

1 Prepare APA Journal Articles with R Markdown

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5 Author Note

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Abstract

12

13 **papaja** addresses computational non-reproducibility in research reports caused by reporting
14 errors, i.e. incomplete or incorrect reporting of the analytic procedure or analytic results.

15 The package is tailored to authors of scientific manuscripts that must adhere to the
16 guidelines of the American Psychological Society (6th edition). This document was written
17 with **papaja** and provides a brief overview of the package's main features: An R Markdown
18 template for APA-style manuscripts and helper-functions that facilitate reporting of analytic
19 results in accordance with APA guidelines.

20 *Keywords:* APA style, R, knitr, R markdown, papaja

21 Word count: 3147

Prepare APA Journal Articles with R Markdown

Computational reproducibility is of fundamental importance to the quantitative sciences (Cacioppo, Kaplan, Krosnick, Olds, & Dean, 2015; Donoho, 2010; Hutson, 2018; Peng, 2011). Yet, non-reproducible results are widely prevalent. Computational reproducibility is threatened by countless sources of errors, but among the most common problems are incomplete or incorrect reporting of statistical procedures and results (Artner et al., 2020). **papaja** was designed to address these problems. The package is tailored to authors of scientific manuscripts that must adhere to the guidelines of the American Psychological Association (APA, 6th edition, American Psychological Association, 2010). **papaja** provides [rmarkdown](#) (Xie, Allaire, & Golemund, 2018) templates to create DOCX documents and PDF documents—using L^AT_EX document class [apa6](#). Moreover, **papaja** provides helper functions to facilitate the reporting of results of your analyses in accordance with APA guidelines. This document was written with **papaja** and provides a brief overview of the package’s main features. For a comprehensive introduction and installation instructions, see the current draft of the [papaja manual](#).¹

The problem: Copy-paste reporting

Readers of scientific journal articles generally assume that numerical results and figures directly flow from the underlying data and analytic procedure. Execution of analyses and reporting of results are typically not considered sources of error that threaten the validity of scientific claims—the computational reproducibility of the reported results is a forgone conclusion. The natural assumption of computational reproducibility reflects its fundamental importance to quantitative sciences as acknowledged by the U.S. National Science Foundation subcommittee on Replicability in Science:

¹ If you have a specific question that is not answered in the manual, feel free to ask a question on Stack Overflow using the [papaja tag](#). If you believe you have found a bug or would like to request a new feature, [open an issue](#) on Github and provide a [minimal complete verifiable example](#).

45 [Computational] Reproducibility is a minimum necessary condition for a finding
46 to be believable and informative. (p. 4, Cacioppo et al., 2015)

47 Non-reproducible results are scientifically and ethically unacceptable. They impede an
48 accumulation of knowledge, waste resources, and when applied could have serious
49 consequences. A recent investigation of breast cancer treatments erroneously concluded that
50 radiotherapy after mastectomy increased mortality because of an error in the analysis code
51 (Henson et al., 2016). A corrected reanalysis indicated that, in fact, the opposite was the
52 case—the treatment appeared to be effectively decrease mortality. Examples like this show
53 that computational reproducibility cannot be a forgone conclusion.

54 Large-scale scrutiny of statistics published in over 30,000 articles in psychology
55 journals shows that every other article reports at least one impossible combination of test
56 statistic, degrees of freedom, and p value; in every tenth article such inconsistencies call the
57 statistical inference into question (Nuijten, Hartgerink, Assen, Epskamp, & Wicherts, 2016).
58 More in-depth investigations that attempted to reproduce reported results from the
59 underlying raw data paint a similar picture. For example, in a sample of 46 articles, two
60 thirds of key claims could be reproduced but in every tenth case only after deviating from
61 the reported analysis plan (Artner et al., 2020). For one in four non-reproducible results, the
62 reproduction attempt yielded results that were no longer statistically significant, calling the
63 original statistical inference into question. These figures clearly show that there is a need for
64 efforts to improve the computational reproducibility of the published literature.

