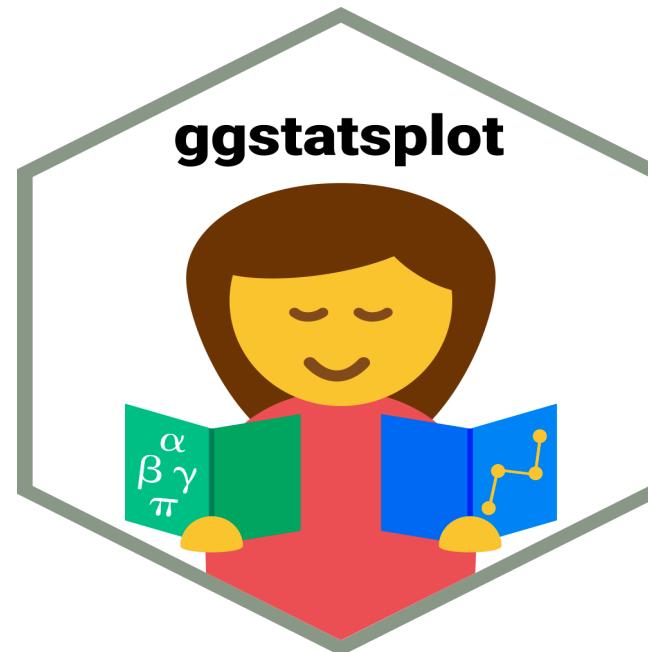


{ggstatsplot}: Informative Statistical Visualizations

Indrajeet Patil



Genesis

Why a new package?

Life in the trenches (c. 2017)

(as an academic researcher)

⚠ Large-scale problems

- **Replication crisis:**

“39% of effects were subjectively rated to have replicated the original result”¹

- **Reporting errors:**

“half of all published psychology papers contained at least one p -value that was inconsistent”²

- **Interpretation errors:**

“in 72% of cases, nonsignificant results were misinterpreted [to mean] that the effect was absent”³

⚠ Personal challenges

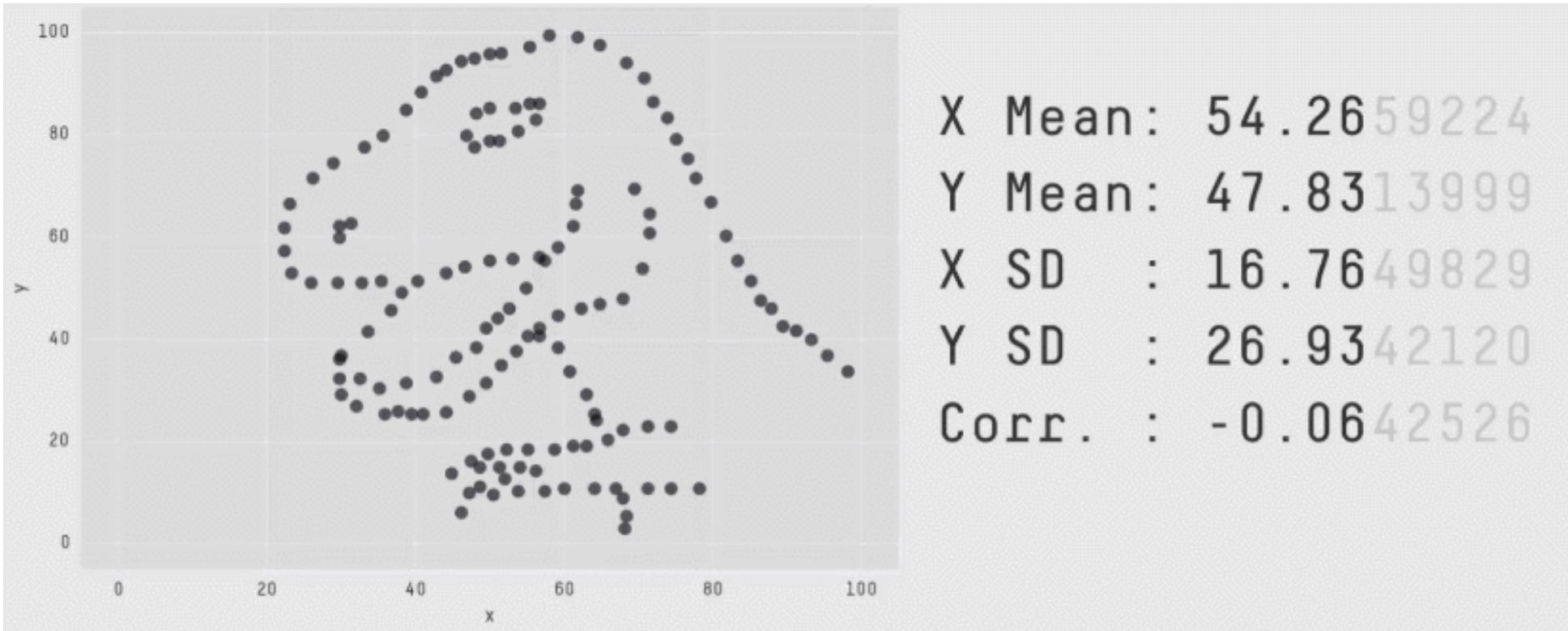


- How to increase reproducibility?
- How to avoid reporting errors?
- How to make visualizing data effortless?
- How to make statistical reporting more informative?
- How to emphasize the importance of the effect?
- How to interpret null results?
- How to easily assess validity of model assumptions?

Proposal

Information-rich, ready-made statistical visualizations

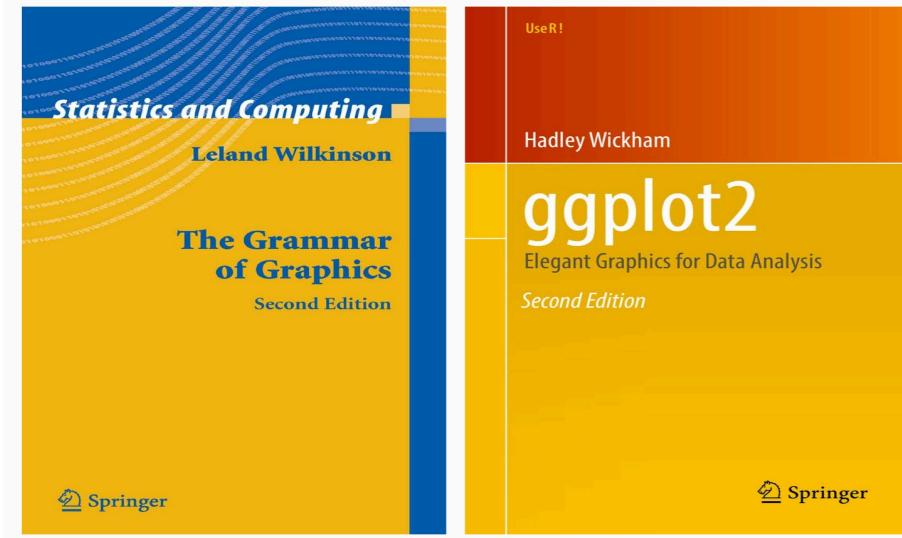
A rich graphic is worth a thousand words



Graphical summaries reveal problems not discernible from numerical statistics.

Lowering the activation energy

The grammar of graphics is a powerful framework and can help you make **any** data visualization!



💡 Using ready-made plots lowers the activation energy for visualizing data.

