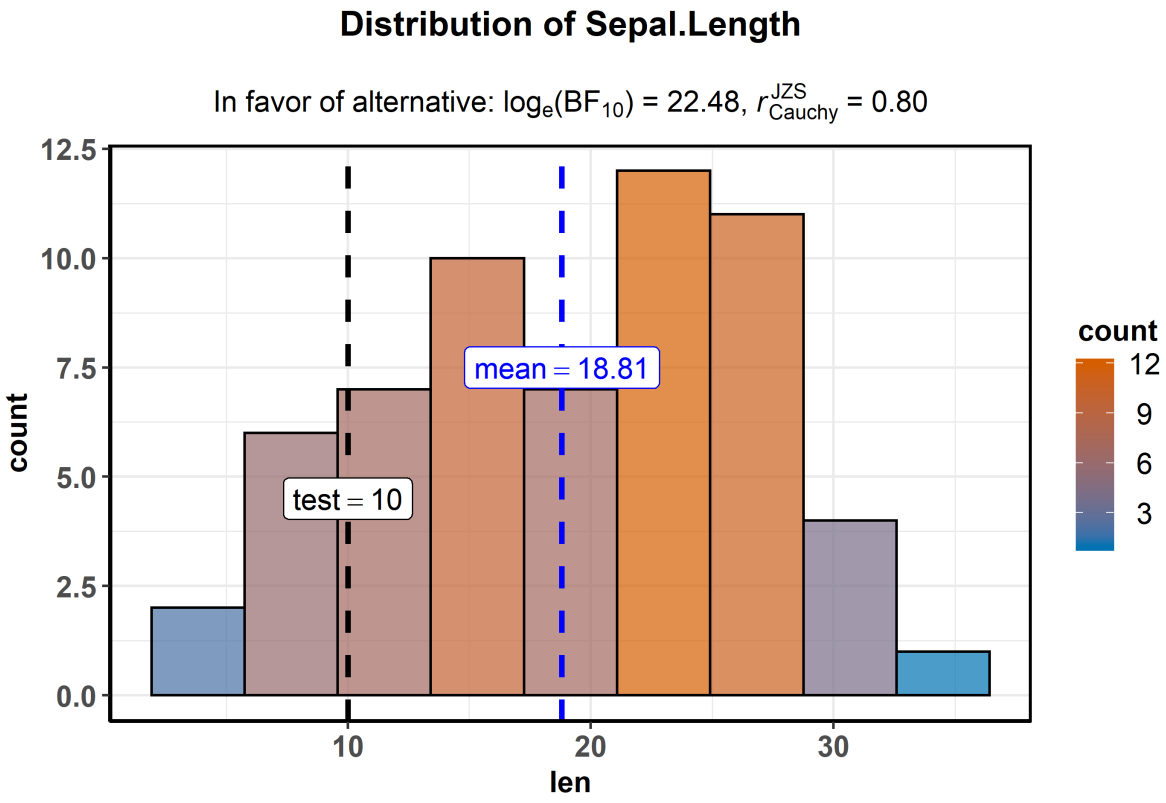
Summary of tests

This is identical to the `ggpiestats` function summary of tests.

gghistostats

In case you would like to see the distribution of a single variable and check if it is significantly different from a specified value with a one sample test, this function will let you do that.

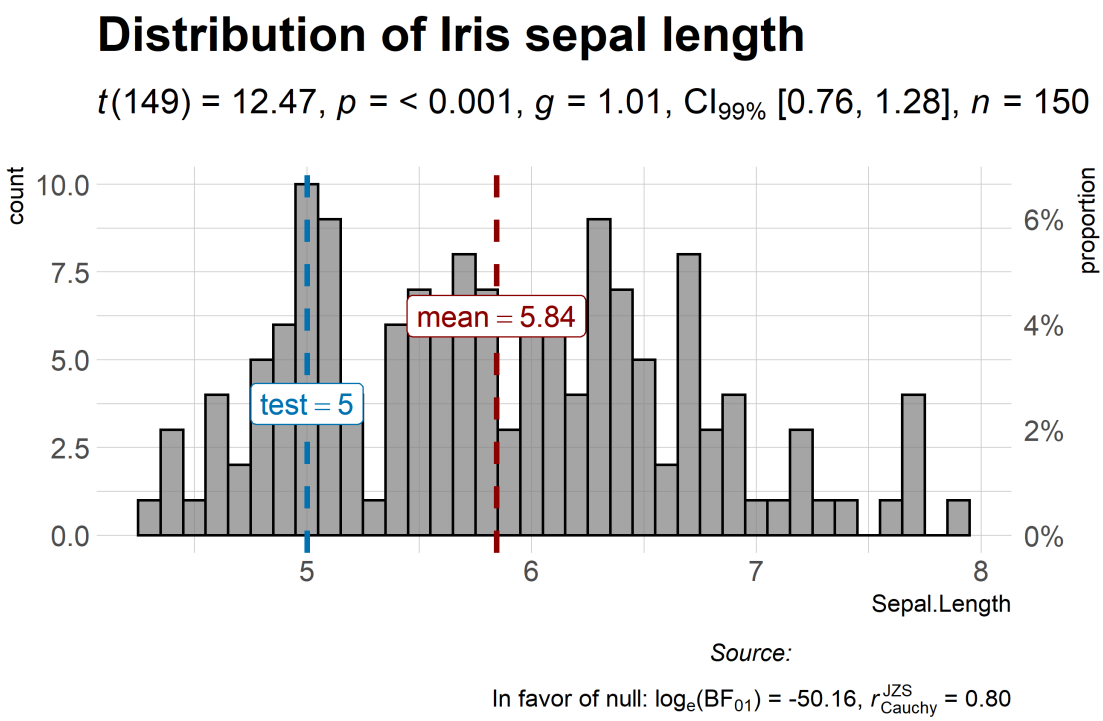
```
ggstatsplot::gghistostats(
  data = ToothGrowth, # dataframe from which variable is to be taken
  x = len, # numeric variable whose distribution is of interest
  title = "Distribution of Sepal.Length", # title for the plot
  fill.gradient = TRUE, # use color gradient
  test.value = 10, # the comparison value for t-test
  test.value.line = TRUE, # display a vertical line at test value
  type = "bayes", # bayes factor for one sample t-test
  bf.prior = 0.8, # prior width for calculating the bayes factor
  messages = FALSE # turn off the messages
)
```



The aesthetic defaults can be easily modified-

```
# for reproducibility
set.seed(123)

# plot
ggstatsplot::gghistostats(
```

```
  data = iris, # dataframe from which variable is to be taken
  x = Sepal.Length, # numeric variable whose distribution is of interest
  title = "Distribution of Iris sepal length", # title for the plot
  caption = substitute(paste(italic("Source:", "Ronald Fisher's Iris data set"))),
  type = "parametric", # one sample t-test
  conf.level = 0.99, # changing confidence level for effect size
  bar.measure = "mix", # what does the bar length denote
  test.value = 5, # default value is 0
  test.value.line = TRUE, # display a vertical line at test value
  test.value.color = "#0072B2", # color for the line for test value
  centrality.para = "mean", # which measure of central tendency is to be plotted
  centrality.color = "darkred", # decides color for central tendency line
  binwidth = 0.10, # binwidth value (experiment)
  bf.prior = 0.8, # prior width for computing bayes factor
  messages = FALSE, # turn off the messages
  ggtheme = hrbrthemes::theme_ipsum_tw(), # choosing a different theme
  ggstatsplot.layer = FALSE # turn off ggstatsplot theme layer
)
```