65 Computational non-reproducibility is, of course, multi-causal. While there is only one
66 way in which a research report is computationally reproducible, there is a countless number of
67 things that can go wrong. Broadly speaking, there are at least four causes for
68 non-reproducible analyses: (1) incomplete or incorrect reporting of the analytic procedure,
69 (2) incorrect execution of the analytic procedure, (3) incorrect reporting of results, and (4)
70 code rot, i.e., non-reproducible caused by (inadvertent) changes to the computational

71 environment (e.g., software updates, changes to data files). We currently see no technical
72 solution to the first two causes. Incomplete reporting (1) may be partially mitigated by
73 strictly enforcing reporting guidelines. However, verifying that the analytic procedure is
74 reported faithfully (1) and was executed correctly (2) ultimately requires manual scrutiny of
75 analysis scripts and/or reproduction and is possible only if authors share their data. Code
76 rot (4), on the other hand, can be adequately addressed by conserving the software
77 environment in which the results were produced (e.g., R and all R packages). Several
78 seasoned technical solutions, such as software containers or a virtual machine, exist (Grüning
79 et al., 2018; Piccolo & Frampton, 2016).² **papaja** provides a technical safeguard for correct
80 reporting of results (3).

81 When it comes to reporting quantitative results, most researchers engage in what we
82 refer to as *copy-paste reporting*. Quantitative analyses and reporting are done in separate
83 software. Thus, by necessity quantitative results are copied from the analysis software and
84 pasted into the report. Copy-paste reporting underlies and contributes to several of the most
85 common causes for computational non-reproducibility: Rounding errors, incorrect labeling of
86 statistical results, typos, and inserting results of a different analysis (pp. 12-13, Artner et al.,
87 2020). We are convinced that errors caused by copy-paste reporting cannot be addressed by
88 appealing to researchers to be more careful. The motivation to avoid such errors should
89 already be high because the reputational cost of errata and retractions due to
90 non-reproducible results is substantial. Even researchers that open their data (and analysis
91 code) to the public or anticipate systematic editorial scrutiny report non-reproducible results
92 (Eubank, 2016; Hardwicke et al., 2018; Obels, Lakens, Coles, Gottfried, & Green, 2020).
93 Evidently, computational reproducibility is difficult to attain.

² **papaja** can be readily combined with these tools as documented in the section on [reproducible software environments](#) in the **papaja** manual.

The solution: Dynamic documents

94

95 We believe copy-paste reporting is a flawed approach to reporting quantitative results.
96 Hence, we believe researchers need stop copy-pasting to safeguard the computational
97 reproducibility of their manuscripts. Manuscripts should be dynamic (or “living”) documents
98 (Knuth, 1984; Xie et al., 2018) that contain direct links to the analytic software. Dynamic
99 documents fuse analysis code and prose such that statistics, figures, and tables are
100 automatically inserted into a manuscript—and updated as data or analysis code change. As
101 an added benefit, dynamic documents have great potential to improve the computational
102 reproducibility of manuscripts beyond reporting errors as they facilitate independent
103 reproduction. Dynamic documents fully document the analytic procedure and establish
104 direct links to the associated scientific claims.

105 **papaja**, and [the software it builds on](#), provides researchers with the tools to create
106 dynamic submission-ready manuscripts in the widely used APA style. The dominant
107 approach to creating dynamic documents in R is to use the [rmarkdown](#) package (Xie et al.,
108 2018). **papaja** provides R Markdown templates to create DOCX and PDF documents (using
109 \LaTeX document class `apa6`). Moreover, **papaja** provides several functions to conveniently
110 report analytic results according to APA guidelines. The remainder of this document
111 illustrates how these functions can be used.

112

Setting up a new document

113 Once **papaja** and all other [required software](#) is installed, the APA template is available
114 through the RStudio menu, see Figure 1. When you click RStudio’s *Knit* button, a
115 manuscript conforming to APA style is rendered, which includes both your text and the
116 output of any embedded R code chunks within the manuscript. Of course, a new document
117 can also be created without RStudio using `rmarkdown::draft()` and rendered using
118 `rmarkdown::render()`.

```

# Create new R Markdown file

rmarkdown::draft(
  "manuscript.Rmd"
  , "apa6"
  , package = "papaja"
  , create_dir = FALSE
  , edit = FALSE
)

# Render manuscript

rmarkdown::render("manuscript.Rmd")