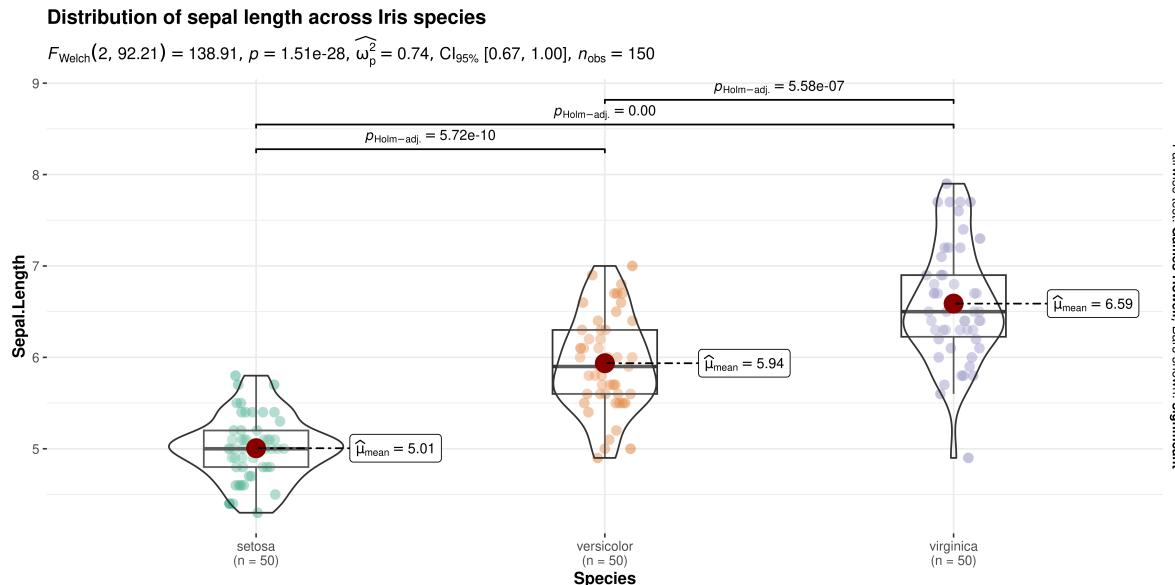
Action Plan

{ggstatsplot} was born!

Example function

E.g., for hypothesis about group differences ([ggbetweenstats\(\)](#))

```
1 ggbetweenstats(  
2   data = iris,  
3   x     = Species,  
4   y     = Sepal.Length,  
5   title = "Distribution of sepal length across Iris species"  
6 )
```



! Important

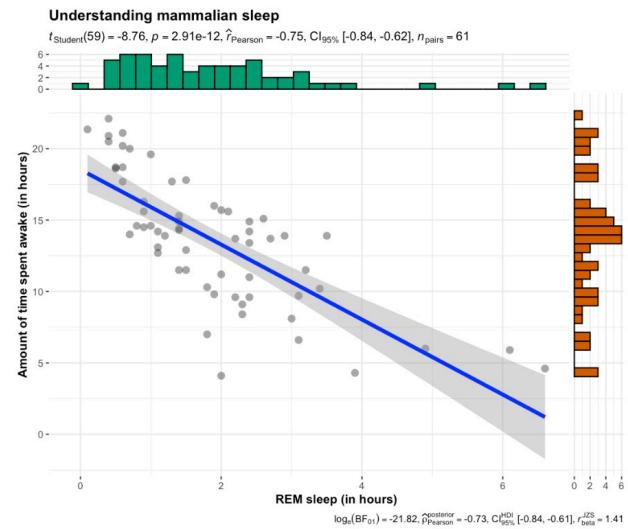
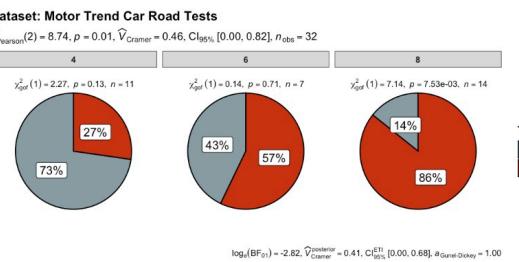
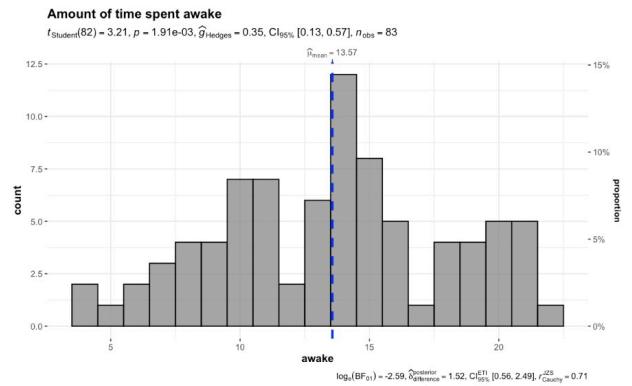
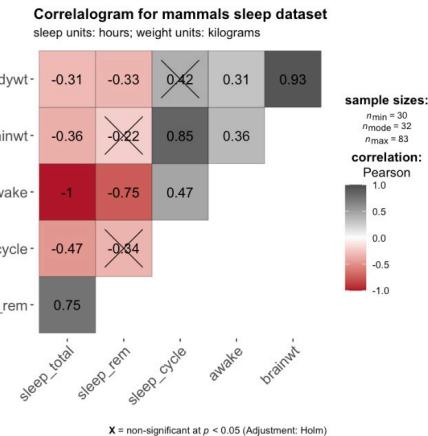
Information-rich defaults

- raw data + distributions
- descriptive statistics
- inferential statistics
- effect size + uncertainty
- pairwise comparisons
- Bayesian hypothesis-testing
- Bayesian estimation

Statistical approaches available

- parametric
- parametric
- robust
- Bayesian

And there is more!



Appendix provides exhaustive details for all functions.

Benefits

Contextual evaluation of models

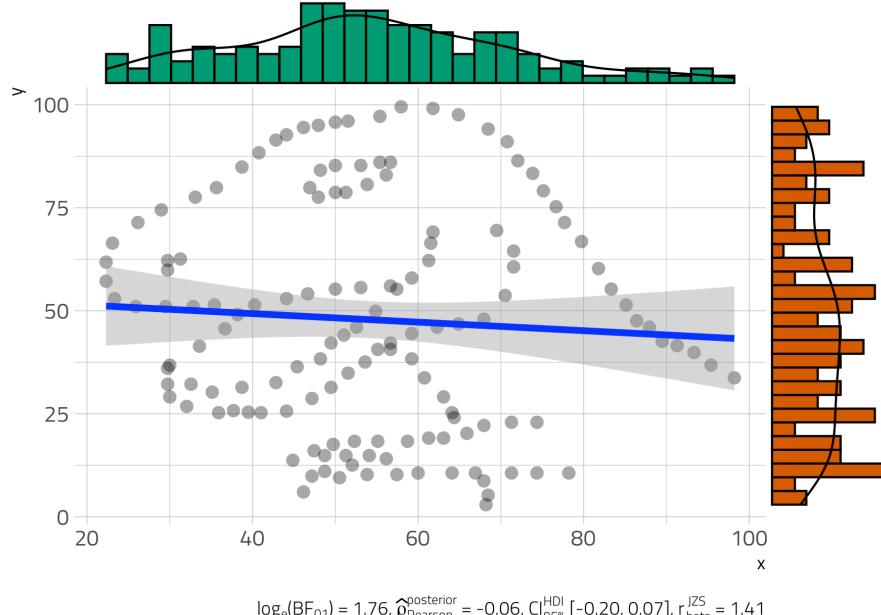
Without `{ggstatsplot}`

Pearson's correlation test revealed that, across 142 participants, variable `x` was negatively correlated with variable `y`: $t(140) = -0.76, p = .446$. The effect size ($r = -0.06, 95\%CI[-.23, .10]$) was small, as per Cohen's (1988) conventions. The Bayes Factor for the same analysis revealed that the data were 5.81 times more probable under the null hypothesis as compared to the alternative hypothesis. This can be considered moderate evidence (Jeffreys, 1961) in favor of the null hypothesis (absence of any correlation between `x` and `y`).