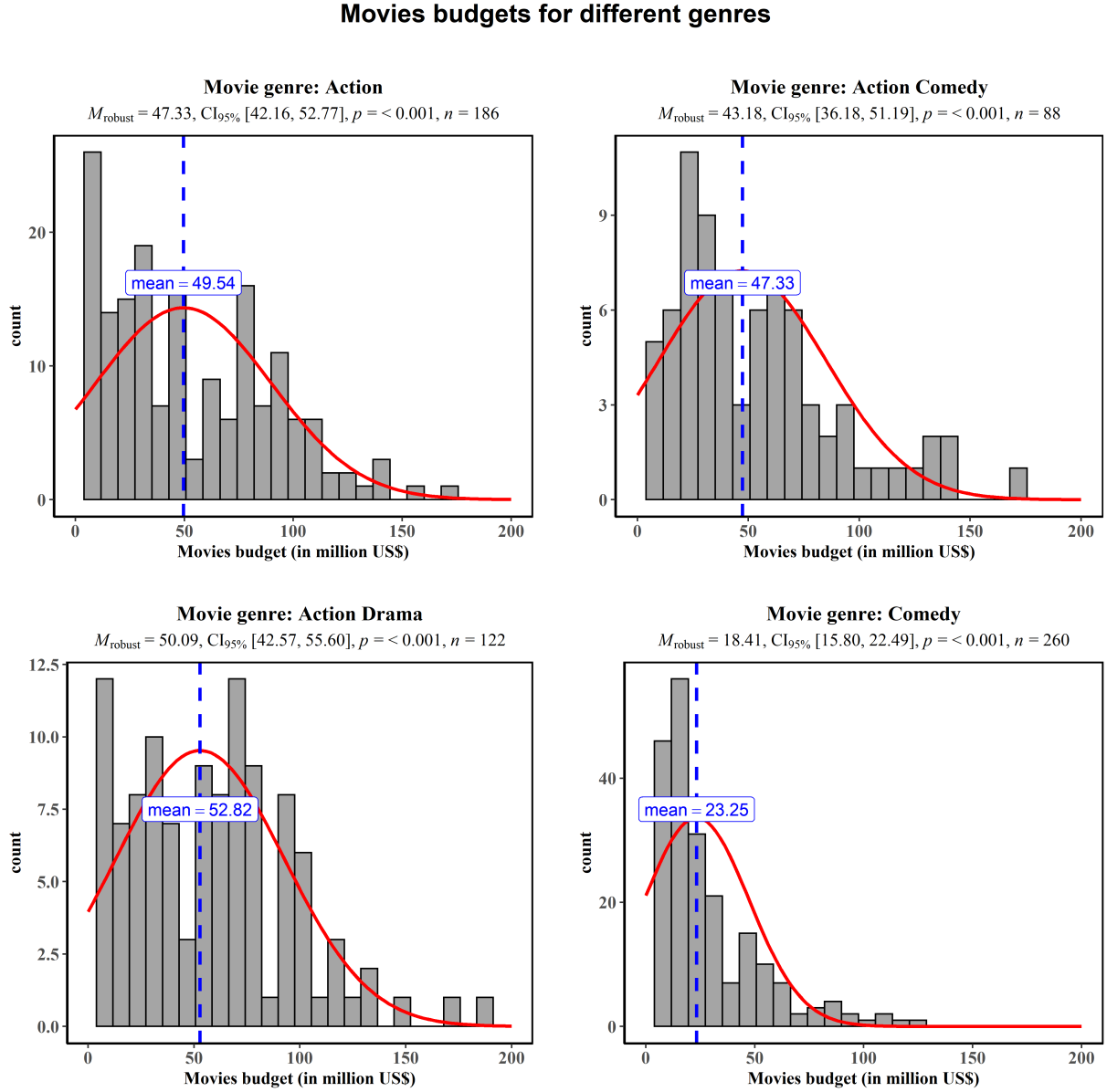


As can be seen from the plot, bayes factor can be attached (`bf.message = TRUE`) to assess evidence in favor of the null hypothesis.

Additionally, there is also a `grouped_` variant of this function that makes it easy to repeat the same operation across a **single** grouping variable:

```
# for reproducibility
set.seed(123)
```

```r
# plot
ggstatsplot::grouped_gghistostats(
  data = dplyr::filter(
    .data = ggstatsplot::movies_long,
    genre %in% c("Action", "Action Comedy", "Action Drama", "Comedy")
  ),
  x = budget,
  xlab = "Movies budget (in million US$)",
  type = "robust", # use robust location measure
  grouping.var = genre, # grouping variable
  normal.curve = TRUE, # superimpose a normal distribution curve
  normal.curve.color = "red",
  title.prefix = "Movie genre",
  ggtheme = ggthemes::theme_tufte(),
  ggplot.component = list( # modify the defaults from `ggstatsplot` for each plot
    ggplot2::scale_x_continuous(breaks = seq(0, 200, 50), limits = (c(0, 200)))
  ),
  messages = FALSE,
  nrow = 2,
  title.text = "Movies budgets for different genres"
)
```



Summary of tests

Following tests are carried out for each type of analyses-

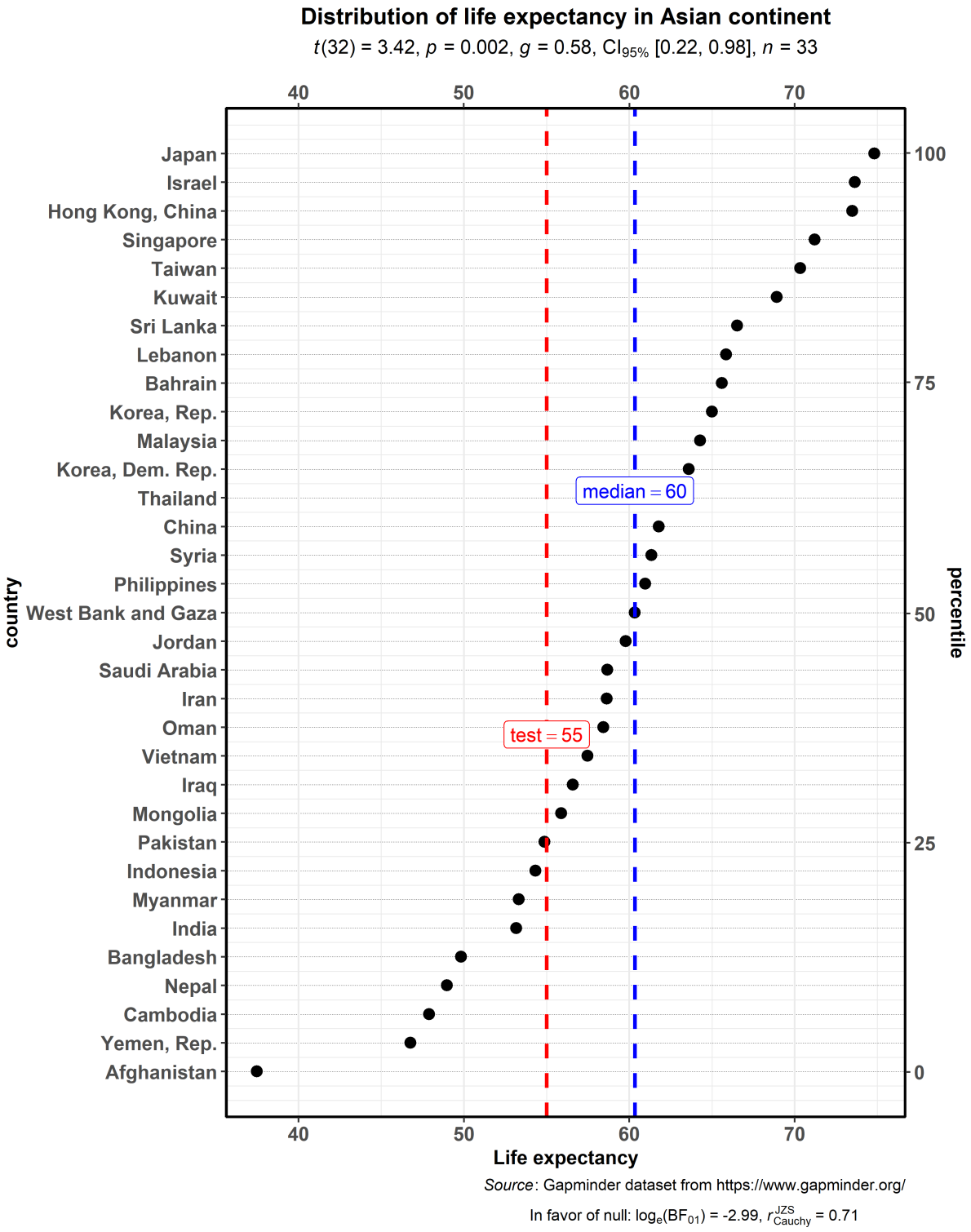
Type	Test
Parametric	One-sample Student's *t*-test
Non-parametric	One-sample Wilcoxon test
Robust	One-sample percentile bootstrap
Bayes Factor	One-sample Student's *t*-test

For more, including information about the variant of this function `grouped_gghistostats`, see the `gghistostats` vignette: https://indrajeetpatil.github.io/ggstatsplot/articles/web_only/gghistostats.html

ggdotplotstats

This function is similar to `gghistostats`, but is intended to be used when the numeric variable also has a label.