```

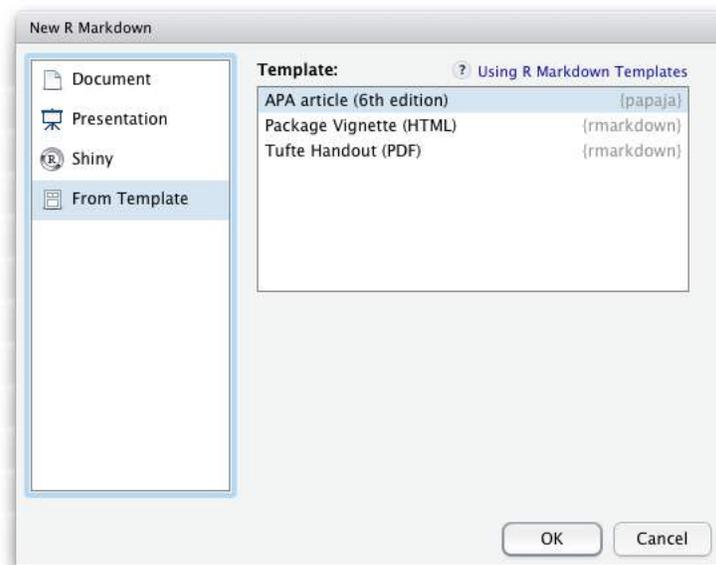


Figure 1. After successful installation the **papaja** APA manuscript template is available via the RStudio menu.

119 This document is in APA manuscript style, but other styles are available for PDF
 120 documents. The document style can be controlled via the `classoption` field of the YAML
 121 front matter. For a thesis-like style change `classoption` to `doc` or use `jou` for a more

122 polished journal-like two-column layout. For a comprehensive overview of other formatting
123 options please refer to the [papaja manual](#).

124 To create DOCX documents, the `output` field in the YAML front matter can be set to
125 `papaja::apa6_docx`. Please note, however, that DOCX documents are somewhat less
126 flexible and less polished than PDF documents. **papaja** builds on **pandoc** to render
127 Markdown into PDF and DOCX documents. Unfortunately, **pandoc**'s capabilities are more
128 limited for DOCX documents. This is why some **papaja** features are only available for PDF
129 documents, for example, see the summary of [rendering options](#) in the manual. Also, DOCX
130 documents require some [limited manual work](#) before they fully comply with APA guidelines.
131 The DOCX documents produced by **papaja** should, however, be suitable for collaboration
132 with colleagues, who prefer Word over R Markdown and to prepare journal submissions.

133

Writing

134 Like **rmarkdown**, **papaja** uses Markdown syntax to format text. A comprehensive
135 overview of the supported Markdown syntax is available in the [pandoc manual](#). In the
136 following, we will highlight a few features that are of particular relevance to the technical
137 writing of research reports.

138 Citations

139 By default, citations in **papaja** are processed by the **pandoc** extension `citeproc`,
140 which works well for both PDF and DOCX documents. `citeproc` takes reference
141 information from a bibliography file, which can be in one of several formats (e.g., CSL-JSON,
142 Bib(La)TeX, EndNote, RIS, Medline). To start citing, specify the path to the bibliography
143 file in `bibliography` field of the YAML front matter. Once `citeproc` knows where to look
144 for reference information, `[@james_1890]` will render to a citation within parentheses, i.e.,
145 (James, 1890). Multiple citations must be separated by a semicolon ; (e.g., `[@james_1890;`
146 `@bem_2011]`) and are automatically ordered alphabetically as per APA style, i.e., (Bem,

147 2011; James, 1890). To cite a source in text simply omit the brackets. The `pandoc` manual
 148 provides a comprehensive overview of `citeproc` and the supported `citation syntax`.

149 To facilitate inserting citations, you may use the RStudio Visual Editor's `bibliography`
 150 `search` and auto-completion of reference handles. If you use VSCode with the `R extension` or
 151 RStudio without the Visual Editor, the add-in provided in `citr` serves a similar purpose.
 152 Both the Visual Editor and `citr` can also access your Zotero database directly and copy
 153 references to your bibliography file.