With `{ggstatsplot}`

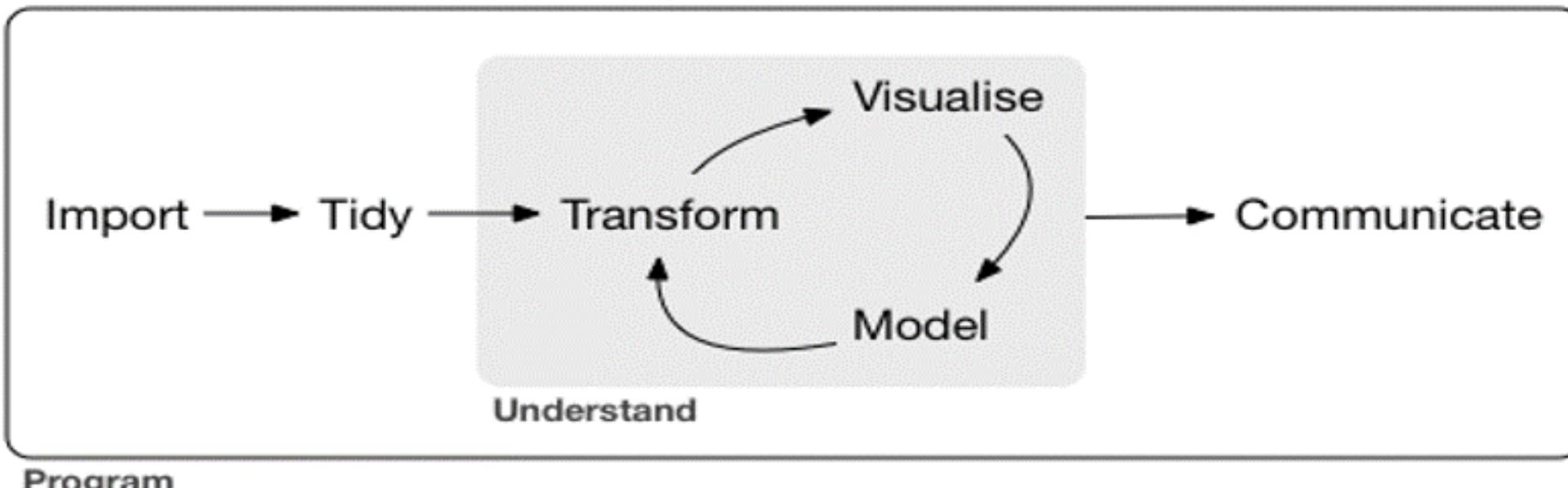
Relationship between `x` and `y`

$t_{Student}(140) = -0.76, p = 0.446, \hat{r}_{Pearson} = -0.06, CI_{95\%} [-0.23, 0.10], n_{pairs} = 142$



$\log_e(BF_{01}) = 1.76, \hat{r}_{Pearson}^{posterior} = -0.06, CI_{95\%}^{HDI} [-0.20, 0.07], r_{beta}^{JZS} = 1.41$

Simplified data analysis workflow



Typical *exploratory* data analysis workflow: visualization informs modeling, and modeling can suggest a different visualization, and so on and so forth.

`{ggstatsplot}` solidifies these two phases into one!

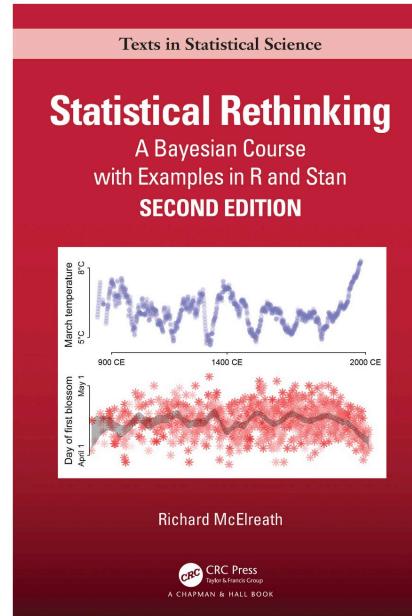
Critical Evaluation

Unintended consequences

The “Golem of Prague” problem

Promotes mindless application of statistical tests.

Easy-to-use software can lead to misuse.



Clunky API

- Too many arguments to remember.
- Not a “real” `{ggplot2}` extension.
- Limited number of functions.
- Statistical proficiency needed.

Skills

Pleasant side effects

Quality Assurance

Each commit must pass many QA checks:

ⓘ CI Checks (GitHub Actions)

- Unit tests (random-order)
- Code coverage (100%)
- Linting (0 lints)
- Formatting (0 issues)
- Documentation (website, link rot, examples)
- CRAN checks (0 E, 0 W, 0 N)
- Pre-commit hooks (0 issues)
- Portability (Linux, macOS, Windows)
- Robustness (dependencies, R versions)



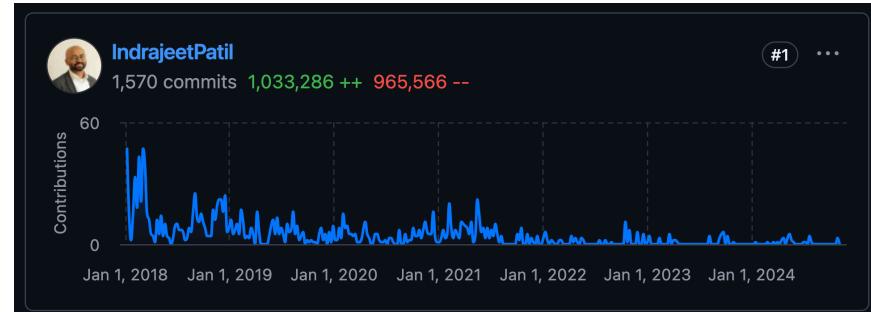
All checks have passed

24 successful checks

Show all checks



Healthy and active code base



Lessons learned while
refactoring `{ggstatsplot}`

Going from 20K to ~1.5K lines of
code

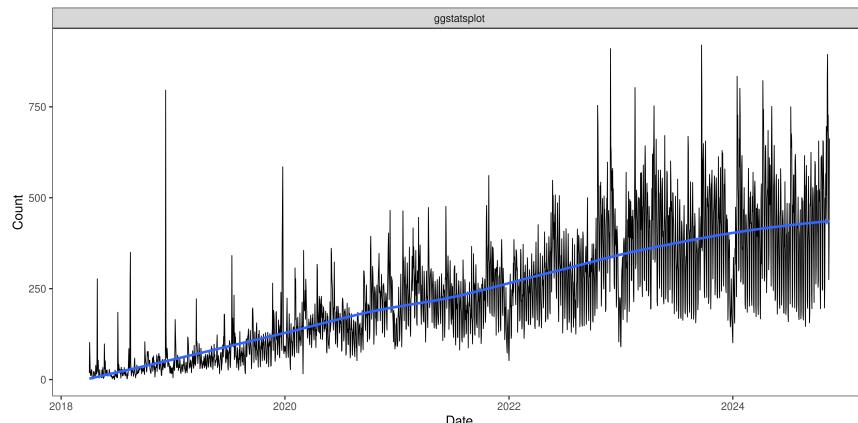
Indrajeet Patil

2023-10-27

User Love

! Total downloads > 500K (97 percentile)

```
1 library(packageRank)
2 plot(
3   cranDownloads("ggstatsplot", from = "2018-04-03", to = Sys.Date()),
4   graphics = "ggplot2", smooth = TRUE
5 )
```



Total citations > 1000



Visualizations with statistical details: The 'ggstatsplot' approach

Indrajeet Patil¹

¹ Center for Humans and Machines, Max Planck Institute for Human Development, Berlin, Germany

Summary

Graphical displays can reveal problems in a statistical model that might not be apparent from purely numerical summaries. Such visualizations can also be helpful for the reader to evaluate the validity of a model if it is reported in a scholarly publication or report. But, given the onerous costs involved, researchers often avoid preparing information-rich graphics and exploring several statistical approaches or tests available. The `ggstatsplot` package in the R programming language (R Core Team, 2021) provides a one-line syntax to enrich `ggplot2`-based visualizations with the results from statistical analysis embedded in the visualization itself. In doing so, the package helps researchers adopt a rigorous, reliable, and robust data exploratory and reporting workflow.

ggstatsplot Public

Enhancing {ggplot2} plots with statistical analysis

R 2k 190

Visualizations with statistical details: The 'ggstatsplot' approach

1277

*

I Patil

Journal of Open Source Software 6 (61), 3167, 2021

Conclusion

Benefits of the `{ggstatsplot}` approach

`{ggstatsplot}` combines data visualization and statistical analysis in a single step.

