Package ‘ggeffects’

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Title Create Tidy Data Frames of Marginal Effects for 'ggplot' from Model Outputs
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Description Compute marginal effects and adjusted predictions from statistical models and returns the result as tidy data frames. These data frames are ready to use with the 'ggplot2'-package. Effects and predictions can be calculated for many different models. Interaction terms, splines and polynomial terms are also supported. The main functions are ggpredict(), ggemmeans() and ggeffect(). There is a generic plot()-method to plot the results using 'ggplot2'.
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as.data.frame.ggeffects

Adjusted predictions from regression models
Description

After fitting a model, it is useful to generate model-based estimates (expected values, or *adjusted predictions*) of the response variable for different combinations of predictor values. Such estimates can be used to make inferences about relationships between variables.

The *ggeffects* package computes marginal means and adjusted predicted values for the response, at the margin of specific values or levels from certain model terms. The package is built around three core functions: `predict_response()` (understanding results), `test_predictions()` (testing results for statistically significant differences) and `plot()` (communicate results).

By default, adjusted predictions or marginal means are by returned on the *response* scale, which is the easiest and most intuitive scale to interpret the results. There are other options for specific models as well, e.g. with zero-inflation component (see documentation of the `type`-argument). The result is returned as consistent data frame, which is nicely printed by default. `plot()` can be used to easily create figures.

The main function to calculate marginal means and adjusted predictions is `predict_response()`. In previous versions of *ggeffects*, the functions `ggpredict()`, `ggemmeans()`, `ggeffect()` and `ggaverage()` were used to calculate marginal means and adjusted predictions. These functions are still available, but `predict_response()` as a "wrapper" around these functions is the preferred way to do this now.

Usage

```r
## S3 method for class 'ggeffects'
as.data.frame(  
  x,  
  row.names = NULL,  
  optional = FALSE,  
  ...,  
  stringsAsFactors = FALSE,  
  terms_to_colnames = FALSE
)
```

```r
ggaverage(  
  model,  
  terms,  
  ci_level = 0.95,  
  type = "fixed",  
  typical = "mean",  
  condition = NULL,  
  back_transform = TRUE,  
  vcov_fun = NULL,  
  vcov_type = NULL,  
  vcov_args = NULL,  
  weights = NULL,  
  verbose = TRUE,  
  ...
)
```
ggeffect(model, terms, ci_level = 0.95, verbose = TRUE, ci.lvl = ci_level, ...)

ggemmeans(
  model,
  terms,
  ci_level = 0.95,
  type = "fixed",
  typical = "mean",
  condition = NULL,
  back_transform = TRUE,
  vcov_fun = NULL,
  vcov_type = NULL,
  vcov_args = NULL,
  interval = "confidence",
  verbose = TRUE,
  ci.lvl = ci_level,
  back.transform = back_transform,
  ...
)

ggpredict(
  model,
  terms,
  ci_level = 0.95,
  type = "fixed",
  typical = "mean",
  condition = NULL,
  back_transform = TRUE,
  ppd = FALSE,
  vcov_fun = NULL,
  vcov_type = NULL,
  vcov_args = NULL,
  interval,
  verbose = TRUE,
  ci.lvl = ci_level,
  back.transform = back_transform,
  vcov.fun = vcov_fun,
  vcov.type = vcov_type,
  vcov.args = vcov_args,
  ...
)

Arguments

x An object of class ggeffects, as returned by predict_response(), ggpredict(), ggeffect(), ggaverage() or ggemmeans().

row.names NULL or a character vector giving the row names for the data frame. Missing values are not allowed.
optional logical. If TRUE, setting row names and converting column names (to syntactic names: see make.names) is optional. Note that all of R’s base package as.data.frame() methods use optional only for column names treatment, basically with the meaning of data.frame(*, check.names = !optional). See also the make_names argument of the matrix method.

Arguments are passed down to ggpredict() (further down to predict()) or ggemmeans() (and thereby to emmeans::emmeans()). If type = "simulate", ... may also be used to set the number of simulation, e.g. nsim = 500. When calling ggeffect(), further arguments passed down to effects::Effect().

stringsAsFactors logical: should the character vector be converted to a factor?

terms_to_colnames Logical, if TRUE, standardized column names (like "x", "group" or "facet") are replaced by the variable names of the focal predictors specified in terms.

model A model object, or a list of model objects.

terms Names of those terms from model, for which predictions should be displayed (so called focal terms). Can be:

- A character vector, specifying the names of the focal terms. This is the preferred and probably most flexible way to specify focal terms, e.g. terms = "x [40:60]", to calculate predictions for the values 40 to 60.
- A list, where each element is a named vector, specifying the focal terms and their values. This is the "classical" R way to specify focal terms, e.g. list(x = 40:60).
- A formula, e.g. terms = ~ x + z, which is internally converted to a character vector. This is probably the least flexible way, as you cannot specify representative values for the focal terms.
- A data frame representing a "data grid" or "reference grid". Predictions are then made for all combinations of the variables in the data frame.

terms at least requires one variable name. The maximum length is four terms, where the second to fourth term indicate the groups, i.e. predictions of the first term are grouped at meaningful values or levels of the remaining terms (see values_at()). It is also possible to define specific values for focal terms, at which adjusted predictions should be calculated (see details below). All remaining covariates that are not specified in terms are "marginalized", see the margin argument in ?predict_response. See also argument condition to fix non-focal terms to specific values, and argument typical for ggpredict() or ggemmeans().

ci_level Numeric, the level of the confidence intervals. Use ci_level = NA if confidence intervals should not be calculated (for instance, due to computation time). Typically, confidence intervals are based on the returned standard errors for the predictions, assuming a t- or normal distribution (based on the model and the available degrees of freedom, i.e. roughly +/- 1.96 * SE). See introduction of this vignette for more details.

type Character, indicating whether predictions should be conditioned on specific model components or not. Consequently, most options only apply for survival models, mixed effects models and/or models with zero-inflation (and their Bayesian
counter-parts); only exception is type = "simulate", which is available for some other model classes as well (which respond to simulate()).

**Note 1:** For brmsfit-models with zero-inflation component, there is no type = "zero_inflated" nor type = "zi_random"; predicted values for these models always condition on the zero-inflation part of the model. The same is true for MixMod-models from GLMMadaptive with zero-inflation component (see 'Details').

**Note 2:** If margin = "empirical", or when calling ggeaverage() respectively, (i.e. counterfactual predictions), the type argument is handled differently. It is set to "response" by default, but usually accepts all possible options from the type-argument of the model's respective predict() method. E.g., passing a glm object would allow the options "response", "link", and "terms". For models with zero-inflation component, the below mentioned options "fixed", "zero_inflated" and "zi_prob" can also be used and will be "translated" into the corresponding type option of the model's respective predict()-method.

- "fixed" (or "fe" or "count")
  Predicted values are conditioned on the fixed effects or conditional model only (for mixed models: predicted values are on the population-level and confidence intervals are returned, i.e. re.form = NA when calling predict()). For instance, for models fitted with zeroinfl from pscl, this would return the predicted mean from the count component (without zero-inflation). For models with zero-inflation component, this type calls predict(..., type = "link") (however, predicted values are back-transformed to the response scale, i.e. the conditional mean of the response).