154 As academics and open source developers, we believe it is important to credit the
 155 software we use for our publications. A lot of R packages are developed by academics free of
 156 charge. As citations are the currency of academia, it is easy to compensate volunteers for
 157 their work by citing their R packages. `papaja` provides two functions that make citing R
 158 and its packages quite convenient:

159 `r_refs()` creates a BibLaTeX file containing citations for R and all currently loaded
 160 packages. `cite_r()` takes these citations and turns them into readily reportable text.
 161 `my_citation` now contains the following text that you can use in your document:

```
R [Version 4.1.2\; @R-base] and the R-packages *afex* [Version 1.0.1\;
→ @R-afex], *dplyr* [Version 1.0.8\; @R-dplyr], *ggforce* [Version 0.3.3\;
→ @R-ggforce], *ggplot2* [Version 3.3.5\; @R-ggplot2], *lme4* [Version
→ 1.1.28\; @R-lme4], *Matrix* [Version 1.3.4\; @R-Matrix], *papaja*
→ [Version 0.2.0\; @R-papaja], and *tinylabels* [Version 0.2.3\;
→ @R-tinylabels]
```

162 Equations

163 Equations can be reported using the powerful \LaTeX syntax. Inline math must be
 164 enclosed in `$` or `\(` and `\)`, for example, `$d' = z(H) - z(\mathit{FA})$`, which renders to
 165 $d' = z(H) - z(FA)$. For larger formulas, displayed equations are more appropriate; they are

166 enclosed in `$$` or `\[and \]`, and will, for example, render to

$$d' = \frac{\mu_{old} - \mu_{new}}{\sqrt{0.5(\sigma_{old}^2 + \sigma_{new}^2)}}.$$

167

Reporting results

168 If you are not familiar with R Markdown and how it can be used to conduct and
 169 document your analyses, we recommend you familiarize yourself with R Markdown first.
 170 RStudio provides a [concise introduction](#).

171 `apa_print()` is a core function in **papaja** to facilitate reporting analytic results for a
 172 growing number of analytic output objects, Table 1. Consider the following example of an
 173 analysis of variance. After performing the analysis, the result is passed to `apa_print()`.
 174 The function takes the R object returned by the analysis function and returns a list that
 175 contains reportable text and tables.

```
recall_anova <- afex::aov_4(
  Recall ~ (Task * Valence * Dosage) + (Task * Valence | Subject)
  , data = mixed_data
)
recall_anova_results <- apa_print(recall_anova)
str(recall_anova_results)
```

```
176 ## List of 4
177 ## $ estimate :List of 7
178 ## ..$ Dosage : chr "$\hat{\eta}^2_G = .267$, 90\% CI $[.000, .507]$"
179 ## ..$ Task : chr "$\hat{\eta}^2_G = .048$, 90\% CI $[.000, .297]$"
180 ## ..$ Valence : chr "$\hat{\eta}^2_G = .008$, 90\% CI $[.000, .052]$"
181 ## .. [list output truncated]
182 ## $ statistic :List of 7
183 ## ..$ Dosage : chr "$F(2, 15) = 2.97$, $p = .082$"
```

```

184 ## ..$ Task : chr "$F(1, 15) = 43.13$, $p < .001$"
185 ## ..$ Valence : chr "$F(1.62, 24.36) = 3.46$, $p = .056$"
186 ## .. [list output truncated]
187 ## $ full_result:List of 7
188 ## ..$ Dosage : chr "$F(2, 15) = 2.97$, $p = .082$, $\hat{\eta}^2_G = .267$, 90\% CI
189 ##      $[.000, .507]$"
190 ## ..$ Task : chr "$F(1, 15) = 43.13$, $p < .001$, $\hat{\eta}^2_G = .048$, 90\% CI
191 ##      $[.000, .297]$"
192 ## ..$ Valence : chr "$F(1.62, 24.36) = 3.46$, $p = .056$, $\hat{\eta}^2_G = .008$,
193 ##      90\% CI $[.000, .052]$"
194 ## .. [list output truncated]
195 ## [list output truncated]
196 ## - attr(*, "class")= chr [1:2] "apa_results" "list"

```

197 The text returned by `apa_print()` can be inserted into manuscript as usual using
 198 inline code chunks:

```

Item valence (`r in_paren(recall_anova_results$full_result$Valence)`) and
the task affected recall performance,
`r recall_anova_results$full_result$Task`; the dosage, however, had no
detectable effect on recall, `r recall_anova_results$full_result$Dosage`.
There was no detectable interaction.