It...

- provides ready-made plots with information-rich defaults
- minimizes the chances of making errors in statistical reporting
- follows best practices in data visualization and statistical reporting
- helps evaluate statistical analysis in the context of the underlying data
- highlights the importance of the effect by providing effect size measures
- provides an easy way to evaluate *absence* of an effect using Bayesian framework
- extremely beginner-friendly

For more

Source code for these slides can be found [on GitHub](#).

If you are interested in good programming and software development practices, check out my other [slide decks](#).

Find me at...

 Twitter

 LinkedIn

 GitHub

 Website

 E-mail

Thank You 😊

Session information

```
1 sessioninfo::session_info(include_base = TRUE)

- Session info -----
  setting  value
  version   R version 4.4.2 (2024-10-31)
  os        Ubuntu 22.04.5 LTS
  system    x86_64, linux-gnu
  hostname  fv-az1780-600
  ui         X11
  language  (EN)
  collate   C.UTF-8
  ctype     C.UTF-8
  tz         UTC
  date      2024-11-12
  pandoc   3.5 @ /opt/hostedtoolcache/pandoc/3.5/x64/ (via rmarkdown)
  quarto    1.6.33 @ /usr/local/bin/quarto
```

```
- Packages -----
  package      * version    date (UTC) lib source
  base          * 4.4.2      2024-10-31 [3] local
  BayesFactor    0.9.12-4.7 2024-01-24 [1] RSPM
  bayestestR     0.15.0     2024-10-17 [1] RSPM
  . . . . .
```

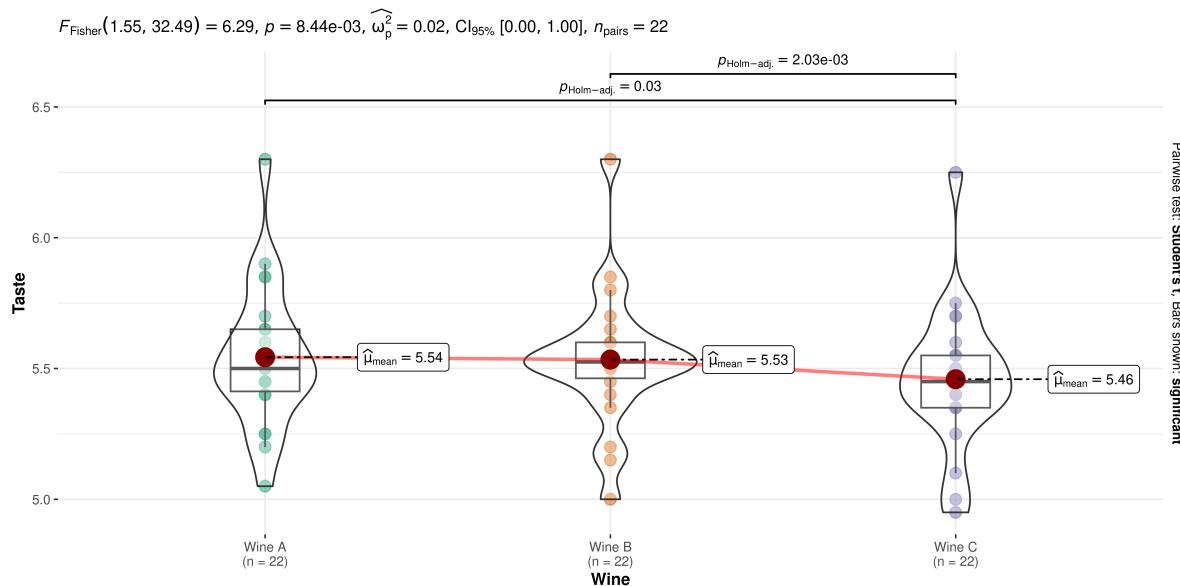
Appendix

Examples of other functions

ggwithinstats()

Hypothesis about group differences: repeated measures design

```
1 ggwithinstats(  
2   data = WRS2::WineTasting,  
3   x = Wine,  
4   y = Taste  
5 )
```



! Important

Defaults

- raw data + distributions
- descriptive statistics
- inferential statistics
- effect size + uncertainty
- pairwise comparisons
- Bayesian hypothesis-testing
- Bayesian estimation

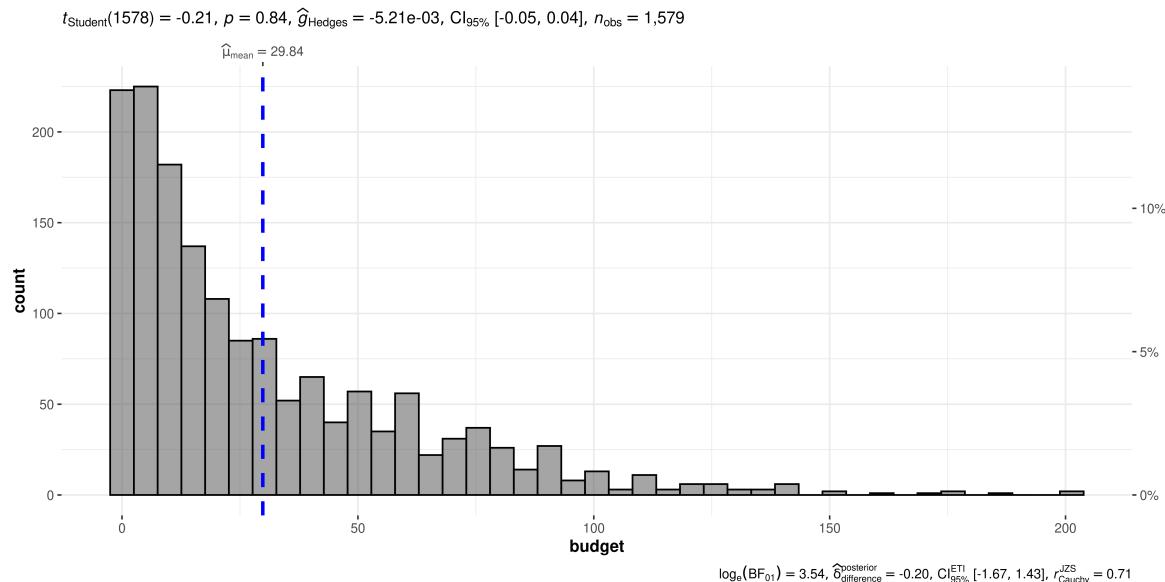
Statistical approaches available

- parametric
- parametric
- robust
- Bayesian

gghistostats()

Distribution of a numeric variable

```
1 gghistostats(  
2   data = movies_long,  
3   x = budget,  
4   test.value = 30  
5 )
```



! Important

💡 Defaults

- counts + proportion for bins
- descriptive statistics
- inferential statistics
- effect size + uncertainty
- pairwise comparisons
- Bayesian hypothesis-testing
- Bayesian estimation