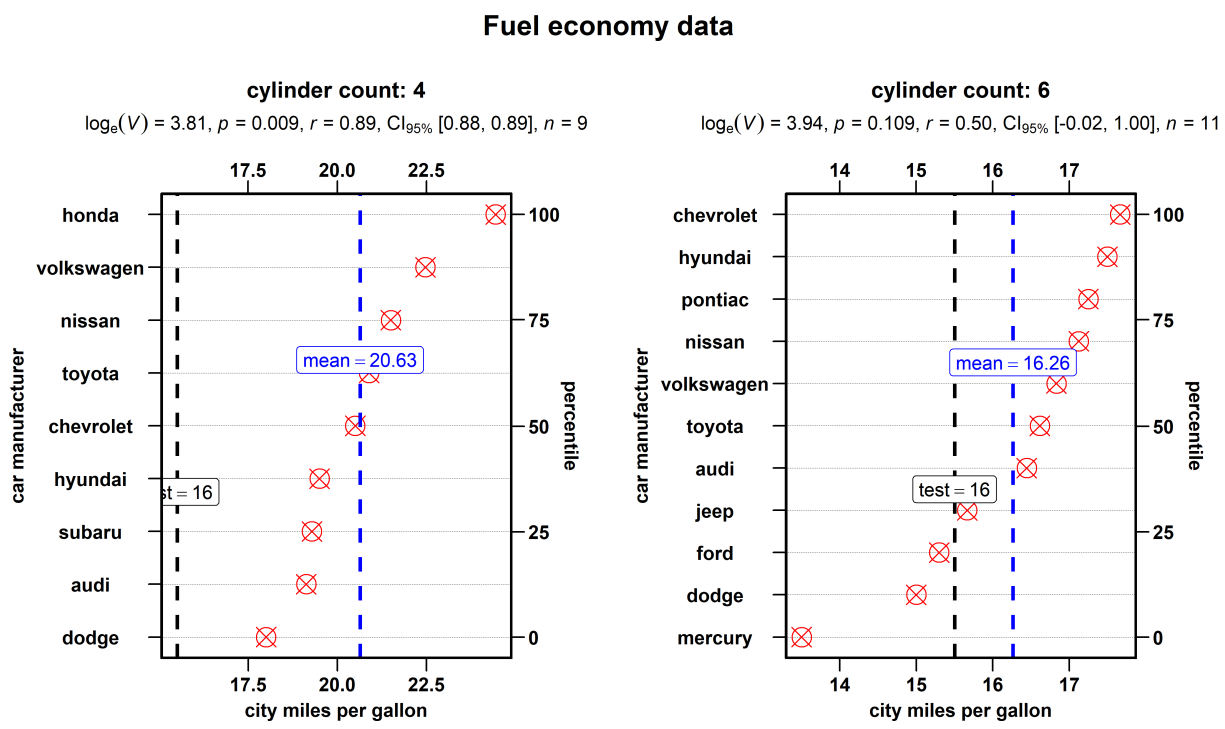
```
# for reproducibility
set.seed(123)

# plot
ggdotplotstats(
  data = dplyr::filter(.data = gapminder::gapminder, continent == "Asia"),
  y = country,
  x = lifeExp,
  test.value = 55,
  test.value.line = TRUE,
  test.line.labeller = TRUE,
  test.value.color = "red",
  centrality.para = "median",
  centrality.k = 0,
  title = "Distribution of life expectancy in Asian continent",
  xlab = "Life expectancy",
  messages = FALSE,
  caption = substitute(
    paste(
      italic("Source"),
      ": Gapminder dataset from https://www.gapminder.org/"
    )
  )
)
```



As with the rest of the functions in this package, there is also a `grouped_` variant of this function to facilitate looping the same operation for all levels of a single grouping variable.

```
# for reproducibility
set.seed(123)
```

```
# removing factor level with very few no. of observations
df <- dplyr::filter(.data = ggplot2::mpg, cyl %in% c("4", "6"))

# plot
ggstatsplot::grouped_ggdotplotstats(
  data = df,
  x = cty,
  y = manufacturer,
  xlab = "city miles per gallon",
  ylab = "car manufacturer",
  type = "nonparametric", # non-parametric test
  grouping.var = cyl, # grouping variable
  test.value = 15.5,
  title.prefix = "cylinder count",
  point.color = "red",
  point.size = 5,
  point.shape = 13,
  test.value.line = TRUE,
  ggtheme = ggthemes::theme_par(),
  messages = FALSE,
  title.text = "Fuel economy data"
)
```



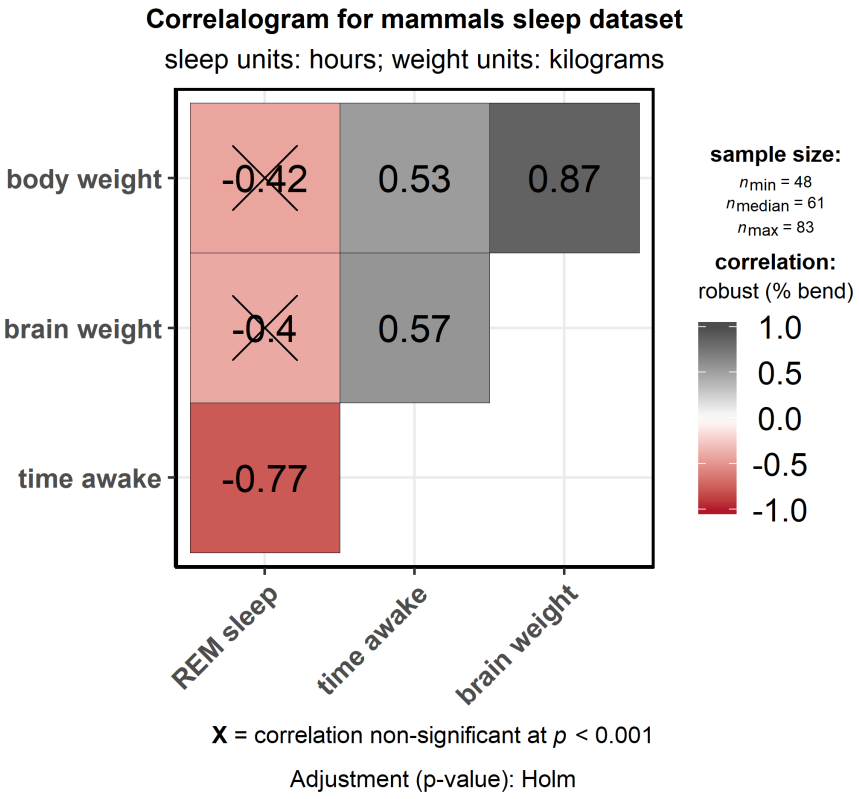
Summary of tests

This is identical to summary of tests for `gghistostats`.

ggcorrmat

`ggcorrmat` makes a correlalogram (a matrix of correlation coefficients) with minimal amount of code. Just sticking to the defaults itself produces publication-ready correlation matrices. But, for the sake of exploring the available options, let's change some of the defaults. For example, multiple aesthetics-related arguments can be modified to change the appearance of the correlation matrix.

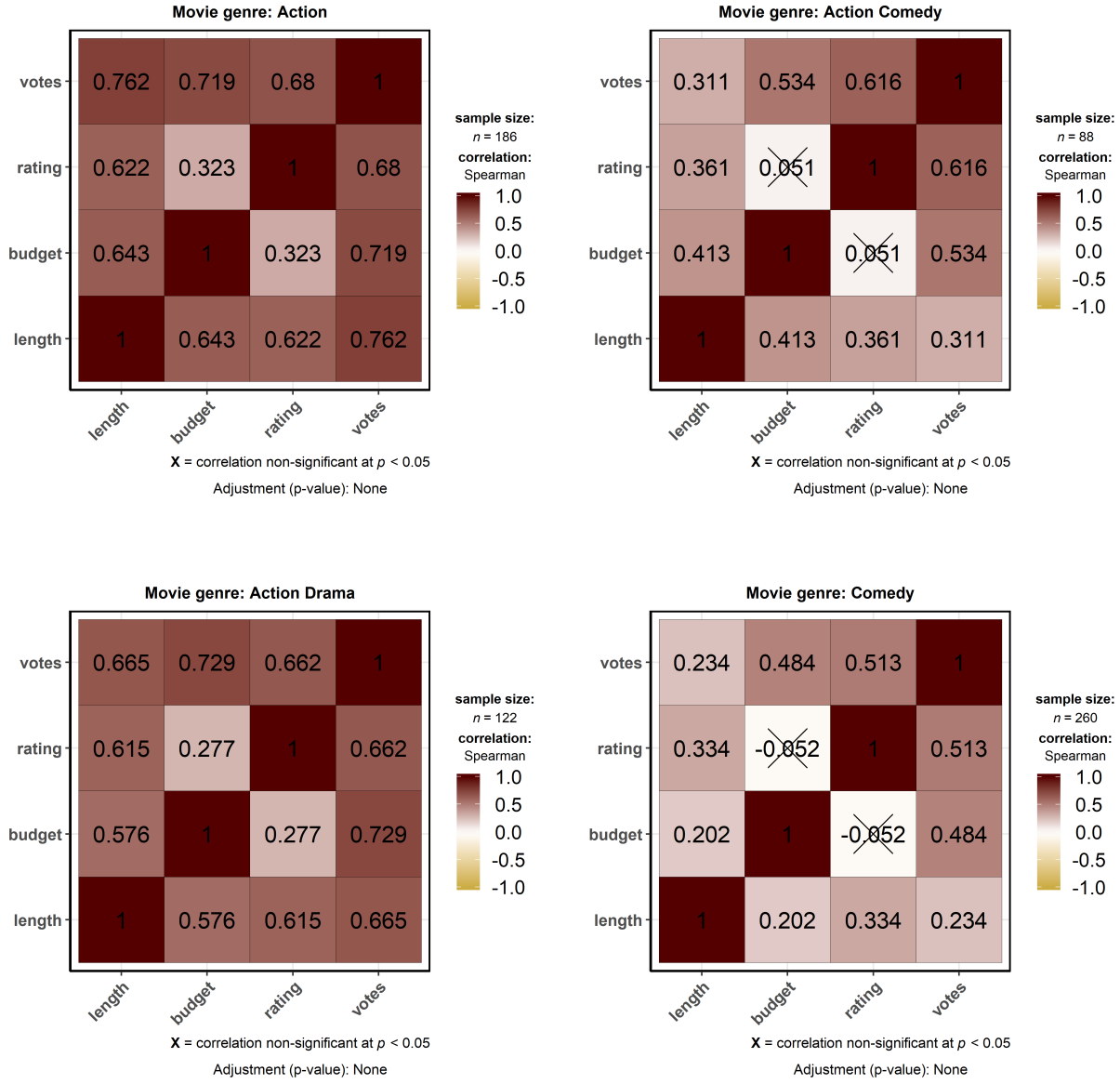
```
# for reproducibility
set.seed(123)

# as a default this function outputs a correlalogram plot
ggstatsplot::ggcorrmat(
  data = ggplot2::msleep,
  corr.method = "robust", # correlation method
  sig.level = 0.001, # threshold of significance
  p.adjust.method = "holm", # p-value adjustment method for multiple comparisons
  cor.vars = c(sleep_rem, awake:bodywt), # a range of variables can be selected
  cor.vars.names = c(
    "REM sleep", # variable names
    "time awake",
    "brain weight",
    "body weight"
  ),
  matrix.type = "upper", # type of visualization matrix
  colors = c("#B2182B", "white", "#4D4D4D"),
  title = "Correlalogram for mammals sleep dataset",
  subtitle = "sleep units: hours; weight units: kilograms"
)
```



Note that if there are `NA`s present in the selected variables, the legend will display minimum, median, and maximum number of pairs used for correlation tests.