- "random" (or "re")
  This only applies to mixed models, and type = "random" does not condition on the zero-inflation component of the model. type = "random" still returns population-level predictions, however, conditioned on random effects and considering individual level predictions, i.e. re.form = NULL when calling predict(). This may affect the returned predicted values, depending on whether REML = TRUE or REML = FALSE was used for model fitting. Furthermore, unlike type = "fixed", intervals also consider the uncertainty in the variance parameters (the mean random effect variance, see Johnson et al. 2014 for details) and hence can be considered as prediction intervals. For models with zero-inflation component, this type calls predict(..., type = "link") (however, predicted values are back-transformed to the response scale). To get predicted values for each level of the random effects groups, add the name of the related random effect term to the terms-argument (for more details, see this vignette).

- "zero_inflated" (or "fe.zi" or "zi")
  Predicted values are conditioned on the fixed effects and the zero-inflation component. For instance, for models fitted with zeroinfl from pscl, this would return the predicted (or expected) response ($\mu*(1-p)$), and for glmmTMB, this would return the expected response $\mu*(1-p)$ without conditioning on random effects (i.e. random effect variances are not taken into account for the confidence intervals). For models with zero-inflation component, this type calls predict(..., type = "response"). See 'Details'.
• "zi_random" (or "re.zi" or "zero_inflated_random")
  Predicted values are conditioned on the zero-inflation component and take
  the random effects uncertainty into account. For models fitted with glmmTMB(),
  hurdle() or zeroInfl(), this would return the expected value \( \mu*(1-p) \).
  For glmmTMB, prediction intervals also consider the uncertainty in
  the random effects variances. This type calls predict(..., type = "response")
  See 'Details'.
• "zi_prob" (or "zi.prob")
  Predicted zero-inflation probability. For glmmTMB models with zero-
  inflation component, this type calls predict(..., type = "zlink")
  models from pscl call predict(..., type = "zero") and for GLMMAdaptive,
  predict(..., type = "zero_part") is called.
• "simulate" (or "sim")
  Predicted values and confidence resp. prediction intervals are based on
  simulations, i.e. calls to simulate(). This type of prediction takes all
  model uncertainty into account, including random effects variances. Cur-
  rently supported models are objects of class lm, glm, glmmTMB, wbm, MixMod
  and merMod. See ... for details on number of simulations.
• "survival" and "cumulative_hazard" (or "surv" and "cumhaz")
  Applies only to coxph-objects from the survival-package and calculates
  the survival probability or the cumulative hazard of an event.

When margin = "empirical" (or when calling ggaverage()), the type argument accepts all values from the type-argument of the model's respective predict()-method.

**typical**
Character vector, naming the function to be applied to the covariates (non-focal terms) over which the effect is "averaged". The default is "mean". Can be "mean", "weighted.mean", "median", "mode" or "zero", which call the corresponding R functions (except "mode", which calls an internal function to compute the most common value); "zero" simply returns 0. By default, if the covariate is a factor, only "mode" is applicable; for all other values (including the default, "mean") the reference level is returned. For character vectors, only the mode is returned. You can use a named vector to apply different functions to integer, numeric and categorical covariates, e.g. typical = c(numeric = "median", factor = "mode"). If typical is "weighted.mean", weights from the model are used. If no weights are available, the function falls back to "mean". **Note** that this argument is ignored for predict_response(), because the margin argument takes care of this.

**condition**
Named character vector, which indicates covariates that should be held constant at specific values. Unlike typical, which applies a function to the covariates to determine the value that is used to hold these covariates constant, condition can be used to define exact values, for instance condition = c(covariate1 = 20, covariate2 = 5). See 'Examples'.

**back_transform**
Logical, if TRUE (the default), predicted values for log- or log-log transformed responses will be back-transformed to original response-scale.

**vcov_fun**
Variance-covariance matrix used to compute uncertainty estimates (e.g., for confidence intervals based on robust standard errors). This argument accepts a co-
variance matrix, a function which returns a covariance matrix, or a string which identifies the function to be used to compute the covariance matrix.

- A (variance-covariance) matrix
- A function which returns a covariance matrix (e.g., stats::vcov())
- A string which indicates the estimation type for the heteroscedasticity-consistent variance-covariance matrix, e.g., vcov_fun = "HC0". Possible values are "HC0", "HC1", "HC2", "HC3", "HC4", "HC4m", and "HC5", which will then call the vcovHC()-function from the sandwich package, using the specified type. Further possible values are "CR0", "CR1", "CR1p", "CR1S", "CR2", and "CR3", which will call the vcovCR()-function from the clubSandwich package.
- A string which indicates the name of the vcov*()-function from the sandwich or clubSandwich packages, e.g., vcov_fun = "vcovCL", which is used to compute (cluster) robust standard errors for predictions.

If NULL, standard errors (and confidence intervals) for predictions are based on the standard errors as returned by the predict()-function. Note that probably not all model objects that work with predict_response() are also supported by the sandwich or clubSandwich packages.

See details in this vignette.

vcov_type Character vector, specifying the estimation type for the robust covariance matrix estimation (see ?sandwich::vcovHC or ?clubSandwich::vcovCR for details). Only used when vcov_fun is a character string indicating one of the functions from those packages. When vcov_fun is a function, a possible type argument must be provided via the vcov_args argument.

vcov_args List of named vectors, used as additional arguments that are passed down to vcov_fun.

weights Character vector, naming the weighting variable in the data, or a vector of weights (of same length as the number of observations in the data). Only applies to margin = "empirical".

verbose Toggle messages or warnings.

ci.lvl, vcov.fun, vcov.type, vcov.args, back.transform

Deprecated arguments. Please use ci_level, vcov.fun, vcov.type, vcov.args and back_transform instead.

interval Type of interval calculation, can either be "confidence" (default) or "prediction". May be abbreviated. Unlike confidence intervals, prediction intervals include the residual variance (sigma^2) to account for the uncertainty of predicted values. For mixed models, interval = "prediction" is the default for type = "random". When type = "fixed", the default is interval = "confidence". Note that prediction intervals are not available for all models, but only for models that work with insight::get_sigma(). For Bayesian models, when interval = "confidence", predictions are based on posterior draws of the linear predictor rstantools::posterior_epred(). If interval = "prediction", rstantools::posterior_predict() is called.

ppd Logical, if TRUE, predictions for Stan-models are based on the posterior predictive distribution rstantools::posterior_predict(). If FALSE (the default),
predictions are based on posterior draws of the linear predictor \texttt{rstantools::posterior_epred()}. This is roughly comparable to the distinction between confidence and prediction intervals. \texttt{ppd = TRUE} incorporates the residual variance and hence returned intervals are similar to prediction intervals. Consequently, if \texttt{interval = "prediction"}, \texttt{ppd} is automatically set to \texttt{TRUE}. The \texttt{ppd} argument will be deprecated in a future version. Please use \texttt{interval = "prediction"} instead.

**Details**

Please see \texttt{?predict_response} for details and examples.

**Value**

A data frame (with \texttt{ggeffects} class attribute) with consistent data columns:

- "\textit{x}": the values of the first term in \texttt{terms}, used as x-position in plots.
- "\textit{predicted}": the predicted values of the response, used as y-position in plots.
- "\textit{std.error}": the standard error of the predictions. \textit{Note that the standard errors are always on the link-scale, and not back-transformed for non-Gaussian models!}
- "\textit{conf.low}": the lower bound of the confidence interval for the predicted values.
- "\textit{conf.high}": the upper bound of the confidence interval for the predicted values.
- "\textit{group}": the grouping level from the second term in \texttt{terms}, used as grouping-aesthetics in plots.
- "\textit{facet}": the grouping level from the third term in \texttt{terms}, used to indicate facets in plots.