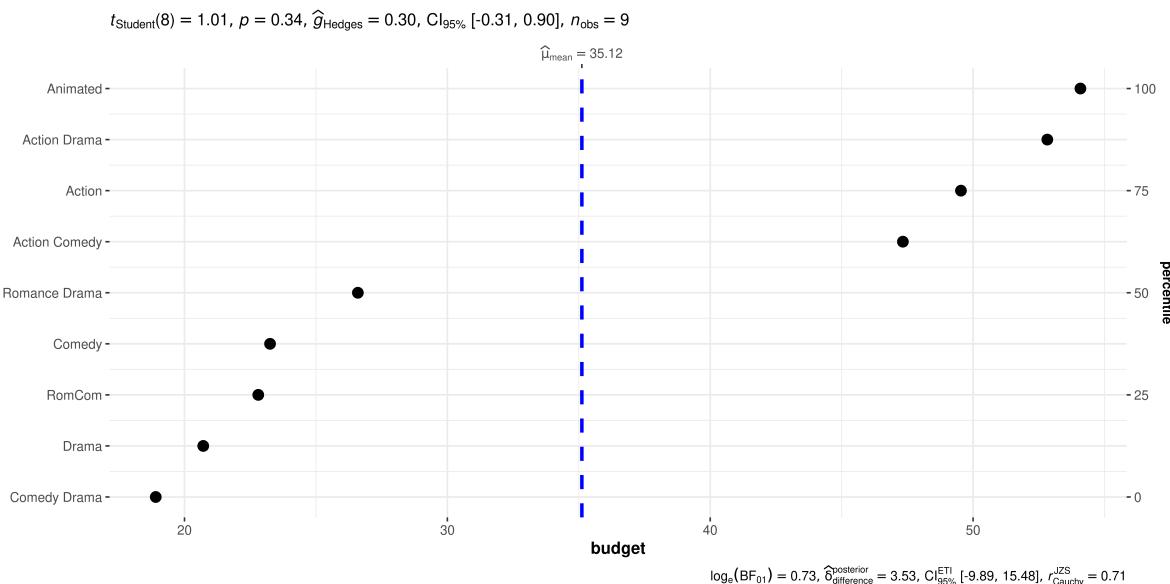
Statistical approaches available

- parametric
- parametric
- robust
- Bayesian

ggdotplotstats()

Labeled numeric variable

```
1 ggdotplotstats(  
2   data = movies_long,  
3   x = budget,  
4   y = genre,  
5   test.value = 30  
6 )
```



! Important

Defaults

- descriptive statistics
- inferential statistics
- effect size + uncertainty
- pairwise comparisons
- Bayesian hypothesis-testing
- Bayesian estimation

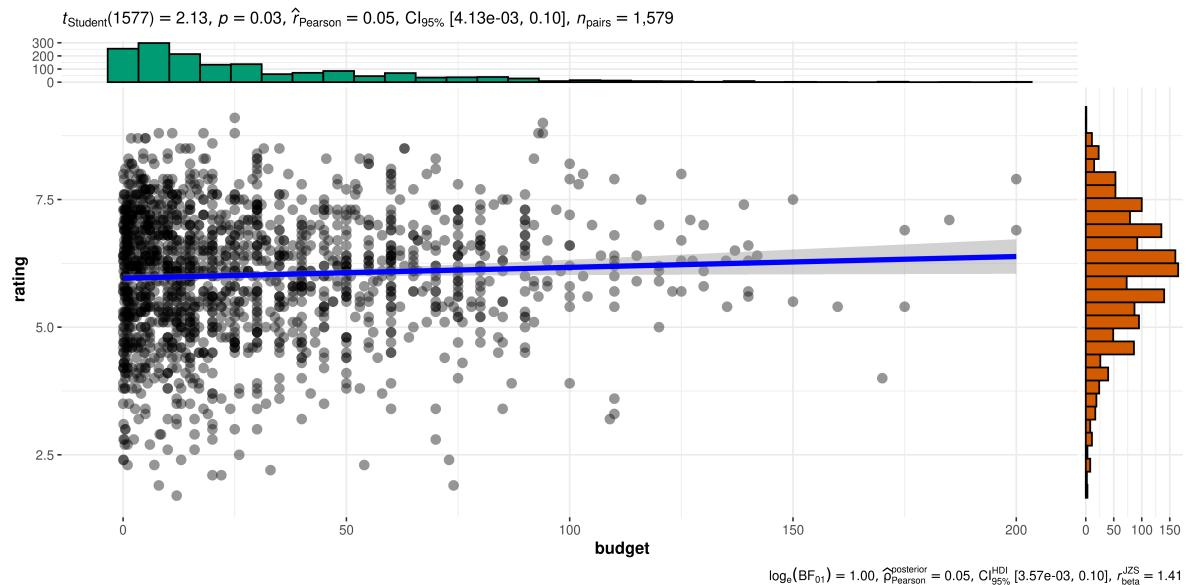
Statistical approaches available

- parametric
- parametric
- robust
- Bayesian

ggscatterstats()

Hypothesis about correlation: Two numeric variables

```
1 ggscatterstats(  
2   data = movies_long,  
3   x = budget,  
4   y = rating  
5 )
```



! Important

Defaults

- joint distribution
- marginal distribution
- effect size + uncertainty
- pairwise comparisons
- Bayesian hypothesis-testing
- Bayesian estimation

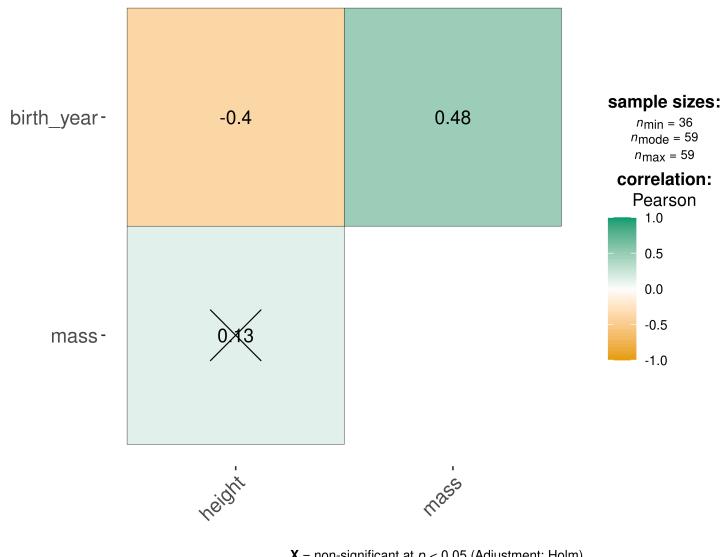
Statistical approaches available

- parametric
- parametric
- robust
- Bayesian

ggcorrmat()

Hypothesis about correlation: Multiple numeric variables

```
1 ggcorrmat(dplyr::starwars)
```



! Important

Defaults

- inferential statistics
- effect size + uncertainty
- careful handling of NAs
- partial correlations

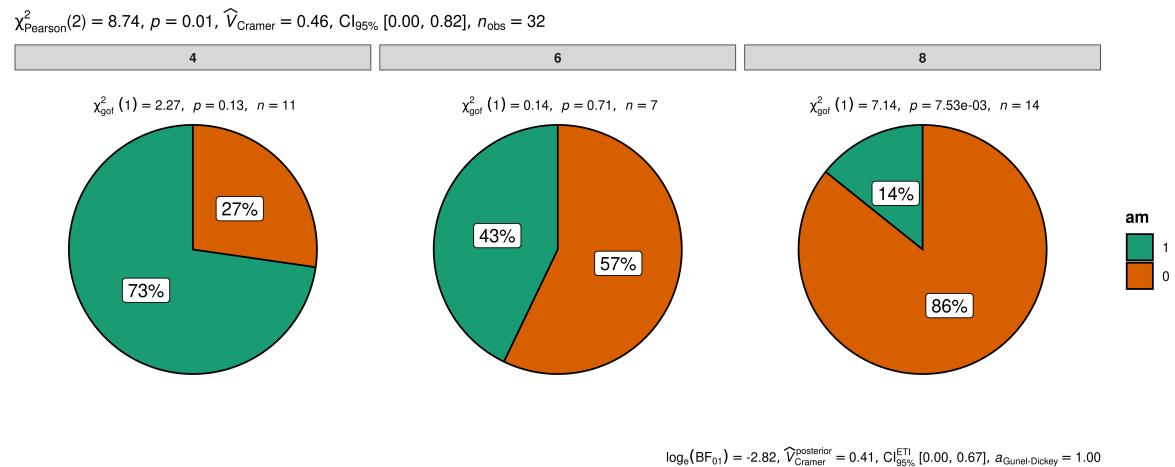
Statistical approaches available

- parametric
- parametric
- robust
- Bayesian

ggpiestats()