There is a `grouped_` variant of this function that makes it easy to repeat the same operation across a **single** grouping variable:

```
# for reproducibility
set.seed(123)

# plot
# let's use only 50% of the data to speed up the process
ggstatsplot::grouped_ggcorrmat(
  data = dplyr::filter(
    .data = ggstatsplot::movies_long,
    genre %in% c("Action", "Action Comedy", "Action Drama", "Comedy")
  ),
  cor.vars = length:votes,
  corr.method = "np",
  colors = c("#cbac43", "white", "#550000"),
  grouping.var = genre, # grouping variable
  digits = 3, # number of digits after decimal point
  title.prefix = "Movie genre",
  messages = FALSE,
  nrow = 2
)
```



Summary of tests

Following tests are carried out for each type of analyses. Additionally, the correlation coefficients (and their confidence intervals) are used as effect sizes-

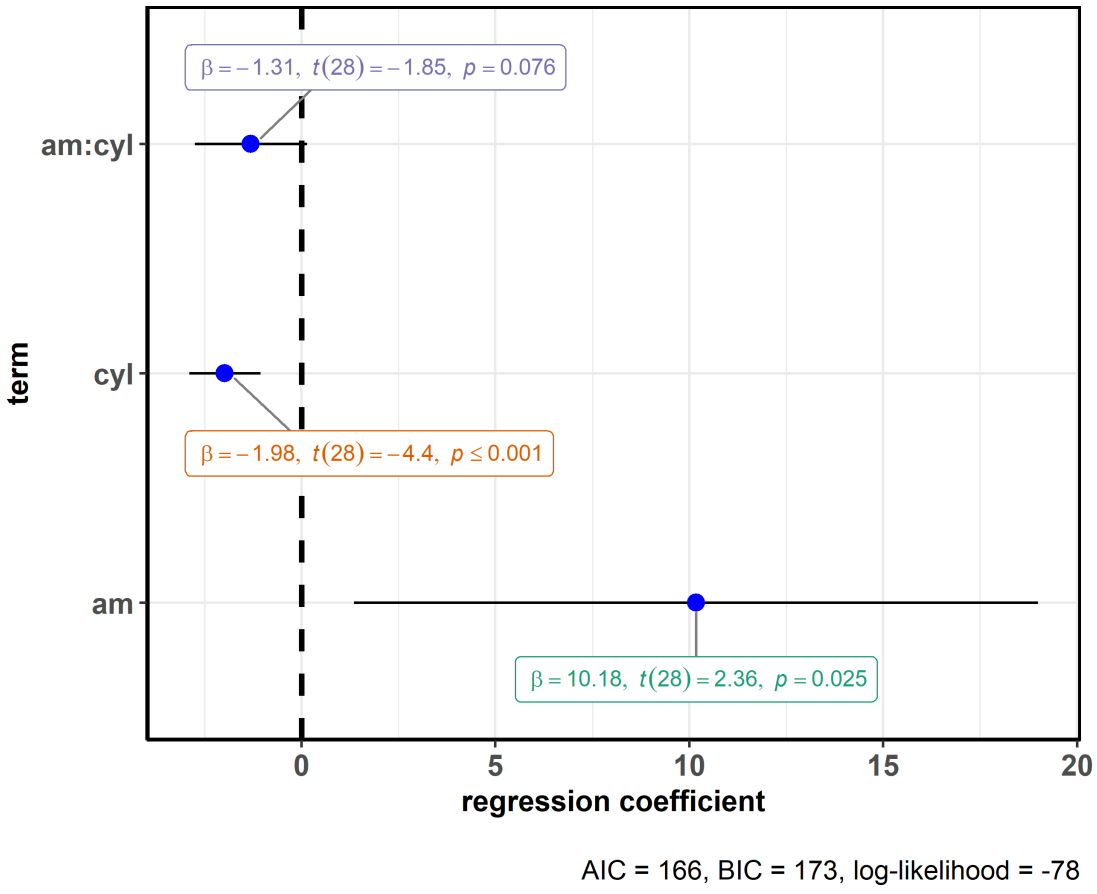
Type	Test	CI?
Parametric	Pearson's correlation coefficient	Yes
Non-parametric	Spearman's rank correlation coefficient	Yes
Robust	Percentage bend correlation coefficient	No
Bayes Factor	Pearson's correlation coefficient	No

For examples and more information, see the `ggcorrmat` vignette: https://indrajeetpatil.github.io/ggstatsplot/articles/web_only/ggcorrmat.html

ggcoefstats

`ggcoefstats` creates a dot-and-whisker plot point estimates for regression coefficients as dots with confidence intervals as whiskers.

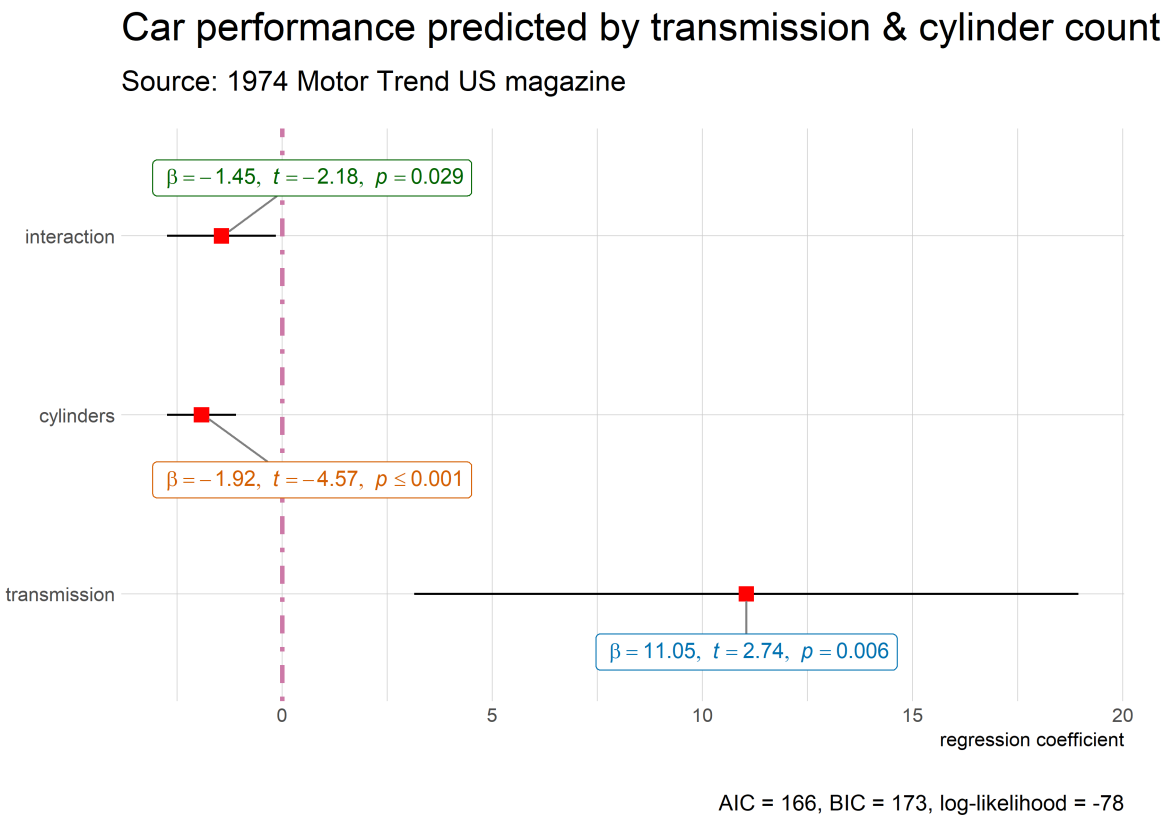
```
# for reproducibility
set.seed(123)

# model
mod <- stats::lm(
  formula = mpg ~ am * cyl,
  data = mtcars
)

# plot
ggstatsplot::ggcoefstats(x = mod)
```