The estimated marginal means (or predicted values) are always on the response scale!

For proportional odds logistic regression (see \texttt{?MASS::polr}) resp. cumulative link models (e.g., see \texttt{?ordinal::clm}), an additional column "\textit{response.level}" is returned, which indicates the grouping of predictions based on the level of the model’s response.

Note that for convenience reasons, the columns for the intervals are always named "\textit{conf.low}" and "\textit{conf.high}”, even though for Bayesian models credible or highest posterior density intervals are returned.

There is an \texttt{as.data.frame()} method for objects of class \texttt{ggeffects}, which has an \texttt{terms_to_colnames} argument, to use the term names as column names instead of the standardized names "\textit{x}" etc.

**coffee_data**

Sample dataset from a course about analysis of factorial designs

**Description**

A sample data set from a course about the analysis of factorial designs, by Mattan S. Ben-Shachar. See following link for more information: https://github.com/mattansb/Analysis-of-Factorial-Designs-for-Psychologists

The data consists of five variables from 120 observations:

- **ID**: A unique identifier for each participant
• sex: The participant's sex
• time: The time of day the participant was tested (morning, noon, or afternoon)
• coffee: Group indicator, whether participant drank coffee or not ("coffee" or "control").
• alertness: The participant’s alertness score.

Examples

```r
# Attach coffee-data
data(coffee_data)
```

collapse_by_group

Description

This function extracts the raw data points (i.e. the data that was used to fit the model) and "averages" (i.e. "collapses") the response variable over the levels of the grouping factor given in `collapse_by`. Only works with mixed models.

Usage

```r
collapse_by_group(grid, model, collapse_by = NULL, residuals = FALSE)
```

Arguments

- `grid`: A data frame representing the data grid, or an object of class `ggeffects`, as returned by `predict_response()`.
- `model`: The model for which to compute partial residuals. The data grid `grid` should match to predictors in the model.
- `collapse_by`: Name of the (random effects) grouping factor. Data is collapsed by the levels of this factor.
- `residuals`: Logical, if TRUE, collapsed partial residuals instead of raw data by the levels of the grouping factor.

Value

A data frame with raw data points, averaged over the levels of the given grouping factor from the random effects. The group level of the random effect is saved in the column "random".
Examples

```r
library(ggeffects)
data(efc, package = "ggeffects")
efc$e15relat <- as.factor(efc$e15relat)
efc$c161sex <- as.factor(efc$c161sex)
levels(efc$c161sex) <- c("male", "female")
model <- lme4::lmer(neg_c_7 ~ c161sex + (1 | e15relat), data = efc)
me <- predict_response(model, terms = "c161sex")
head(attributes(me)$rawdata)
collapse_by_group(me, model, "e15relat")
```

efc  
*Sample dataset from the EUROFAMCARE project*

Description

An SPSS sample data set, imported with the `sjlabelled::read_spss()` function. Consists of 28 variables from 908 observations. The data set is part of the EUROFAMCARE project, a cross-national survey on informal caregiving in Europe.

Examples

```r
# Attach EFC-data
data(efc)

# Show structure
str(efc)

# show first rows
head(efc)
```

fish  
*Sample data set*

Description

A sample data set, used in tests and some examples. Useful for demonstrating count models (with or without zero-inflation component). It consists of nine variables from 250 observations.
Description

A generic print-method for ggeffects-objects.

Usage

```r
## S3 method for class 'ggeffects'
format(
  x,
  variable_labels = FALSE,
  value_labels = FALSE,
  group_name = FALSE,
  row_header_separator = "",",
  digits = 2,
  collapse_ci = FALSE,
  collapse_tables = FALSE,
  n,
  ...
)

## S3 method for class 'ggcomparisons'
format(x, collapse_ci = FALSE, collapse_p = FALSE, combine_levels = FALSE, ...)

## S3 method for class 'ggeffects'
print(x, group_name = TRUE, digits = 2, verbose = TRUE, ...)

## S3 method for class 'ggeffects'
print_md(x, group_name = TRUE, digits = 2, ...)

## S3 method for class 'ggeffects'
print_html(
  x,
  group_name = TRUE,
  digits = 2,
  theme = NULL,
  engine = c("tt", "gt"),
  ...
)

## S3 method for class 'ggcomparisons'
print(x, collapse_tables = FALSE, ...)

## S3 method for class 'ggcomparisons'
print_html(
```
Arguments

**x**  
An object of class `ggeffects`, as returned by the functions from this package.

**variable_labels**  
Logical, if TRUE variable labels are used as column headers. If FALSE, variable names are used.

**value_labels**  
Logical, if TRUE, value labels are used as values in the table output. If FALSE, the numeric values or factor levels are used.

**group_name**  
Logical, if TRUE, the name of further focal terms are used in the sub-headings of the table. If FALSE, only the values of the focal terms are used.

**row_header_separator**  
Character, separator between the different subgroups in the table output.

**digits**  
Number of digits to print.

**collapse_ci**  
Logical, if TRUE, the columns with predicted values and confidence intervals are collapsed into one column, e.g. Predicted (95% CI).

**collapse_tables**  
Logical, if TRUE, all tables are combined into one. The tables are not split by further focal terms, but rather are added as columns. Only works when there is more than one focal term.

**n**  
Number of rows to print per subgroup. If NULL, a default number of rows is printed, depending on the number of subgroups.

...  
Further arguments passed down to `format.ggeffects()`, some of them are also passed down further to `insight::format_table()` or `insight::format_value()`.

**collapse_p**  
Logical, if TRUE, the columns with predicted values and p-values are collapsed into one column, where significant p-values are indicated as asterisks.

**combine_levels**  
Logical, if TRUE, the levels of the first comparison of each focal term against the second are combined into one column. This is useful when comparing multiple focal terms, e.g. `education = low-high` and `gender = male-female` are combined into `first = low-male` and `second = high-female`.

**verbose**  
Toggle messages.

**theme**  
The theme to apply to the table. One of "grid", "striped", "bootstrap", or "darklines".

**engine**  
The engine to use for printing. One of "tt" (default) or "gt". "tt" uses the `tinytable` package, "gt" uses the `gt` package.
Value

format() return a formatted data frame, print() prints a formatted data frame printed to the console. print_html() returns a tinytable object by default (unless changed with engine = "gt"), which is printed as HTML, markdown or LaTeX table (depending on the context from which print_html() is called, see tinytable::tt() for details).