Hypothesis about composition of categorical variables

```
1 ggpiestats(  
2   data = mtcars,  
3   x = am,  
4   y = cyl  
5 )
```



! Important

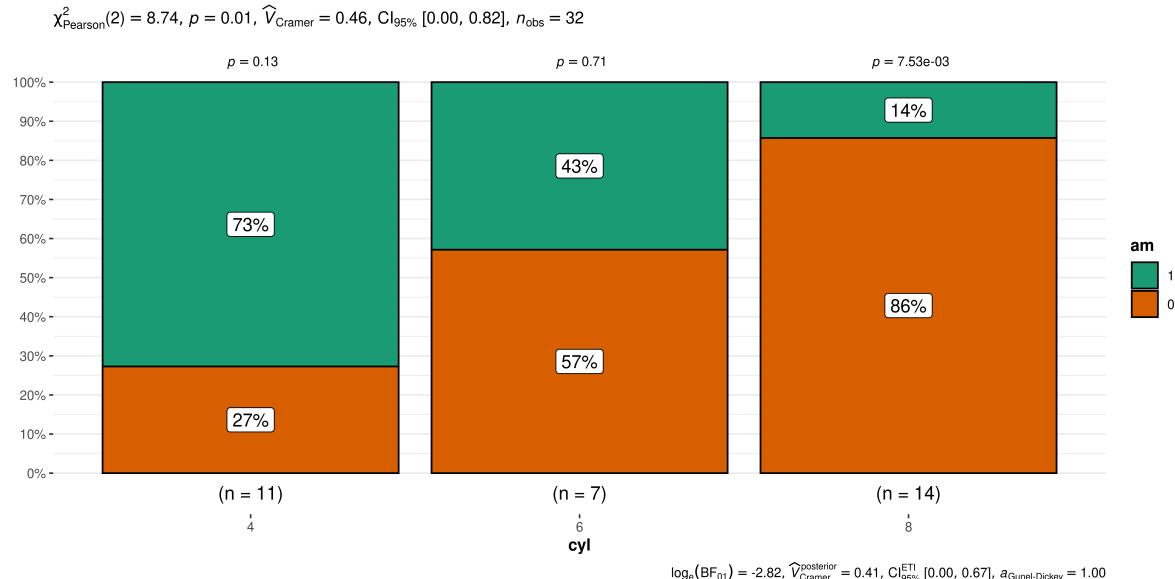
Defaults

- descriptive statistics
- inferential statistics
- effect size + uncertainty
- goodness-of-fit tests
- Bayesian hypothesis-testing
- Bayesian estimation

ggbarstats()

Hypothesis about composition of categorical variables

```
1 ggbarstats(  
2   data = mtcars,  
3   x = am,  
4   y = cyl  
5 )
```



! Important

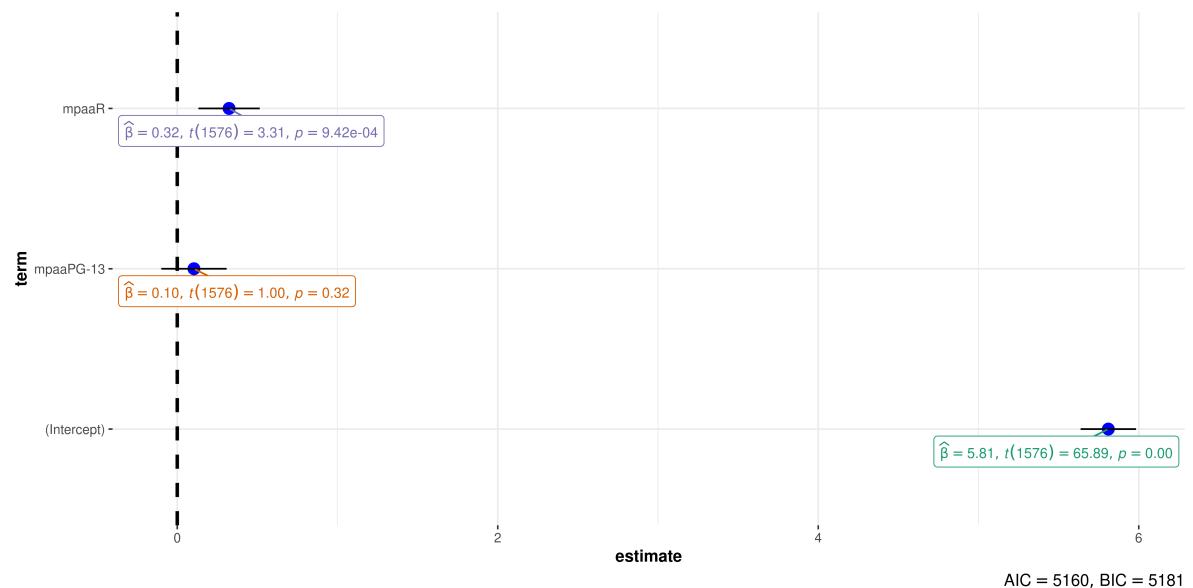
Defaults

- descriptive statistics
- inferential statistics
- effect size + uncertainty
- goodness-of-fit tests
- Bayesian hypothesis-testing
- Bayesian estimation

ggcoefstats()

Hypothesis about regression coefficients

```
1 mod <- lm(  
2   formula = rating ~ mpaa,  
3   data = movies_long  
4 )  
5  
6 ggcoefstats(mod)
```



! Important

Defaults

- estimate + uncertainty
- inferential statistics (t, z, F, χ^2)
- model fit indices (AIC + BIC)

Supports all regression models supported in `{easystats}` ecosystem.

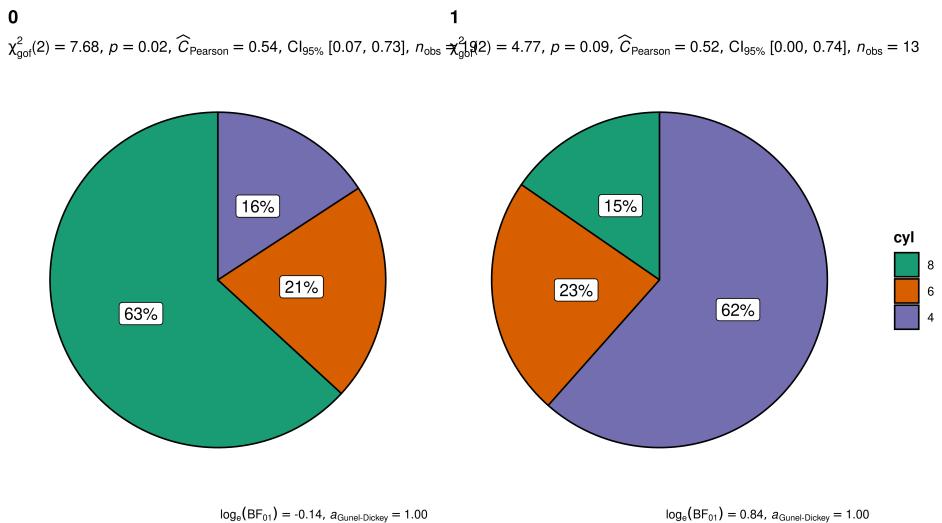
Meta-analysis is also supported!

grouped_ variants

Iterating over a grouping variable

grouped_ functions

```
1 grouped_ggpiestats(  
2   data = mtcars,  
3   x = cyl,  
4   grouping.var = am  
5 )
```



Available **grouped_** variants:

- `grouped_ggbetweenstats()`
- `grouped_ggwithinstats()`
- `grouped_gghistostats()`
- `grouped_ggdotplotstats()`
- `grouped_ggscatterstats()`
- `grouped_ggcorrmat()`
- `grouped_ggpiestats()`
- `grouped_ggbarstats()`

Customizability

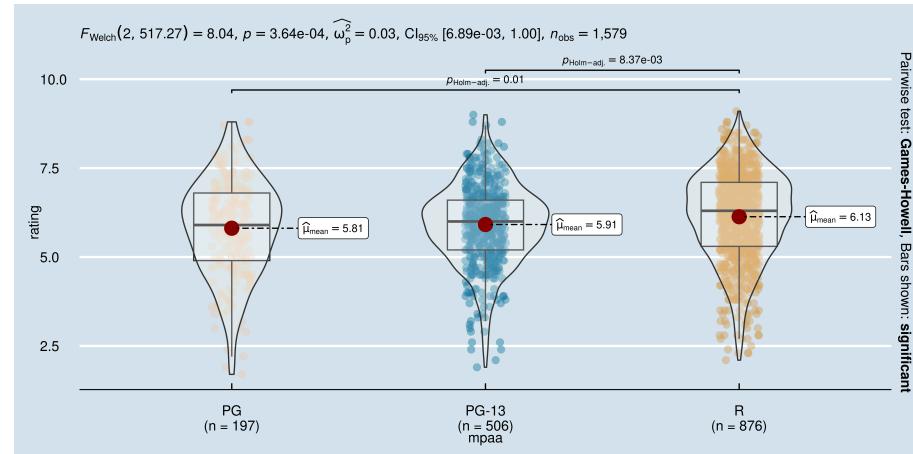
“What if I don’t like the default plots?” 🤔

Modify the look



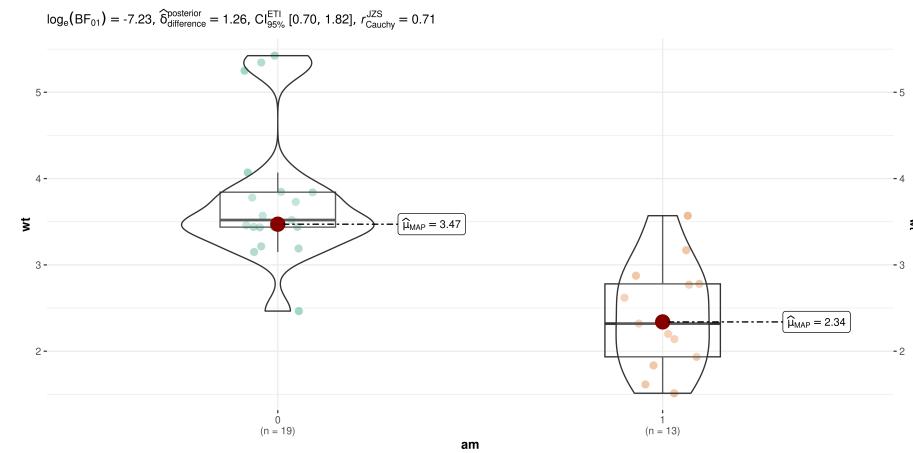
By changing theme and palette

```
1 ggbetweenstats(  
2   data = movies_long,  
3   x = mpaa,  
4   y = rating,  
5   ggtheme = ggthemes::theme_economist(),  
6   palette = "Darjeeling2",  
7   package = "wesanderson"  
8 )
```



By using `{ggplot2}` functions

```
1 ggbetweenstats(  
2   data = mtcars,  
3   x = am,  
4   y = wt,  
5   type = "bayes"  
6 ) +  
7   scale_y_continuous(sec.axis = dup_axis())
```

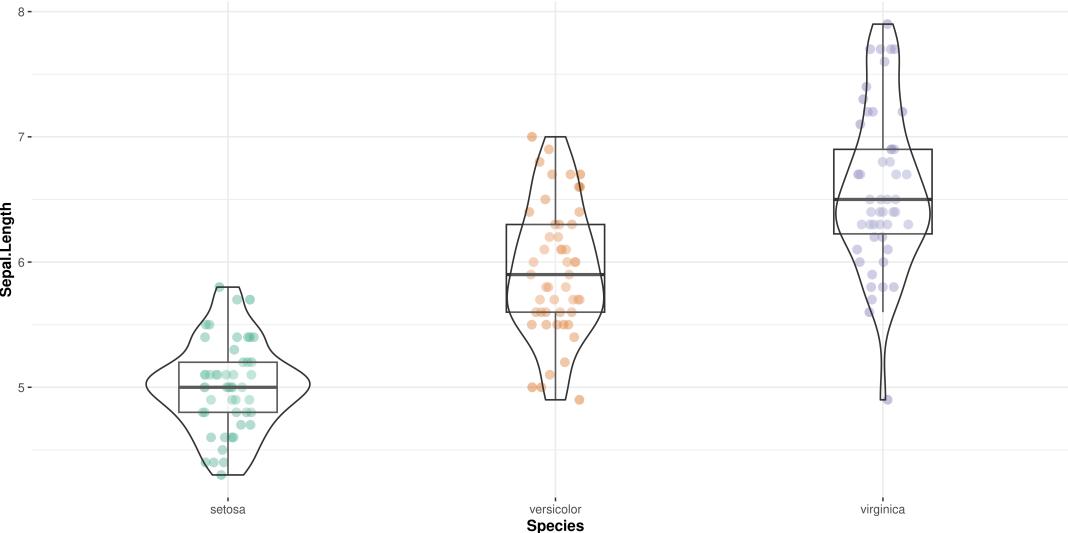


Too much information



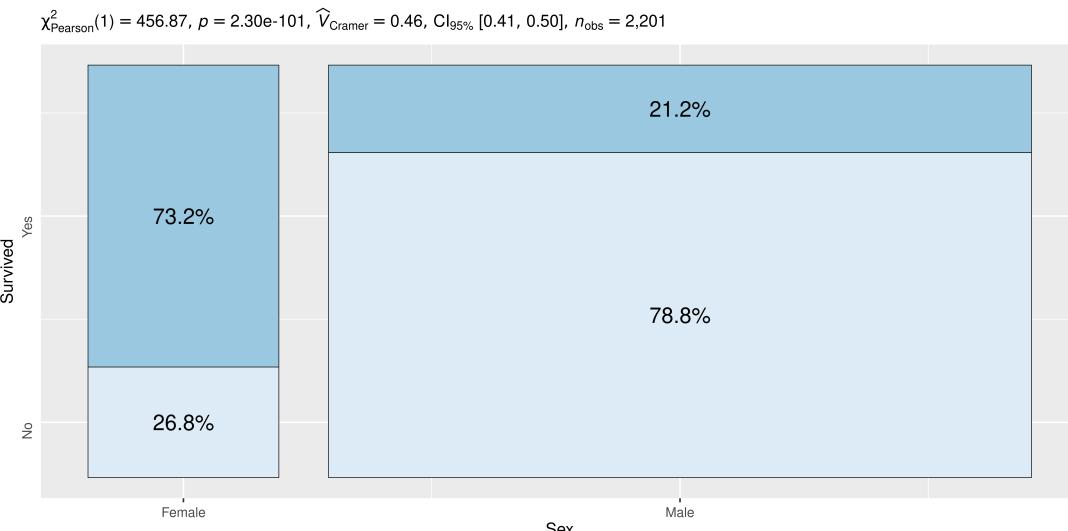
Get only plots:

```
1 ggbetweenstats(
2   data = iris,
3   x = Species,
4   y = Sepal.Length,
5   # turn off statistical analysis
6   centrality.plotting = FALSE,
7   results.subtitle = FALSE,
8   bf.message = FALSE,
9   # turn off pairwise comparisons
10 pairwise.display = "none"
11 )
```