This default plot can be further modified to one's liking with additional arguments (also, let's use a robust linear model instead of a simple linear model now):

```
# for reproducibility
set.seed(123)

# model
mod <- MASS::rlm(
```

```
  formula = mpg ~ am * cyl,
  data = mtcars
)

# plot
ggstatsplot::ggcoefstats(
  x = mod,
  point.color = "red",
  point.shape = 15,
  vline.color = "#CC79A7",
  vline.linetype = "dotdash",
  stats.label.size = 3.5,
  stats.label.color = c("#0072B2", "#D55E00", "darkgreen"),
  title = "Car performance predicted by transmission & cylinder count",
  subtitle = "Source: 1974 Motor Trend US magazine",
  ggtheme = hrbrthemes::theme_ipsum_ps(),
  ggstatsplot.layer = FALSE
) + # further modification with the ggplot2 commands
  # note the order in which the labels are entered
  ggplot2::scale_y_discrete(labels = c("transmission", "cylinders", "interaction")) +
  ggplot2::labs(
    x = "regression coefficient",
    y = NULL
  )
```



Most of the regression models that are supported in the `broom` and `broom.mixed` packages with `tidy` and `glance` methods are also supported by `ggcoefstats`. For example-

`aareg`, `anova`, `aov`, `aovlist`, `Arima`, `bigglm`, `biglm`, `brmsfit`, `btergm`, `cch`, `clm`, `clmm`, `confusionMatrix`, `coxph`, `drc`, `emmGrid`, `epi.2by2`, `ergm`, `felm`, `fitdistr`, `glmerMod`, `glmmTMB`, `gls`, `gam`, `Gam`, `gamlss`, `garch`, `glm`, `glmmadmb`, `glmmPQL`, `glmmTMB`, `glmRob`, `glmrob`, `gmm`, `ivreg`, `lm`, `lm.beta`, `lmerMod`, `lmodel2`, `lmRob`, `lmrob`, `mcmc`, `MCMCglmm`, `mediate`, `mjoint`, `mle2`, `mlm`, `multinom`, `negbin`, `nlmerMod`, `nlrq`, `nls`, `orcutt`, `plm`, `polr`, `ridgelm`, `rjags`, `rlm`, `rlmerMod`, `rq`, `speedglm`, `speedlm`, `stanreg`, `survreg`, `svyglm`, `svyolr`, `svyglm`, etc.

Although not shown here, this function can also be used to carry out both frequentist and Bayesian random-effects meta-analysis.

For a more exhaustive account of this function, see the associated vignette- https://indrajeetpatil.github.io/ggstatsplot/articles/web_only/ggcoefstats.html

combine_plots

`ggstatsplot` contains a helper function `combine_plots` to combine multiple plots, which can be useful for combining a list of plots produced with `purrr`. This is a wrapper around `cowplot::plot_grid` and lets you combine multiple plots and add a combination of title, caption, and annotation texts with suitable defaults.

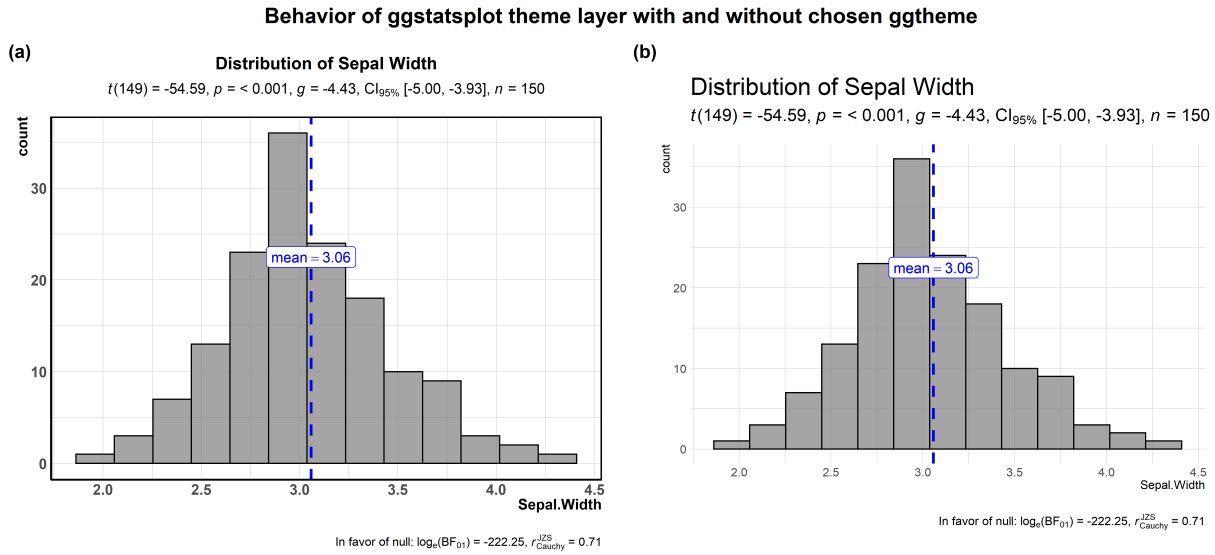
For examples (both with `plyr` and `purrr`), see the associated vignette- https://indrajeetpatil.github.io/ggstatsplot/articles/web_only/combine_plots.html

theme_ggstatsplot

All plots from `ggstatsplot` have a default theme: `theme_ggstatsplot`. You can change this theme by using the `ggtheme` argument. It is important to note that irrespective of which `ggplot` theme you choose, `ggstatsplot` in the backdrop adds a new layer with its idiosyncratic theme settings, chosen to make the graphs more readable or aesthetically pleasing.

Let's see an example with `gghistostats` and see how a certain theme from `hrbrthemes` package looks like with and without the `ggstatsplot` layer.

```
set.seed(123)
# to use hrbrthemes themes, first make sure you have all the necessary fonts
library(hrbrthemes)

# try this yourself
ggstatsplot::combine_plots(
  # with the ggstatsplot layer
  ggstatsplot::gghistostats(
    data = iris,
    x = Sepal.Width,
    messages = FALSE,
    title = "Distribution of Sepal Width",
    test.value = 5,
    ggtheme = hrbrthemes::theme_ipsum(),
    ggstatsplot.layer = TRUE
  ),
  # without the ggstatsplot layer
  ggstatsplot::gghistostats(
    data = iris,
    x = Sepal.Width,
    messages = FALSE,
    title = "Distribution of Sepal Width",
    test.value = 5,
    ggtheme = hrbrthemes::theme_ipsum_ps(),
    ggstatsplot.layer = FALSE
  ),
  nrow = 1,
  labels = c("(a)", "(b)"),
  title.text = "Behavior of ggstatsplot theme layer with and without chosen ggtheme"
)
```



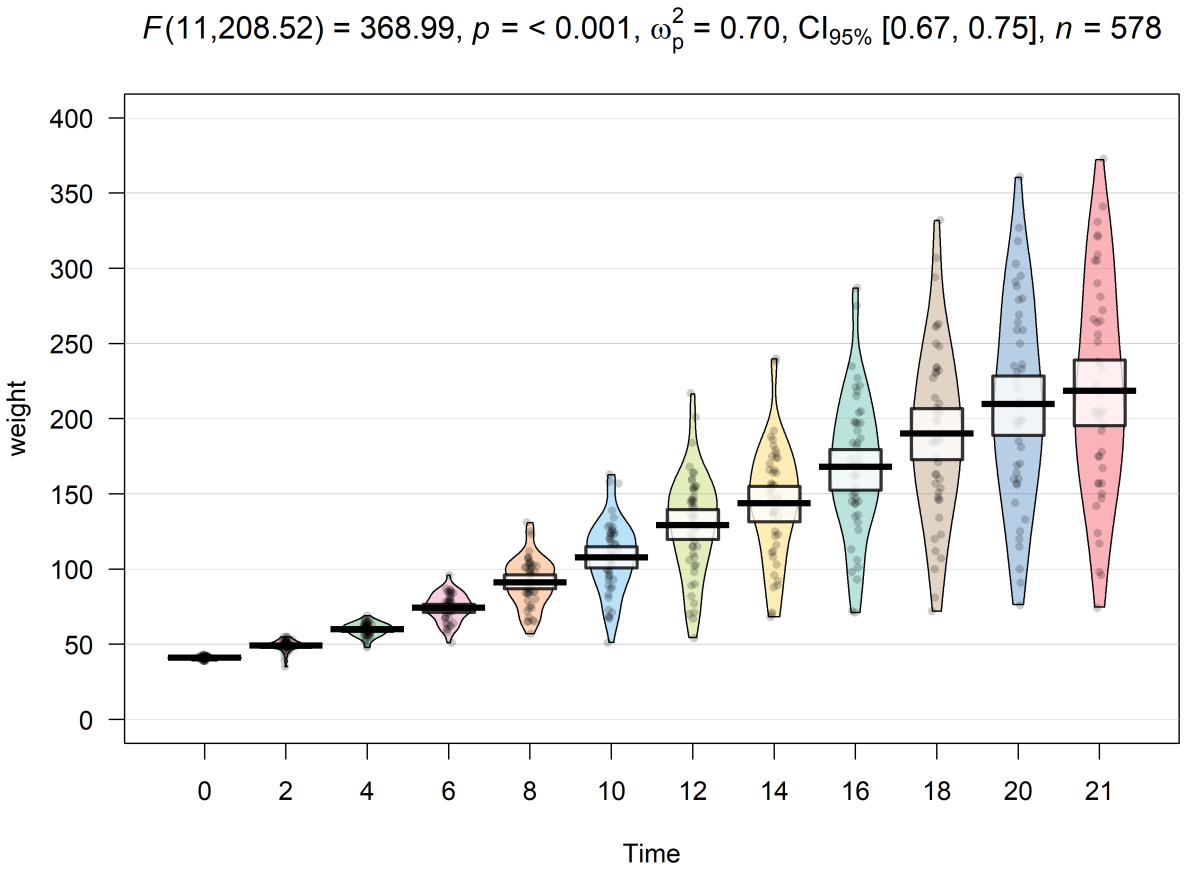
For more on how to modify it, see the associated vignette- https://indrajeetpatil.github.io/ggstatsplot/articles/web_only/theme_ggstatsplot.html