Global Options to Customize Tables when Printing

The verbose argument can be used to display or silence messages and warnings. Furthermore, options() can be used to set defaults for the print() and print_html() method. The following options are available, which can simply be run in the console:

- ggeffects_ci_brackets: Define a character vector of length two, indicating the opening and closing parentheses that encompass the confidence intervals values, e.g. options(ggeffects_ci_brackets = c("[", "]")).
- ggeffectsCollapse_ci: Logical, if TRUE, the columns with predicted values (or contrasts) and confidence intervals are collapsed into one column, e.g. options(ggeffectsCollapse_ci = TRUE).
- ggeffectsCollapse_p: Logical, if TRUE, the columns with predicted values (or contrasts) and p-values are collapsed into one column, e.g. options(ggeffectsCollapse_p = TRUE). Note that p-values are replaced by asterisk-symbols (stars) or empty strings when ggeffectsCollapse_p = TRUE, depending on the significance level.
- ggeffectsCollapse_tables: Logical, if TRUE, multiple tables for subgroups are combined into one table. Only works when there is more than one focal term, e.g. options(ggeffectsCollapse_tables = TRUE).
- ggeffectsOutput_format: String, either "text", "markdown" or "html". Defines the default output format from predict_response(). If "html", a formatted HTML table is created and printed to the view pane. "markdown" creates a markdown-formatted table inside Rmarkdown documents, and prints a text-format table to the console when used interactively. If "text" or NULL, a formatted table is printed to the console, e.g. options(ggeffectsOutput_format = "html").
- ggeffectsHtml_engine: String, either "tt" or "gt". Defines the default engine to use for printing HTML tables. If "tt", the tinytable package is used, if "gt", the gt package is used, e.g. options(ggeffectsHtml_engine = "gt").

Use options(<option_name> = NULL) to remove the option.

Examples

data(efc, package = "ggeffects")
fit <- lm(barthtot ~ c12hour + e42dep, data = efc)

# default print
predict_response(fit, "e42dep")

# surround CI values with parentheses
print(predict_response(fit, "e42dep"), ci_brackets = c("([", "]")
# you can also use 'options(ggeffects_ci_brackets = c([", "]'))

# to set this globally

# collapse CI columns into column with predicted values
print(predict_response(fit, "e42dep"), collapse_ci = TRUE)

# include value labels
print(predict_response(fit, "e42dep"), value_labels = TRUE)

# include variable labels in column headers
print(predict_response(fit, "e42dep"), variable_labels = TRUE)

# include value labels and variable labels
print(predict_response(fit, "e42dep"), variable_labels = TRUE, value_labels = TRUE)

data(iris)
m <- lm(Sepal.Length ~ Species * Petal.Length, data = iris)

# default print with subgroups
predict_response(m, c("Petal.Length", "Species"))

# omit name of grouping variable in subgroup table headers
print(predict_response(m, c("Petal.Length", "Species")), group_name = FALSE)

# collapse tables into one
predict_response(m, c("Petal.Length", "Species"), collapse_tables = TRUE, n = 3)

# increase number of digits
print(predict_response(fit, "e42dep"), digits = 5)

---

**get_title**

*Get titles and labels from data*

**Description**

Get variable and value labels from ggeffects-objects. `predict_response()` saves information on variable names and value labels as additional attributes in the returned data frame. This is especially helpful for labelled data (see `sjlabelled`), since these labels can be used to set axis labels and titles.

**Usage**

```r
get_title(x, case = NULL)
get_x_title(x, case = NULL)
get_y_title(x, case = NULL)
get_legend_title(x, case = NULL)
```
get_legend_labels(x, case = NULL)

gget_title

gget_x_labels(x, case = NULL)

gget_complete_df(x, case = NULL)

Arguments

x  An object of class ggeffects, as returned by any ggeffects-function; for get_complete_df(), must be a list of ggeffects-objects.

case  Desired target case. Labels will automatically converted into the specified character case. See ?sjlabelled::convert_case for more details on this argument.

Value

The titles or labels as character string, or NULL, if variables had no labels; get_complete_df() returns the input list x as single data frame, where the grouping variable indicates the predicted values for each term.

Examples

library(ggeffects)
library(ggplot2)
data(efc, package = "ggeffects")
ecf$c172code <- datawizard::to_factor(ecf$c172code)
fit <- lm(barthtot ~ c12hour + neg_c_7 + c161sex + c172code, data = efc)
mydf <- predict_response(fit, terms = c("c12hour", "c161sex", "c172code"))

ggplot(mydf, aes(x = x, y = predicted, colour = group)) +
  stat_smooth(method = "lm") +
  facet_wrap(~facet, ncol = 2) +
  labs(
    x = get_x_title(mydf),
    y = get_y_title(mydf),
    colour = get_legend_title(mydf)
  )

get_complete_df(mydf)

# adjusted predictions, a list of data frames (one data frame per term)
eff <- ggeffect(fit)
eff
gget_complete_df(eff)

# adjusted predictions for education only, and get x-axis-labels
mydat <- eff[["c172code"]]

# adjusted predictions for education only, and get x-axis-labels
mydat <- eff[["c172code"]]

ggplot(mydat, aes(x = x, y = predicted, group = group)) +
  stat_summary(fun = sum, geom = "line") +
  scale_x_discrete(labels = get_x_labels(mydat))
install_latest

Update latest ggeffects-version from R-universe (GitHub) or CRAN

Description

This function can be used to install the latest package version of ggeffects, either the development version (from R-universe/GitHub) or the current version from CRAN.

Usage

install_latest(
  source = c("development", "cran"),
  force = FALSE,
  verbose = TRUE
)

Arguments

source Character. Either "development" or "cran". If "cran", ggeffects will be installed from the default CRAN mirror returned by getOption("repos")[['CRAN']]. If "development" (the default), ggeffects is installed from the r-universe repository (https://strengejacke.r-universe.dev/).

force Logical, if FALSE, the update will only be installed if a newer version is available. Use force=TRUE to force installation, even if the version number for the locally installed package is identical to the latest development-version. Only applies when source="development".

verbose Toggle messages.

Value

Invisible NULL.

Examples

# install latest development-version of ggeffects from the
# r-universe repository
install_latest()
**johnson_neyman**

Spotlight-analysis: Create Johnson-Neyman confidence intervals and plots

**Description**

Function conduct a spotlight-analysis to create so-called Johnson-Neyman intervals. The `plot()` method can be used to visualize the results of the Johnson-Neyman test.

**Usage**

```r
johnson_neyman(x, precision = 500, p_adjust = NULL, ...)
spotlight_analysis(x, precision = 500, p_adjust = NULL, ...)
```

```r
## S3 method for class 'ggjohnson_neyman'
plot(
x,
  colors = c("#f44336", "#2196F3"),
  show_association = TRUE,
  show_rug = FALSE,
  verbose = TRUE,
  ...
)
```

**Arguments**

- `x` An object of class `ggeffects`, as returned by the functions from this package.
- `precision` Number of values used for the range of the moderator variable to calculate the Johnson-Neyman interval. This argument is passed down to `pretty(..., n = precision)`. Usually, the default value of 500 is sufficient. Increasing this value will result in a smoother plot and more accurate values for the interval bounds, but can also slightly increase the computation time.
- `p_adjust` Character vector, if not `NULL`, indicates the method to adjust p-values. See `stats::p.adjust()` or `stats::p.adjust.methods` for details. Further possible adjustment methods are "tukey" or "sidak", and for `johnson_neyman()`, "fdr" (or "bh") and "esarey" (or its short-cut "es") are available options. Some caution is necessary when adjusting p-value for multiple comparisons. See also section P-value adjustment below.
- `...` Arguments passed down to `test_predictions()` (and then probably further to `marginaleffects::slopes()`). See ?test_predictions for further details.
- `colors` Colors used for the plot. Must be a vector with two color values. Only used if `show_association = TRUE`.
- `show_association` Logical, if `TRUE`, highlights the range where values of the moderator are positively or negatively associated with the outcome.
show_rug Logical, if TRUE, adds a rug with raw data of the moderator variable to the plot. This helps visualizing its distribution.

verbose Show/hide printed message for plots.