Get only expressions:

```
1 stats_expr <- ggpiestats(
2   Titanic_full, Survived, Sex,
3 ) %>%
4   extract_subtitle()
5
6 ggiraphExtra:::ggSpine(
7   data = Titanic_full,
8   aes(x = Sex, fill = Survived)
9 ) +
10 labs(subtitle = stats_expr)
```



`{ggstatsplot}`: Details about
statistical reporting

Supports different statistical approaches

Note

| Functions | Description | Parametric | Non-parametric | Robust | Bayesian |
|--|---|------------|----------------|--------|----------|
| <code>ggbetweenstats()</code> | Between group comparisons | ✓ | ✓ | ✓ | ✓ |
| <code>ggwithinstats()</code> | Within group comparisons | ✓ | ✓ | ✓ | ✓ |
| <code>gghistostats()</code> , <code>gddotplotstats()</code> | Distribution of a numeric variable | ✓ | ✓ | ✓ | ✓ |
| <code>ggcorrrmat()</code> | Correlation matrix | ✓ | ✓ | ✓ | ✓ |
| <code>ggscatterstats()</code> | Correlation between two variables | ✓ | ✓ | ✓ | ✓ |
| <code>ggpiestats()</code> , <code>ggbarstats()</code> | Association between categorical variables | ✓ | NA | NA | ✓ |
| <code>ggpiestats()</code> , <code>ggbarstats()</code> | Equal proportions for categorical variable levels | ✓ | NA | NA | ✓ |
| <code>ggcoefstats()</code> | Regression modeling | ✓ | ✓ | ✓ | ✓ |
| <code>ggcoefstats()</code> | Random-effects meta-analysis | ✓ | NA | ✓ | ✓ |

Toggling statistical approaches



Parametric

```
1 # anova
2 ggbetweenstats(
3   data = mtcars,
4   x = cyl,
5   y = wt,
6   type = "p"
7 )
8
9 # correlation analysis
10 ggscatterstats(
11   data = mtcars,
12   x = wt,
13   y = mpg,
14   type = "p"
15 )
16
17 # t-test
18 gghistostats(
19   data = mtcars,
20   x = wt,
21   test.value = 2,
22   type = "p"
23 )
```

Non-parametric

```
1 # anova
2 ggbetweenstats(
3   data = mtcars,
4   x = cyl,
5   y = wt,
6   type = "np"
7 )
8
9 # correlation analysis
10 ggscatterstats(
11   data = mtcars,
12   x = wt,
13   y = mpg,
14   type = "np"
15 )
16
17 # t-test
18 gghistostats(
19   data = mtcars,
20   x = wt,
21   test.value = 2,
22   type = "np"
23 )
```

Alternative: Pure Pain



Hunting for packages

- 📦 for inferential statistics (`{stats}`)
- 📦 computing effect size + CIs (`{effectsize}`)
- 📦 for descriptive statistics (`{skimr}`)
- 📦 pairwise comparisons (`{multcomp}`)
- 📦 Bayesian hypothesis testing (`{BayesFactor}`)
- 📦 Bayesian estimation (`{bayestestR}`)
- 📦 ...



Inconsistent APIs

- 🤔 accepts data frame, vector, matrix?
- 🤔 long/wide format data?
- 🤔 works with `NAs`?
- 🤔 returns data frame, vector, matrix?
- 🤔 works with tibbles?
- 🤔 has all necessary details?
- 🤔 ...

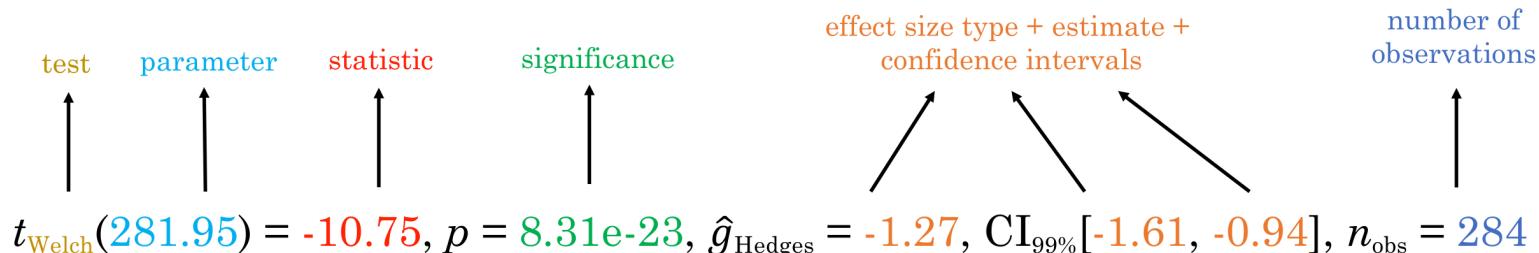


Best practices in statistical reporting

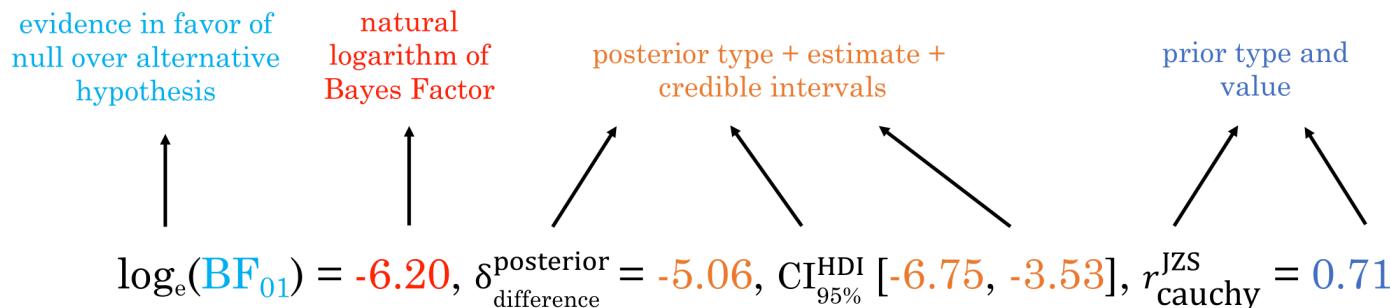


Results from Welch's t-test with {statsExpressions}

Template for Frequentist analysis



Template for Bayesian analysis



<<https://indrajeetpatil.github.io/statsExpressions/>>

src: @patilindrajeets

Avoiding reporting errors

“half of all published psychology papers that use NHST contained at least one p -value that was inconsistent with its test statistic and degrees of freedom. One in eight papers contained a grossly inconsistent p -value that may have affected the statistical conclusion”

(Nuijten et al., *Behavior Research Methods*, 2016)

Since the plot and the statistical analysis are yoked together, the chances of making an error in reporting the results are minimized.

No need to worry about updating figures and statistical details **separately.** 

Making sense of null results

$p > 0.05$: The null hypothesis (H_0) can't be rejected

But can it be **accepted**?! Null Hypothesis Significance Testing 🤔

“In 72% of cases, nonsignificant results were misinterpreted, in that the authors inferred that the effect was absent. A Bayesian reanalysis revealed that fewer than 5% of the nonsignificant findings provided strong evidence (i.e., $BF_{01} > 10$) in favor of the null hypothesis over the alternative hypothesis.”

(Aczel et al., AMPPS, 2018)

Juxtaposing frequentist and Bayesian statistics for the same analysis helps to properly interpret the null results.

Misconceptions: This package is...

-  an alternative to learning `ggplot2`
-  the more you know `ggplot2`, the better you can modify the defaults to your liking)

-  meant to be used in talks/presentations
-  defaults too complicated for effectively communicating results in time-constrained presentation settings, e.g. conference talks)

-  only relevant when used in publications
-  not necessary; can also be useful *only* during exploratory phase

-  the only game in town
-  excellent GUI open-source software: `JASP` and `jamovi`)

Footnotes

1. Open Science Collaboration, *Science*, 2015
2. (Nuijten et al., *Behavior Research Methods*, 2016)
3. (Aczel et al., *AMPPS*, 2018)