Working with custom plots

Sometimes you may not like the defaults in a plot produced by `ggstatsplot`. In such cases, you can use other custom plots (from `ggplot2` or other plotting packages) and still use `ggstatsplot` functions to display results from relevant statistical test.

For example, in the following chunk, we will create plot (*pirateplot*) using `yarrr` package and use `ggstatsplot` function for extracting results.

```
# for reproducibility
set.seed(123)

# loading the needed libraries
library(yarrr)
library(ggstatsplot)

# using `ggstatsplot` to get call with statistical results
stats_results <-
  ggstatsplot::ggbetweenstats(
    data = ChickWeight,
    x = Time,
    y = weight,
    return = "subtitle",
    messages = FALSE
  )

# using `yarrr` to create plot
yarrr::pirateplot(
  formula = weight ~ Time,
  data = ChickWeight,
  theme = 1,
  main = stats_results
)
```



Graphical integrity (and clean design)

Graphical excellence consists of communicating complex ideas with clarity and in a way that the viewer understands the greatest number of ideas in a short amount of time all the while not quoting the data out of context. The package follows the principles for **graphical integrity** (as outlined in Tufte, 2001):

- The physical representation of numbers is proportional to the numerical quantities they represent (e.g., Figure-1 and Figure-2 show how means (in `ggbetweenstats`) or percentages (`ggpiestats`) are proportional to the vertical distance or the area, respectively).
- All important events in the data have clear, detailed, and thorough labeling (e.g., Figure-1 plot shows how `ggbetweenstats` labels means, sample size information, outliers, and pairwise comparisons; same can be appreciated for `ggpiestats` in Figure-2 and `gghistostats` in Figure-5). Note that data labels in the data region are designed in a way that they don't interfere with our ability to assess the overall pattern of the data (Cleveland, 1985; p.44-45). This is achieved by using `ggrepel` package to place labels in a way that reduces their visual prominence.
- None of the plots have *design* variation (e.g., abrupt change in scales) over the surface of a same graphic because this can lead to a false impression about variation in *data*.
- The number of information-carrying dimensions never exceed the number of dimensions in the data (e.g., using area to show one-dimensional data).
- All plots are designed to have no **chartjunk** (like moiré vibrations, fake perspective, dark grid lines, etc.) (Tufte, 2001, Chapter 5).

There are some instances where `ggstatsplot` graphs don't follow principles of clean graphics, as formulated in the Tufte theory of data graphics (Tufte, 2001, Chapter 4). The theory has four key principles:

1. Above all else show the data.
2. Maximize the data-ink ratio.
3. Erase non-data-ink.
4. Erase redundant data-ink, within reason.

In particular, default plots in `ggstatsplot` can sometimes violate one of the principles from 2-4. According to these principles, every bit of ink should have reason for its inclusion in the graphic and should convey some new information to the viewer. If not, such ink should be removed. One instance of this is bilateral symmetry of data measures. For example, in Figure-1, we can see that both the box and violin plots are mirrored, which consumes twice the space in the graphic without adding any new information. But this redundancy is tolerated for the sake of beauty that such symmetrical shapes can bring to the graphic. Even Tufte admits that efficiency is but one consideration in the design of statistical graphics (Tufte, 2001, p. 137). Additionally, these principles were formulated in an era in which computer graphics had yet to revolutionize the ease with which graphics could be produced and thus some of the concerns about minimizing data-ink for easier production of graphics are not as relevant as they were.

Statistical analysis

As an extension of `ggplot2`, `ggstatsplot` has the same expectations about the structure of the data. More specifically,

- The `data` should be an object of class `data.frame` (a `tibble` dataframe will also work).
- The data should be organized following the principles of *tidy data*, which specify how statistical structure of a data frame (variables and observations) should be mapped to physical structure (columns and rows). More specifically, tidy data means all variables have their own columns and each row corresponds to a unique observation (Wickham, 2014).
- All `ggstatsplot` functions remove `NA`s from variables of interest (similar to `ggplot2`; Wickham, 2016, p.207) in the data and display total sample size (n, either observations for between-subjects or pairs for within-subjects designs) in the subtitle to inform the user/reader about the number of observations included for both the statistical analysis and the visualization. But, when sample sizes differ *across* tests in the same function, `ggstatsplot` makes an effort to inform the user of this aspect. For example, `ggcorrmat` features several correlation test pairs and, depending on variables in a given pair, the sample sizes may vary (Figure-4).

```
# creating a new dataset without any NAs in variables of interest
msleep_no_na <-
  dplyr::filter(
    .data = ggplot2::msleep,
    !is.na(sleep_rem),
    !is.na(awake),
    !is.na(brainwt),
    !is.na(bodywt)
  )

# variable names vector
var_names <- c(
  "REM sleep",
  "time awake",
  "brain weight",
  "body weight"
)
```

```
# combining two plots
ggstatsplot::combine_plots(
  # plot *without* any NAs
  ggstatsplot::ggcorrmat(
    data = msleep_no_na,
    corr.method = "kendall",
    sig.level = 0.001,
    p.adjust.method = "holm",
    cor.vars = c(sleep_rem, awake:bodywt),
    cor.vars.names = var_names,
    matrix.type = "upper",
    colors = c("#B2182B", "white", "#4D4D4D"),
    title = "Correlalogram for mammals sleep dataset",
    subtitle = "sleep units: hours; weight units: kilograms",
    messages = FALSE
  ),
  # plot *with* NAs
  ggstatsplot::ggcorrmat(
    data = ggplot2::msleep,
    corr.method = "kendall",
    sig.level = 0.001,
    p.adjust.method = "holm",
    cor.vars = c(sleep_rem, awake:bodywt),
    cor.vars.names = var_names,
    matrix.type = "upper",
    colors = c("#B2182B", "white", "#4D4D4D"),
    title = "Correlalogram for mammals sleep dataset",
    subtitle = "sleep units: hours; weight units: kilograms",
    messages = FALSE
  ),
  labels = c("(a)", "(b)"),
  nrow = 1
)
```

Types of statistics supported

Functions	Description	Parametric	Non-parametric	Robust	Bayes Factor
`ggbetweenstats`	Between group/condition comparisons	✓	✓	✓	✓
`ggwithinstats`	Within group/condition comparisons	✓	✓	✓	✓
`gghistostats`, `ggdotplotstats`	Distribution of a numeric variable	✓	✓	✓	✓
`ggcorrmat`	Correlation matrix	✓	✓	✓	×
`ggscatterstats`	Correlation between two variables	✓	✓	✓	✓
`ggpiestats`, `ggbarstats`	Association between categorical variables	✓	`NA`	`NA`	✓
`ggpiestats`, `ggbarstats`	Equal proportions for categorical variable levels	✓	`NA`	`NA`	×
`ggcoefstats`	Regression model coefficients	✓	×	✓	×