Details

The Johnson-Neyman intervals help to understand where slopes are significant in the context of interactions in regression models. Thus, the interval is only useful if the model contains at least one interaction term. The function accepts the results of a call to \texttt{predict_response()}. The \texttt{first} and the \texttt{last} focal term used in the \texttt{terms} argument of \texttt{predict_response()} must be numeric. The function will then test the slopes of the first focal terms against zero, for different moderator values of the last focal term. If only one numeric focal term is given, the function will create contrasts by levels of the categorical focal term. Use \texttt{plot()} to create a plot of the results.

To avoid misleading interpretations of the plot, we speak of "positive" and "negative" associations, respectively, and "no clear" associations (instead of "significant" or "non-significant"). This should prevent the user from considering a non-significant range of values of the moderator as "accepting the null hypothesis".

Value

A data frame including contrasts of the \texttt{test_predictions()} for the given interaction terms; for \texttt{plot()}, returns a Johnson-Neyman plot.

P-value adjustment for multiple comparisons

Note that p-value adjustment for methods supported by \texttt{p.adjust()} (see also \texttt{p.adjust.methods}), each row is considered as one set of comparisons, no matter which test was specified. That is, for instance, when \texttt{test_predictions()} returns eight rows of predictions (when \texttt{test = NULL}), and \texttt{p.adjust = "bonferroni"}, the p-values are adjusted in the same way as if we had a test of pairwise comparisons (\texttt{test = "pairwise"}) where eight rows of comparisons are returned. For methods "tukey" or "sidak", a rank adjustment is done based on the number of combinations of levels from the focal predictors in terms. Thus, the latter two methods may be useful for certain tests only, in particular pairwise comparisons.

For \texttt{johnson_neyman()}, the only available adjustment methods are "fdr" (or "bh") \citep{benjamini1995false} and "esarey" (or "es") \citep{esarey2017marginal}. These usually return similar results. The major difference is that "fdr" can be slightly faster and more stable in edge cases, however, confidence intervals are not updated. Only the p-values are adjusted. "esarey" is slower, but confidence intervals are updated as well.

References

\citep{bauer2005probing} \citep{esarey2017marginal}

\citep{johnson1950johnson}

\citep{esarey2017marginal}

\citep{bauer2005probing}


Examples

```r
## Not run:
data(efc, package = "ggeffects")
ecf$c172code <- as.factor(ecf$c172code)
m <- lm(neg_c_7 ~ c12hour * barthtot * c172code, data = efc)

pr <- predict_response(m, c("c12hour", "barthtot"))
johnson_neyman(pr)
plot(johnson_neyman(pr))

pr <- predict_response(m, c("c12hour", "c172code", "barthtot"))
johnson_neyman(pr)
plot(johnson_neyman(pr))

# robust standard errors
if (requireNamespace("sandwich")) {
  johnson_neyman(pr, vcov = sandwich::vcovHC)
}
## End(Not run)
```

lung2

**Sample data set**

A sample data set, used in tests and examples for survival models. This dataset is originally included in the `survival` package, but for convenience reasons it is also available in this package.

new_data

**Create a data frame from all combinations of predictor values**

Description

Create a data frame for the "newdata"-argument that contains all combinations of values from the terms in questions. Similar to `expand.grid()`. The `terms`-argument accepts all shortcuts for representative values as in `predict_response()`.
Usage

new_data(model, terms, typical = "mean", condition = NULL, ...)
data_grid(model, terms, typical = "mean", condition = NULL, ...)

Arguments

model A fitted model object.
terms Character vector with the names of those terms from model for which all combinations of values should be created. This argument works in the same way as the terms argument in predict_response(). See also this vignette.
typical Character vector, naming the function to be applied to the covariates (non-focal terms) over which the effect is "averaged". The default is "mean". Can be "mean", "weighted.mean", "median", "mode" or "zero", which call the corresponding R functions (except "mode", which calls an internal function to compute the most common value); "zero" simply returns 0. By default, if the covariate is a factor, only "mode" is applicable; for all other values (including the default, "mean") the reference level is returned. For character vectors, only the mode is returned. You can use a named vector to apply different functions to integer, numeric and categorical covariates, e.g. typical = c(numeric = "median", factor = "mode"). If typical is "weighted.mean", weights from the model are used. If no weights are available, the function falls back to "mean". Note that this argument is ignored for predict_response(), because the margin argument takes care of this.
condition Named character vector, which indicates covariates that should be held constant at specific values. Unlike typical, which applies a function to the covariates to determine the value that is used to hold these covariates constant, condition can be used to define exact values, for instance condition = c(covariate1 = 20, covariate2 = 5). See 'Examples'.

... Currently not used.

Value

A data frame containing one row for each combination of values of the supplied variables.

Examples

data(efc, package = "ggeffects")
fit <- lm(barthtot ~ c12hour + neg_c_7 + c161sex + c172code, data = efc)
new_data(fit, c("c12hour [meansd]", "c161sex"))

nd <- new_data(fit, c("c12hour [meansd]", "c161sex"))
pr <- predict(fit, type = "response", newdata = nd)
nd$predicted <- pr
nd

# compare to
predict_response(fit, c("c12hour [meansd]", "c161sex"))
**Plot ggeffects-objects**

### Description

A generic plot-method for ggeffects-objects.

### Usage

```r
## S3 method for class 'ggeffects'
plot(
  x,
  show_ci = TRUE,
  ci_style = c("ribbon", "errorbar", "dash", "dot"),
  show_data = FALSE,
  show_residuals = FALSE,
  show_residuals_line = FALSE,
  data_labels = FALSE,
  limit_range = FALSE,
  collapse_group = FALSE,
  show_legend = TRUE,
  show_title = TRUE,
  show_x_title = TRUE,
  show_y_title = TRUE,
  case = NULL,
  colors = NULL,
  alpha = 0.15,
  dot_alpha = 0.35,
  jitter = NULL,
  dodge = 0.25,
  dot_size = NULL,
  line_size = NULL,
  use_theme = TRUE,
  log_y = FALSE,
  connect_lines = FALSE,
  facets,
  grid,
  one_plot = TRUE,
  n_rows = NULL,
  verbose = TRUE,
  ci = show_ci,
  ci_style = ci_style,
  rawdata = show_data,
  add.data = show_data,
  residuals = show_residuals,
  residuals.line = show_residuals_line,
  label.data = data_labels,
)```

```
plot

limit.range = limit_range,
collapse.group = collapse_group,
dot.alpha = dot.alpha,
dot.size = dot_size,
line.size = line_size,
connect.lines = connect_lines,
show.title = show_title,
show.x.title = show.x.title,
show.y.title = show.y.title,
use.theme = use_theme,
show.legend = show.legend,
one.plot = one_plot,
log.y = log_y,
...
)

theme_ggeffects(base_size = 11, base_family = "")

show_pals()

Arguments

x An object of class ggeffects, as returned by the functions from this package.
show_ci Logical, if TRUE, confidence bands (for continuous variables at x-axis) resp. error bars (for factors at x-axis) are plotted.

show_residuals_line Logical, if TRUE, a loess-fit line is added to the partial residuals plot. Only applies if residuals is TRUE.
data_labels Logical, if TRUE and row names in data are available, data points will be labelled by their related row name.
limit_range Logical, if TRUE, limits the range of the prediction bands to the range of the data.
collapse_group For mixed effects models, name of the grouping variable of random effects. If collapse_group = TRUE, data points "collapsed" by the first random effect groups are added to the plot. Else, if collapse_group is a name of a group factor, data is collapsed by that specific random effect. See collapse_by_group() for further details.
show_legend Logical, shows or hides the plot legend.

show_title Logical, shows or hides the plot title.

show_x_title Logical, shows or hides the plot title for the x-axis.

show_y_title Logical, shows or hides the plot title for the y-axis.

case Desired target case. Labels will automatically converted into the specified character case. See ?sjlabelled::convert_case for more details on this argument.

colors Character vector with color values in hex-format, valid color value names (see demo("colors")) or a name of a ggeffects-color-palette.