```

199 The above excerpt from an R Markdown document yields the following in the rendered
 200 document. Note that the function `in_paren()` replaces parentheses with brackets as per
 201 APA guidelines when statistics are reported in parentheses.

202 Item valence ($F[1.62, 24.36] = 3.46, p = .056, \hat{\eta}_G^2 = .008, 90\% \text{ CI } [.000, .052]$) and
 203 the task affected recall performance, $F(1, 15) = 43.13, p < .001, \hat{\eta}_G^2 = .048, 90\%$
 204 $\text{CI } [.000, .297]$; the dosage, however, had no effect on recall, $F(2, 15) = 2.97,$
 205 $p = .082, \hat{\eta}_G^2 = .267, 90\% \text{ CI } [.000, .507]$. There was no significant interaction.

Table 1

Object classes currently supported by `apa_print()`.

A-B	D-L	L-S	S-Z
afex_aov	default	lsmobj	summary.aovlist
anova	emmGrid	manova	summary.glht*
anova.lme	glht*	merMod	summary.glm
Anova.mlm	glm	mixed	summary.lm
aov	htest	papaja_wsci	summary.manova
aovlist	list	summary_emm	summary.ref.grid
BFBayesFactor*	lm	summary.Anova.mlm	
BFBayesFactorTop*	lme	summary.aov	

Note. * These methods are not fully tested; don't trust blindly!

206 In addition to individual text strings, `apa_print()` also summarizes all results in a
 207 standardized `data.frame`.³ The column names conform to the [naming conventions](#) used in
 208 the **broom** package (e.g. `estimate`, `statistic`, and `p.value`). `apa_print()` assigns each
 209 column an additional descriptive variable label.

```
head(recall_anova_results$table, 3)
```

```
210 ## A data.frame with 7 labelled columns:
211 ##
212 ##      term estimate      conf.int statistic    df df.residual p.value
213 ## 1 Dosage      .267 [.000, .507]      2.97     2          15    .082
214 ## 2  Task       .048 [.000, .297]     43.13     1          15 < .001
215 ## 3 Valence     .008 [.000, .052]      3.46  1.62         24.36    .056
```

³ For more complex analyses the `table` element may contain a named list of multiple tables.

```

216 ##
217 ## term      : Effect
218 ## estimate  :  $\hat{\eta}^2_G$ 
219 ## conf.int  : 90% CI
220 ## statistic: F
221 ## df        :  $\mathit{df}^{\mathrm{GG}}$ 
222 ## ... (2 more labels)

```

223 Tables

224 Tables returned by `apa_print()` can be conveniently included in a manuscript by
 225 passing them to `apa_table()`. This function was designed with exemplary tables from the
 226 APA manual in mind and to work well with `apa_print()`. Conveniently, `apa_table()` uses
 227 any available variable labels as informative column headers, Table 2. Unfortunately, table
 228 formatting is somewhat limited for DOCX documents due to the limited table representation
 229 in `pandoc` (e.g., it is currently not possible span header cells across multiple columns or have
 230 multiple header rows). Of course, popular packages for creating tables, such as [kableExtra](#),
 231 [huxtable](#), or [flextable](#) can also be used and may be preferable for more complex tables.

```

apa_table(
  recall_anova_results$table
  , caption = "ANOVA table for recall performance as a function of task,
              valence, and dosage."
  , note = "This is a table created using apa_print() and apa_table()."
  , align = "lrcrllr"
  , midrules = c(3, 6)
)

```

232 As required by the APA guidelines, tables are deferred to the final pages of the

Table 2

ANOVA table for recall performance as a function of task, valence, and dosage.