Types of statistical tests supported

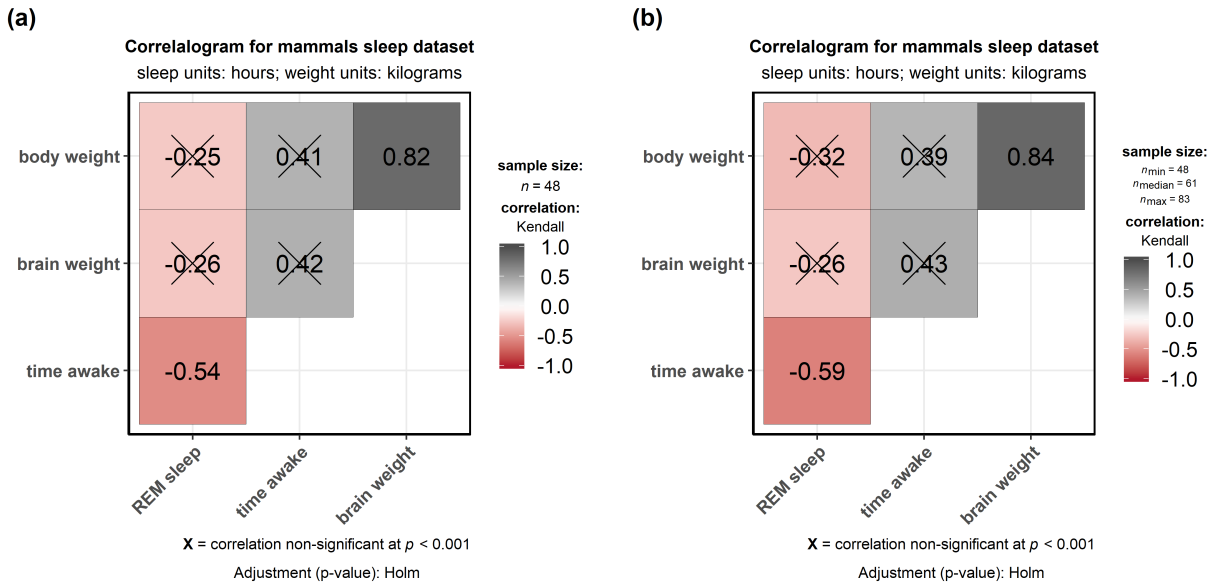


Figure 2: **Figure-4**. 'ggstatsplot' functions remove 'NA's from variables of interest and display total sample size *n*, but they can give more nuanced information about sample sizes when *n* differs across tests. For example, 'ggcorrmat' will display (a) only one total sample size once when no 'NA's present, but (b) will instead show minimum, median, and maximum sample sizes across all correlation tests when 'NA's are present across correlation variables.

Functions	Type	Test	Effect size	95% CI available?
`ggbetweenstats`	Parametric	Student's and Welch's t-test	Cohen's d, Hedge's g	✓
`ggbetweenstats`	Parametric	Fisher's and Welch's one-way ANOVA	$\eta^2, \eta_p^2, \omega^2, \omega_p^2$	✓
`ggbetweenstats`	Non-parametric	Mann-Whitney U-test	r	✓
`ggbetweenstats`	Non-parametric	Kruskal-Wallis Rank Sum Test	ϵ^2	✓
`ggbetweenstats`	Robust	Yuen's test for trimmed means	ξ	✓
`ggbetweenstats`	Robust	Heteroscedastic one-way ANOVA for trimmed means	ξ	✓
`ggwithinstats`	Parametric	Student's t-test	Cohen's d, Hedge's g	✓
`ggwithinstats`	Parametric	Fisher's one-way repeated measures ANOVA	η_p^2, ω^2	✓
`ggwithinstats`	Non-parametric	Wilcoxon signed-rank test	r	✓

Functions	Type	Test	Effect size	95% CI available?
`ggwithinstats`	Non-parametric	Friedman test	$W_{Kendall}$	✓
`ggwithinstats`	Robust	Yuen's test on trimmed means for dependent samples	ξ	✓
`ggwithinstats`	Robust	Heteroscedastic one-way repeated measures ANOVA for trimmed means	×	×
`ggpiestats`	Parametric	Pearson's χ^2 test	Cramér's V	✓
`ggpiestats`	Parametric	McNemar's test	Cohen's g	✓
`ggpiestats`	Parametric	One-sample proportion test	Cramér's V	✓
`ggscatterstats`/`ggcorrmat`	Parametric	Pearson's r	r	✓
`ggscatterstats`/`ggcorrmat`	Non-parametric	Spearman's ρ	ρ	✓
`ggscatterstats`/`ggcorrmat`	Robust	Percentage bend correlation	r	✓
`gghistostats`/`ggdotplotstats`	Parametric	One-sample t-test	Cohen's d, Hedge's g	✓
`gghistostats`	Non-parametric	One-sample Wilcoxon signed rank test	r	✓
`gghistostats`/`ggdotplotstats`	Robust	One-sample percentile bootstrap	robust estimator	✓
`gghistostats`/`ggdotplotstats`	Bayesian	Regression models	β	✓

For the `ggbetweenstats` function, the following post-hoc tests are available for (adjusted) pairwise multiple comparisons:

Type	Design	Equal variance assumed?	Pairwise comparison test	p-value adjustment?
Parametric	between-subjects	No	Games-Howell test	✓
Parametric	between-subjects	Yes	Student's t-test	✓
Parametric	within-subjects	`NA`	Student's t-test	✓
Non-parametric	between-subjects	No	Dwass-Steel-Crichtlow-Fligner test	✓
Non-parametric	within-subjects	No	Durbin-Conover test	✓
Robust	between-subjects	No	Yuen's two-sample trimmed means t-test	✓
Robust	within-subjects	`NA`	Yuen's trimmed means test	✓
Bayes Factor	between-subjects	No	×	×
Bayes Factor	between-subjects	Yes	×	×
Bayes Factor	within-subjects	`NA`	×	×

Note-

- `NA`: not applicable
- available methods for *p*-value adjustment: "holm", "hochberg", "hommel", "bonferroni", "BH", "BY", "fdr", "none"

Statistical variation

One of the important functions of a plot is to show the variation in the data, which comes in two forms:

- **Measurement noise**: In `ggstatsplot`, the actual variation in measurements is shown by plotting a combination of (jittered) raw data points with a boxplot laid on top (Figure-1) or a histogram (Figure-5). None of the plots, where empirical distribution of the data is concerned, show the sample standard deviation because they are poor at conveying information about limits of the sample and presence of outliers (Cleveland, 1985, p.220).

```
# for reproducibility
set.seed(123)

# plot
ggstatsplot::gghistostats(
  data = morley,
  x = Speed,
  test.value = 792,
  test.value.line = TRUE,
  xlab = "Speed of light (km/sec, with 299000 subtracted)",
  title = "Figure-5: Distribution of Speed of light",
  caption = "Note: Data collected across 5 experiments (20 measurements each)",
  messages = FALSE
)
```

- **Sample-to-sample statistic variation**: Although, traditionally, this variation has been shown using the standard error of the mean (SEM) of the statistic, `ggstatsplot` plots instead use 95% confidence intervals (e.g., Figure-6). This is because the interval formed by error bars correspond to a 68% confidence interval, which is not a particularly interesting interval (Cleveland, 1985, p.222-225).

```
# for reproducibility
set.seed(123)

# creating model object
mod <- lme4::lmer(
  formula = total.fruits ~ nutrient + rack + (nutrient | popu / gen),
  data = lme4::Arabidopsis
)
#> boundary (singular) fit: see ?isSingular

# plot
ggstatsplot::ggcoefstats(
  x = mod,
  p.kr = FALSE
)
#> Computing p-values via Wald-statistics approximation (treating t as Wald z).
```

Reporting results

The default setting in `ggstatsplot` is to produce plots with statistical details included. Most often than not, the results are displayed as a `subtitle` in the plot. Great care has been taken into which details are

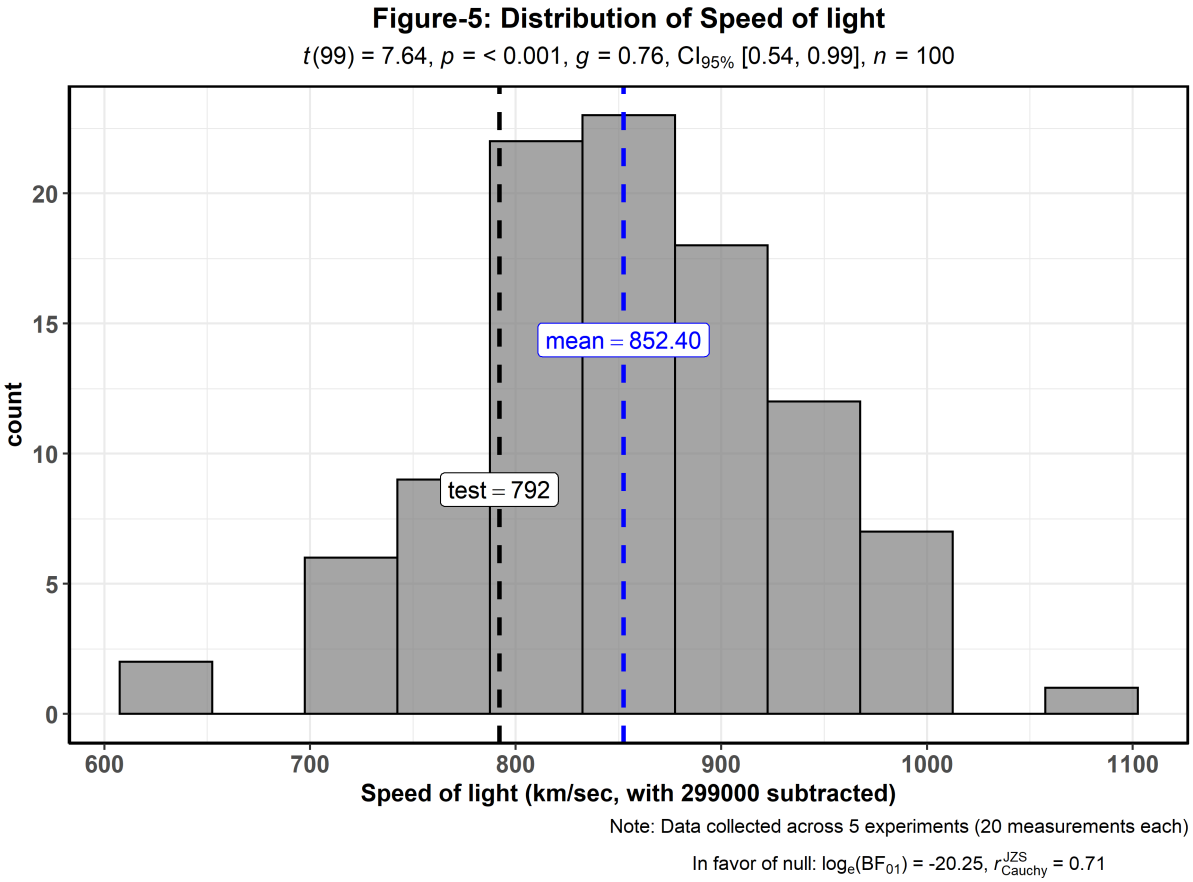


Figure 3: **Figure-5**. Distribution of a variable shown using ‘gghistostats‘.