Following options are valid for colors:

• If not specified, the color brewer palette "Set1" will be used.
• If "gs", a greyscale will be used.
• If "bw", the plot is black/white and uses different line types to distinguish groups.
• There are some pre-defined color-palettes in this package that can be used, e.g. colors = "metro". See show_pals() to show all available palettes.
• Else specify own color values or names as vector (e.g. colors = c("#f00000", "#00ff00").

alpha Alpha value for the confidence bands.

dot_alpha Alpha value for data points, when show_data = TRUE.

jitter Numeric, between 0 and 1. If not NULL and show_data = TRUE, adds a small amount of random variation to the location of data points dots, to avoid overplotting. Hence the points don't reflect exact values in the data. May also be a numeric vector of length two, to add different horizontal and vertical jittering. For binary outcomes, raw data is not jittered by default to avoid that data points exceed the axis limits.

dodge Value for offsetting or shifting error bars, to avoid overlapping. Only applies, if a factor is plotted at the x-axis (in such cases, the confidence bands are replaced by error bars automatically), or if ci_style = "errorbars".

dot_size Numeric, size of the point geoms.

line_size Numeric, size of the line geoms.

use_theme Logical, if TRUE, a slightly tweaked version of ggplot’s minimal-theme, theme_ggeffects(), is applied to the plot. If FALSE, no theme-modifications are applied.

log_y Logical, if TRUE, the y-axis scale is log-transformed. This might be useful for binomial models with predicted probabilities on the y-axis.

connect_lines Logical, if TRUE and plot has point-geoms with error bars (this is usually the case when the x-axis is discrete), points of same groups will be connected with a line.

facets grid Logical, defaults to TRUE if x has a column named facet, and defaults to FALSE if x has no such column. Set facets = TRUE to wrap the plot into facets even for grouping variables (see 'Examples'). grid is an alias for facets.

one_plot Logical, if TRUE and x has a panel column (i.e. when four terms were used), a single, integrated plot is produced.
n_rows  Number of rows to align plots. By default, all plots are aligned in one row. For facets, or multiple panels, plots can also be aligned in multiple rows, to avoid that plots are too small.

verbose  Logical, toggle warnings and messages.

ci, add.data, rawdata, residuals, residuals.line, label.data, limit.range, collapse.group, dot.alpha, dot.size, line.size, connect.lines, show.title, show.x.title, show.y.title, use.theme, one.plot, ci.style, show.legend, log.y  
   Deprecated arguments. Use show.ci, show_data, show_residuals, show_residuals_line, data_labels, limit_range, collapse_group, dot_alpha, dot_size, line_size, connect_lines, show_title, show_x_title, show_y_title, use_theme, ci_style, show_legend, log_y and one_plot instead.

...  Further arguments passed down to ggplot::scale_y*(), to control the appearance of the y-axis.

base_size  Base font size.

base_family  Base font family.

Details  
For proportional odds logistic regression (see ?MASS::polr) or cumulative link models in general, plots are automatically facetted by response.level, which indicates the grouping of predictions based on the level of the model’s response.

Value  
A ggplot2-object.

Partial Residuals  
For generalized linear models (glm's), residualized scores are computed as \( \text{inv.link(link(Y) + r)} \) where \( Y \) are the predicted values on the response scale, and \( r \) are the working residuals.

For (generalized) linear mixed models, the random effect are also partialled out.

Note  
Load library(ggplot2) and use theme_set(theme_ggeffects()) to set the ggeffects-theme as default plotting theme. You can then use further plot-modifiers, e.g. from sjPlot, like legend_style() or font_size() without losing the theme-modifications.

There are pre-defined colour palettes in this package. Use show_pals() to show all available colour palettes.

Examples  
library(sjlabelled)  
data(efc)  
efc$c172code <- as_label(efc$c172code)  
fit <- lm(barthtot ~ c12hour + neg_c_7 + c161sex + c172code, data = efc)
dat <- predict_response(fit, terms = "c12hour")
plot(dat)

# facet by group, use pre-defined color palette
dat <- predict_response(fit, terms = c("c12hour", "c172code"))
plot(dat, facet = TRUE, colors = "hero")

# don't use facets, b/w figure, w/o confidence bands
dat <- predict_response(fit, terms = c("c12hour", "c172code"))
plot(dat, colors = "bw", show_ci = FALSE)

# factor at x axis, plot exact data points and error bars
dat <- predict_response(fit, terms = c("c172code", "c161sex"))
plot(dat)

# for three variables, automatic facetting
dat <- predict_response(fit, terms = c("c12hour", "c172code", "c161sex"))
plot(dat)

# show all color palettes
show_pals()

---

**pool_comparisons**  
*Pool contrasts and comparisons from test_predictions()*

**Description**

This function "pools" (i.e. combines) multiple ggcomparisons objects, returned by `test_predictions()`, in a similar fashion as `mice::pool()`.

**Usage**

`pool_comparisons(x, ...)`

**Arguments**

- `x`  
  A list of ggcomparisons objects, as returned by `test_predictions()`.

- `...`  
  Currently not used.

**Details**

Averaging of parameters follows Rubin’s rules (*Rubin, 1987, p. 76*).

**Value**

A data frame with pooled comparisons or contrasts of predictions.
References


Examples

```r
data("nhanes2", package = "mice")
imp <- mice::mice(nhanes2, printFlag = FALSE)
comparisons <- lapply(1:5, function(i) {
  m <- lm(bmi ~ age + hyp + chl, data = mice::complete(imp, action = i))
  test_predictions(m, "age")
})
pool_comparisons(comparisons)
```

---

pool_predictions

Pool Predictions or Estimated Marginal Means

Description

This function "pools" (i.e. combines) multiple ggeffects objects, in a similar fashion as `mice::pool()`.

Usage

```r
pool_predictions(x, ...)
```

Arguments

- `x` A list of ggeffects objects, as returned by `predict_response()`.
- `...` Currently not used.

Details

Averaging of parameters follows Rubin’s rules (Rubin, 1987, p. 76).

Value

A data frame with pooled predictions.

References

Examples

# example for multiple imputed datasets
data("nhanes2", package = "mice")
imp <- mice::mice(nhanes2, printFlag = FALSE)
predictions <- lapply(1:5, function(i) {
  m <- lm(bmi ~ age + hyp + chl, data = mice::complete(imp, action = i))
predict_response(m, "age")
})
pool_predictions(predictions)

predict_response Adjusted predictions and estimated marginal means from regression models

Description

After fitting a model, it is useful to generate model-based estimates (expected values, or adjusted predictions) of the response variable for different combinations of predictor values. Such estimates can be used to make inferences about relationships between variables.