Effect	$\hat{\eta}_G^2$	90% CI	F	df^{GG}	df_{res}^{GG}	p
Dosage	.267	[.000, .507]	2.97	2	15	.082
Task	.048	[.000, .297]	43.13	1	15	< .001
Valence	.008	[.000, .052]	3.46	1.62	24.36	.056
Dosage × Task	.004	[.000, .000]	1.83	2	15	.195
Dosage × Valence	.011	[.000, .000]	2.38	3.25	24.36	.090
Task × Valence	.003	[.000, .000]	1.50	1.35	20.20	.242
Dosage × Task × Valence	.001	[.000, .000]	0.39	2.69	20.20	.743

Note. This is a table created using `apa_print()` and `apa_table()`.

233 manuscript when creating PDF documents.⁴ To place tables and figures in text instead, the
 234 `floatsintext` field in the YAML header can be set to `yes`.

235 Figures

236 Figures generated in R are automatically inserted into the document. **papaja** provides
 237 a set of functions built around `apa_factorial_plot()` that facilitate visualizing data from
 238 factorial study designs, Figure 2(A). For **ggplot2** users, **papaja** provides `theme_apa()`, a
 239 theme designed with APA manuscript guidelines in mind, Figure 2(B).

```
apa_beeplot(
  mixed_data
  , id = "Subject"
  , dv = "Recall"
  , factors = c("Valence", "Dosage", "Task")
```

⁴ Again, this is currently not the case in DOCX documents.

```
, ylim = c(0, 30)
, las = 1
, args_points = list(cex = 1.25)
, args_arrows = list(length = 0.025)
, args_legend = list(x = "top", horiz = TRUE)
)
```

240 Again, as required by the APA guidelines, figures are deferred to the final pages of the
241 document unless the `floatsintext` field in the YAML header can be set to `yes`.

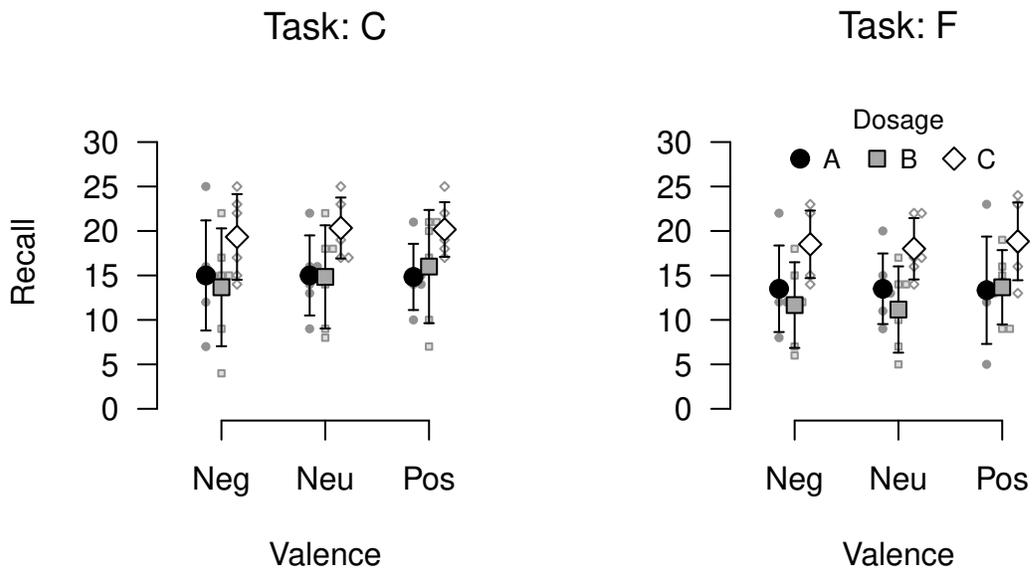
242 Referencing tables and figures

243 `papaja` builds on the `bookdown` package, which provides limited cross-referencing
244 capabilities within documents. By default, automatically generated table and figure numbers
245 can be inserted into the text using `\@ref(tab:chunk-name)` for tables or
246 `\@ref(fig:chunk-name)` for figures. Note that for this syntax to work chunk names cannot
247 include underscores (i.e., `_`).