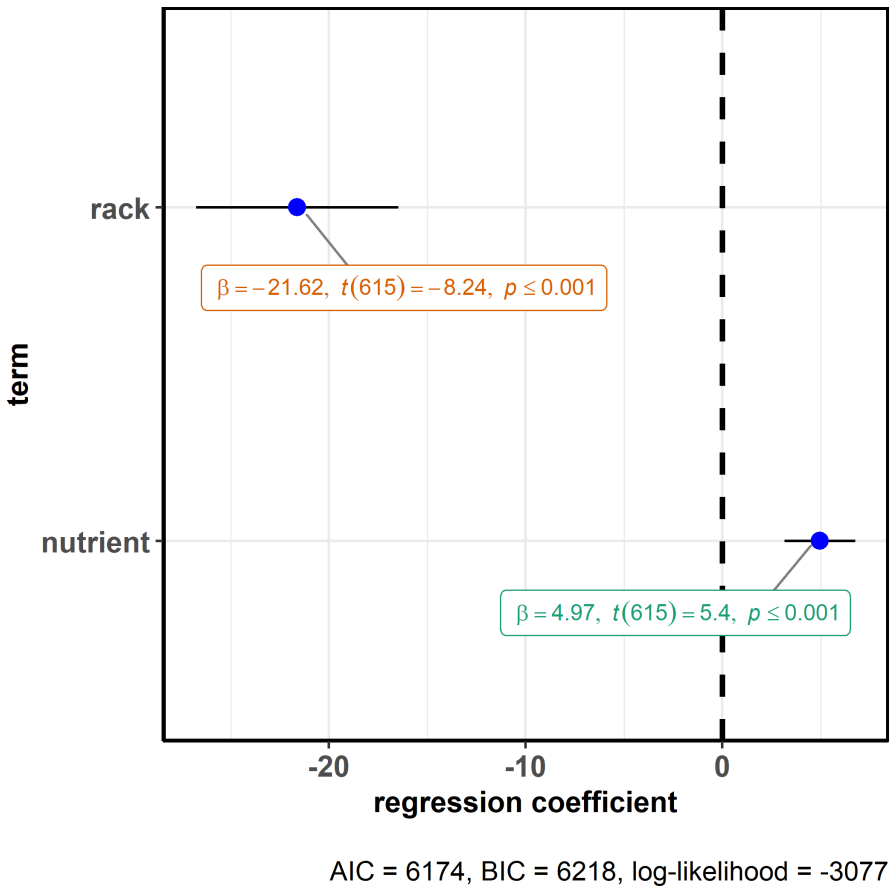


Figure 4: **Figure-6**. Sample-to-sample variation in regression estimates is displayed using confidence intervals in ‘ggcoefstats‘.

included in statistical reporting and why.

1. **APA guidelines** (APA, 2009) are followed (for the most part) by default:

- Percentages are displayed with no decimal places (Figure-2).
- Correlations, t-tests, and χ^2-tests are reported with the degrees of freedom in parentheses and the significance level (Figure-2, Figure-3b, Figure-5).
- ANOVAs are reported with two degrees of freedom and the significance level (Figure-1).
- Regression results are presented with the unstandardized or standardized estimate (beta), whichever was specified by the user, along with the statistic (depending on the model, this can be a t or z statistic) and the corresponding significance level (Figure-6).
- With the exception of p-values, most statistics are rounded to two decimal places by default.

2. Default statistical tests:

3. Dealing with **null results**:

4. Avoiding the **"p-value error"**:
   The p-value indexes the probability that the researchers have falsely rejected a true null hypothesis (Type I error, i.e.) and can rarely be *exactly* 0. And yet over 97,000 manuscripts on Google Scholar report the p-value to be `p = 0.000` (Lilienfeld et al., 2015), putatively due to relying on default computer outputs. All p-values displayed in `ggstatsplot` plots avoid this mistake. Anything less than `p < 0.001` is displayed as such (e.g, Figure-1). The package deems it unimportant how infinitesimally small the p-values are and, instead, puts emphasis on the effect size magnitudes and their 95% CIs.

Usage and syntax simplicity

Overall consistency in API

Attempt has been made to make the application program interface (API) consistent enough that no struggle is expected while thinking about specifying function calls-

- When a given function depends on variables in a dataframe, `data` argument must always be specified.
- Often, package functions relevant for between-subjects versus within-subjects design expect tidy/long versus Cartesian/wide format data, respectively. `ggstatsplot` functions consistently expect tidy/long form data.
- All functions accept both quoted (`x = "var1"`) and unquoted (`x = var1`) arguments.

These set principles combined with the fact that almost all functions produce publication-ready plots that require very few arguments if one finds the aesthetic and statistical defaults satisfying make the syntax much less cognitively demanding and easy to remember/reconstruct.

Helpful messages and aesthetic modifications

`ggstatsplot` is a very chatty package and will by default print helpful notes on assumptions about statistical tests, warnings, etc. If you don't want your console to be cluttered with such messages, they can be turned off by setting argument `messages = FALSE` in the function call.

All relevant functions in `ggstatsplot` have a `return` argument which can be used to not only return plots (which is the default), but also to return a `subtitle` or `caption`, which are objects of type `call` and can be used to display statistical details in conjunction with a custom plot and at a custom location in the plot.

Additionally, all functions share the `ggtheme` and `palette` arguments that can be used to specify your favorite `ggplot` theme and color palette.

```r
# group difference tests - between-subjects
ggbetweenstats(data, x, y, ...)

# group difference tests - within-subjects
ggwithinstats(data, x, y, ...)

# correlation analyses
ggscatterstats(data, x, y, ...)

# correlation matrix
ggcorrmat(data, ...)

# numeric variable
gghistostats(data, x, ...)

# labelled numeric variable
ggdotplotstats(data, x, y, ...)

# contingency table analyses
ggpiestats(data, x, y, ...)
ggbarstats(data, x, y, ...)

# goodness of fit (proportion) tests
ggpiestats(data, x, ...)

# regression analyses
ggcoefstats(x, ...)
```

Figure 5: Consistent API

Appendix

Appendix A: Documentation

There are three main documents one can rely on to learn how to use `ggstatsplot`:

- **Presentation**: The quickest (and the most fun) way to get an overview of the philosophy behind this package and the offered functionality is to go through the following slides: https://indrajeetpatil.github.io/ggstatsplot_slides/slides/ggstatsplot_presentation.html#1
- **Manual**:
  The `CRAN` reference manual provides detailed documentation about arguments for each function and examples: https://cran.r-project.org/web/packages/ggstatsplot/ggstatsplot.pdf
- **Vignettes**:
  Vignettes contain probably the most detailed exposition. Every single function in `ggstatsplot` has an associated vignette which describes in depth how to use the function and modify the defaults to customize the plot to your liking. All these vignettes can be accessed from the package website: https://indrajeetpatil.github.io/ggstatsplot/articles/

Appendix B: Suggestions

If you find any bugs or have any suggestions/remarks, please file an issue on `GitHub` repository for this package: https://github.com/IndrajeetPatil/ggstatsplot/issues

Contributing

`ggstatsplot` is happy to receive bug reports, suggestions, questions, and (most of all) contributions to fix problems and add features. Pull Requests for contributions are encouraged.

Here are some simple ways in which one can contribute (in the increasing order of commitment):

- Read and correct any inconsistencies in the documentation
- Raise issues about bugs or wanted features
- Review code
- Add new functionality (in the form of new plotting functions or helpers for preparing subtitles)

Please note that this project is released with a Contributor Code of Conduct. By participating in this project you agree to abide by its terms.

Appendix D: Session information

For reproducibility purposes, the details about the session information in which this document was rendered, see- https://indrajeetpatil.github.io/ggstatsplot/articles/web_only/session_info.html

References

Nuijten, M. B., Hartgerink, C. H. J., van Assen, M. A. L. M., Epskamp, S., & Wicherts, J. M. (2016). The prevalence of statistical reporting errors in psychology (19852013). *Behavior Research Methods*, *48*(4), 1205–1226. https://doi.org/10.3758/s13428-015-0664-2