The ggeffects package computes marginal means and adjusted predicted values for the response, at the margin of specific values or levels from certain model terms. The package is built around three core functions: predict_response() (understanding results), test_predictions() (importance of results) and plot() (communicate results).

By default, adjusted predictions or marginal means are returned on the response scale, which is the easiest and most intuitive scale to interpret the results. There are other options for specific models as well, e.g. with zero-inflation component (see documentation of the type-argument). The result is returned as structured data frame, which is nicely printed by default. plot() can be used to easily create figures.

The main function to calculate marginal means and adjusted predictions is predict_response(), which returns adjusted predictions, marginal means or averaged counterfactual predictions depending on value of the margin-argument.

In previous versions of ggeffects, the functions ggpredict(), ggemmeans(), ggeffect() and ggaverage() were used to calculate marginal means and adjusted predictions. These functions are still available, but predict_response() as a "wrapper" around these functions is the preferred way to calculate marginal means and adjusted predictions now.

Usage

predict_response(
  model,
  terms,
  margin = "mean_reference",
  ci_level = 0.95,
  type = "fixed",
  condition = NULL,
back_transform = TRUE,
ppd = FALSE,
vcov_fun = NULL,
vcov_type = NULL,
vcov_args = NULL,
weights = NULL,
interval,
verbose = TRUE,
...)

Arguments

model A model object.
terms Names of those terms from model, for which predictions should be displayed (so called focal terms). Can be:

- A character vector, specifying the names of the focal terms. This is the preferred and probably most flexible way to specify focal terms, e.g. terms = "x [40:60]", to calculate predictions for the values 40 to 60.
- A list, where each element is a named vector, specifying the focal terms and their values. This is the "classical" R way to specify focal terms, e.g. list(x = 40:60).
- A formula, e.g. terms = ~ x + z, which is internally converted to a character vector. This is probably the least flexible way, as you cannot specify representative values for the focal terms.
- A data frame representing a "data grid" or "reference grid". Predictions are then made for all combinations of the variables in the data frame.

terms at least requires one variable name. The maximum length is four terms, where the second to fourth term indicate the groups, i.e. predictions of the first term are grouped at meaningful values or levels of the remaining terms (see values_at()). It is also possible to define specific values for focal terms, at which adjusted predictions should be calculated (see details below). All remaining covariates that are not specified in terms are "marginalized", see the margin argument in predict_response. See also argument condition to fix non-focal terms to specific values, and argument typical for ggpredict() or ggemmeans().

margin Character string, indicating how to marginalize over the non-focal predictors, i.e. those variables that are not specified in terms. Possible values are "mean_reference", "mean_mode", "marginalmeans" and "empirical" (or "counterfactual", aka average "counterfactual" predictions). You can set a default-option for the margin argument via options(), e.g. options(ggeffects_margin = "empirical"), so you don’t have to specify your preferred marginalization method each time you call predict_response(). See details in the documentation below.

ci_level Numeric, the level of the confidence intervals. Use ci_level = NA if confidence intervals should not be calculated (for instance, due to computation time). Typically, confidence intervals are based on the returned standard errors for the predictions, assuming a t- or normal distribution (based on the model and the
predict_response

available degrees of freedom, i.e. roughly +/- 1.96 * SE). See introduction of this vignette for more details.

**type**  
Character, indicating whether predictions should be conditioned on specific model components or not. Consequently, most options only apply for survival models, mixed effects models and/or models with zero-inflation (and their Bayesian counter-parts); only exception is type = "simulate", which is available for some other model classes as well (which respond to simulate()).

**Note 1:** For brmsfit-models with zero-inflation component, there is no type = "zero_inflated" nor type = "zi_random"; predicted values for these models always condition on the zero-inflation part of the model. The same is true for MixMod-models from GLMMadaptive with zero-inflation component (see 'Details').

**Note 2:** If margin = "empirical", or when calling ggaverage() respectively, (i.e. counterfactual predictions), the type argument is handled differently. It is set to "response" by default, but usually accepts all possible options from the type-argument of the model's respective predict() method. E.g., passing a glm object would allow the options "response", "link", and "terms". For models with zero-inflation component, the below mentioned options "fixed", "zero_inflated" and "zi_prob" can also be used and will be "translated" into the corresponding type option of the model's respective predict()-method.

- **"fixed"** (or "fe" or "count")
  Predicted values are conditioned on the fixed effects or conditional model only (for mixed models: predicted values are on the population-level and confidence intervals are returned, i.e. re.form = NA when calling predict()). For instance, for models fitted with zeroinfl from pscl, this would return the predicted mean from the count component (without zero-inflation). For models with zero-inflation component, this type calls predict(..., type = "link") (however, predicted values are back-transformed to the response scale, i.e. the conditional mean of the response).

- **"random"** (or "re")
  This only applies to mixed models, and type = "random" does not condition on the zero-inflation component of the model. type = "random" still returns population-level predictions, however, conditioned on random effects and considering individual level predictions, i.e. re.form = NULL when calling predict(). This may affect the returned predicted values, depending on whether REML = TRUE or REML = FALSE was used for model fitting. Furthermore, unlike type = "fixed", intervals also consider the uncertainty in the variance parameters (the mean random effect variance, see Johnson et al. 2014 for details) and hence can be considered as prediction intervals. For models with zero-inflation component, this type calls predict(..., type = "link") (however, predicted values are back-transformed to the response scale).
  To get predicted values for each level of the random effects groups, add the name of the related random effect term to the terms-argument (for more details, see this vignette).

- **"zero_inflated"** (or "fe.zi" or "zi")
  Predicted values are conditioned on the fixed effects and the zero-inflation component. For instance, for models fitted with zeroinfl from pscl, this
would return the predicted (or expected) response \((\mu(1-p))\), and for \texttt{glmmTMB}, this would return the expected response \(\mu(1-p)\) without conditioning on random effects (i.e. random effect variances are not taken into account for the confidence intervals). For models with zero-inflation component, this type calls \texttt{predict(..., type = "response")}. See 'Details'.

- **"zi_random"** (or "re.zi" or "zero_inflated_random")
  Predicted values are conditioned on the zero-inflation component and take the random effects uncertainty into account. For models fitted with \texttt{glmmTMB()}, \texttt{hurdle()} or \texttt{zeroinfl()}, this would return the expected value \(\mu(1-p)\). For \texttt{glmmTMB}, prediction intervals also consider the uncertainty in the random effects variances. This type calls \texttt{predict(..., type = "response")}. See 'Details'.

- **"zi_prob"** (or "zi.prob")
  Predicted zero-inflation probability. For \texttt{glmmTMB} models with zero-inflation component, this type calls \texttt{predict(..., type = "zlink")}; models from \texttt{pscl} call \texttt{predict(..., type = "zero")} and for \texttt{GLMMadaptive}, \texttt{predict(..., type = "zero_part")} is called.

- **"simulate"** (or "sim")
  Predicted values and confidence resp. prediction intervals are based on simulations, i.e. calls to \texttt{simulate()}. This type of prediction takes all model uncertainty into account, including random effects variances. Currently supported models are objects of class \texttt{lm}, \texttt{glm}, \texttt{glmmTMB}, \texttt{wbm}, \texttt{MixMod} and \texttt{merMod}. See ... for details on number of simulations.