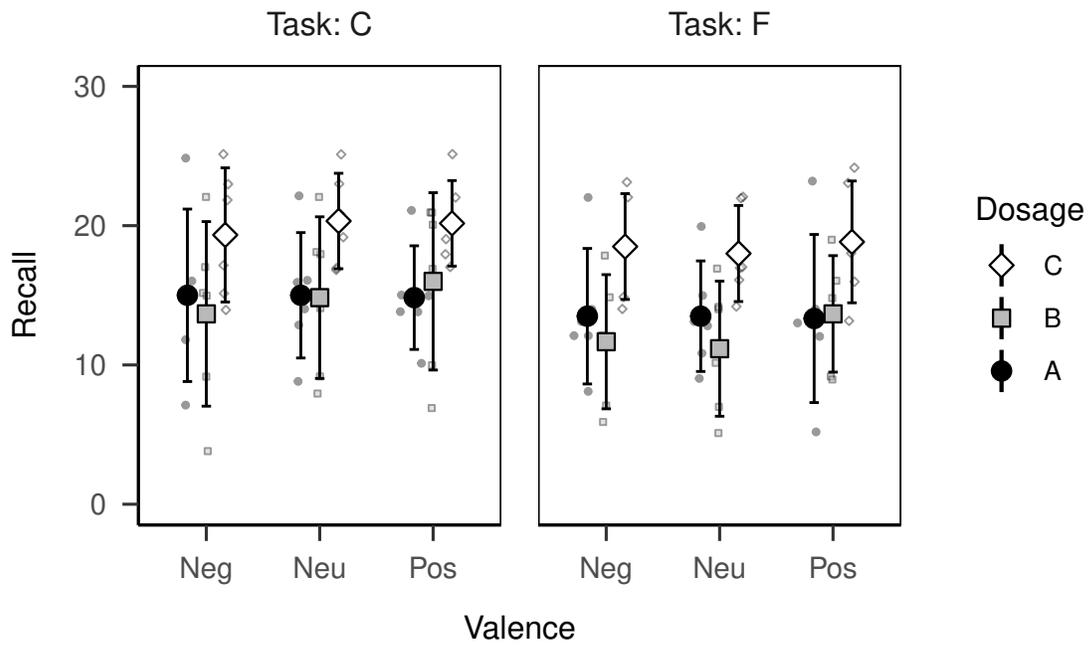
248 Getting help

249 For a comprehensive introduction to `papaja`, check out the current draft of the
250 [papaja manual](#). If you have a specific question that is not answered in the manual, feel free
251 to ask a question on Stack Overflow [using the papaja tag](#). If you believe you have found a
252 bug or you want to request a new feature, [open an issue](#) on Github and provide a [minimal](#)
253 [complete verifiable example](#).

254 If you are interested to see how others use `papaja`, take a look at some of the publicly
255 available R Markdown files. The file used to create this document is available at the [papaja](#)
256 [GitHub repository](#). Moreover, a [collection of papers](#) written with `papaja`, including the
257 corresponding R Markdown files, is listed in the manual. If you have published a paper that



(A) Figure created using `apa_factorial_plot()`.



(B) Figure created using `ggplot()` and `theme_apa()`.

Figure 2. Bee plots of the example data set. Small points represent individual observations, large points represent means, and error bars represent 95% confidence intervals.

258 was written with **papaja**, please add the reference to the [public Zotero group](#) yourself or
259 send us to me.

260

Contributing

261 If you like **papaja** and would like to contribute, we highly appreciate any contributions
262 to the R package or its documentation. Take a look at the [open issues](#) if you need
263 inspiration. There are many additional analyses that we would like `apa_print()` to support;
264 new S3/S4-methods are always appreciated (e.g., for `factanal`, `fa`, `lavaan`). For a primer
265 on adding new `apa_print()`-methods, see the getting-started-vignette
266 (`vignette("extending_apa_print", package = "papaja")`). Before working on a
267 contribution, please review our brief [contributing guidelines](#) and [code of conduct](#).

268 Enjoy writing. :)

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282 [content/uploads/2015/09/NSF-Robust-Research-Workshop-Report.pdf](http://web.stanford.edu/group/bps/cgi-bin/wordpress/wp-content/uploads/2015/09/NSF-Robust-Research-Workshop-Report.pdf)
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