- **"survival"** and **"cumulative_hazard"** (or "surv" and "cumhaz")
  Applies only to \texttt{coxph}-objects from the \texttt{survival}-package and calculates the survival probability or the cumulative hazard of an event.

When \texttt{margin = "empirical"} (or when calling \texttt{ggaverage()}), the type argument accepts all values from the \texttt{type}-argument of the model's respective \texttt{predict()-method}.

**condition**
Named character vector, which indicates covariates that should be held constant at specific values. Unlike \texttt{typical}, which applies a function to the covariates to determine the value that is used to hold these covariates constant, condition can be used to define exact values, for instance condition = \texttt{c(covariate1 = 20, covariate2 = 5)}. See 'Examples'.

**back_transform**
Logical, if \texttt{TRUE} (the default), predicted values for log- or log-log transformed responses will be back-transformed to original response-scale.

**ppd**
Logical, if \texttt{TRUE}, predictions for Stan-models are based on the posterior predictive distribution \texttt{rstantools::posterior_predict()}, if \texttt{FALSE} (the default), predictions are based on posterior draws of the linear predictor \texttt{rstantools::posterior_epred()}. This is roughly comparable to the distinction between confidence and prediction intervals. \texttt{ppd = TRUE} incorporates the residual variance and hence returned intervals are similar to prediction intervals. Consequently, if \texttt{interval = "prediction"}, \texttt{ppd} is automatically set to \texttt{TRUE}. The \texttt{ppd} argument will be deprecated in a future version. Please use \texttt{interval = "prediction"} instead.

**vcov_fun**
Variance-covariance matrix used to compute uncertainty estimates (e.g., for confidence intervals based on robust standard errors). This argument accepts a co-
variance matrix, a function which returns a covariance matrix, or a string which identifies the function to be used to compute the covariance matrix.

- A (variance-covariance) matrix
- A function which returns a covariance matrix (e.g., stats::vcov())
- A string which indicates the estimation type for the heteroscedasticity-consistent variance-covariance matrix, e.g. vcov.fun = "HC0". Possible values are "HC0", "HC1", "HC2", "HC3", "HC4", "HC4m", and "HC5", which will then call the vcovHC() function from the sandwich package, using the specified type. Further possible values are "CR0", "CR1", "CR1p", "CR1S", "CR2", and "CR3", which will call the vcovCR() function from the clubSandwich package.
- A string which indicates the name of the vcov*() function from the sandwich or clubSandwich packages, e.g. vcov.fun = "vcovCL", which is used to compute (cluster) robust standard errors for predictions.

If NULL, standard errors (and confidence intervals) for predictions are based on the standard errors as returned by the predict()-function. Note that probably not all model objects that work with predict_response() are also supported by the sandwich or clubSandwich packages.

See details in this vignette.

vcov_type Character vector, specifying the estimation type for the robust covariance matrix estimation (see ?sandwich::vcovHC or ?clubSandwich::vcovCR for details). Only used when vcov.fun is a character string indicating one of the functions from those packages. When vcov.fun is a function, a possible type argument must be provided via the vcov.args argument.

vcov_args List of named vectors, used as additional arguments that are passed down to vcov.fun.

weights Character vector, naming the weighing variable in the data, or a vector of weights (of same length as the number of observations in the data). Only applies to margin = "empirical".

interval Type of interval calculation, can either be "confidence" (default) or "prediction". May be abbreviated. Unlike confidence intervals, prediction intervals include the residual variance ($\sigma^2$) to account for the uncertainty of predicted values. For mixed models, interval = "prediction" is the default for type = "random". When type = "fixed", the default is interval = "confidence". Note that prediction intervals are not available for all models, but only for models that work with insight::get.sigma(). For Bayesian models, when interval = "confidence", predictions are based on posterior draws of the linear predictor rstantools::posterior_epred(). If interval = "prediction", rstantools::posterior_predict() is called.

verbose Toggle messages or warnings.

... If margin is set to "mean_reference" or "mean_mode", arguments are passed down to ggpredict() (further down to predict()); for margin = "marginalmeans", further arguments passed down to ggemmeans() and thereby to emmeans::emmeans(); if margin = "empirical", further arguments are passed down to marginaleffects::avg_predictions(); if type = "simulate", ... may also be used to set the number of simulation, e.g. nsim = 500. When calling ggeffect(), further arguments passed down to effects::Effect().
**predict_response**

**Value**

A data frame (with `ggeffects` class attribute) with consistent data columns:

- "x": the values of the first term in `terms`, used as x-position in plots.
- "predicted": the predicted values of the response, used as y-position in plots.
- "std.error": the standard error of the predictions. *Note that the standard errors are always on the link-scale, and not back-transformed for non-Gaussian models!*
- "conf.low": the lower bound of the confidence interval for the predicted values.
- "conf.high": the upper bound of the confidence interval for the predicted values.
- "group": the grouping level from the second term in `terms`, used as grouping-aesthetics in plots.
- "facet": the grouping level from the third term in `terms`, used to indicate facets in plots.

The estimated marginal means (or predicted values) are always on the response scale!

For proportional odds logistic regression (see `MASS::polr`) resp. cumulative link models (e.g., see `ordinal::clm`), an additional column "response.level" is returned, which indicates the grouping of predictions based on the level of the model’s response.

Note that for convenience reasons, the columns for the intervals are always named "conf.low" and "conf.high", even though for Bayesian models credible or highest posterior density intervals are returned.

There is an `as.data.frame()` method for objects of class `ggeffects`, which has an `terms_to_colnames` argument, to use the term names as column names instead of the standardized names “x” etc.

**Supported Models**

A list of supported models can be found at [the package website](https://example.com). Support for models varies by marginalization method (the `margin` argument), i.e. although `predict_response()` supports most models, some models are only supported exclusively by one of the four downstream functions (`ggpredict()`, `ggemmeans()`, `ggeffect()` or `ggaverage()`). This means that not all models work for every `margin` option of `predict_response()`.

**Holding covariates at constant values, or how to marginalize over the non-focal predictors**

`predict_response()` is a wrapper around `ggpredict()`, `ggemmeans()` and `ggaverage()`. Depending on the value of the `margin` argument, `predict_response()` calls one of those functions. The `margin` argument indicates how to marginalize over the *non-focal* predictors, i.e. those variables that are *not* specified in `terms`. Possible values are:

- "mean_reference" and "mean_mode": For "mean_reference", non-focal predictors are set to their mean (numeric variables), reference level (factors), or "most common" value (mode) in case of character vectors. For "mean_mode", non-focal predictors are set to their mean (numeric variables) or mode (factors, or "most common" value in case of character vectors).

These predictions represent a rather "theoretical" view on your data, which does not necessarily exactly reflect the characteristics of your sample. It helps answer the question, "What is the predicted value of the response at meaningful values or levels of my focal terms for a 'typical' observation in my data?", where 'typical' refers to certain characteristics of the remaining predictors.
• "marginalmeans": non-focal predictors are set to their mean (numeric variables) or averaged over the levels or "values" for factors and character vectors. Averaging over the factor levels of non-focal terms computes a kind of "weighted average" for the values at which these terms are hold constant. Thus, non-focal categorical terms are conditioned on "weighted averages" of their levels. These predictions come closer to the sample, because all possible values and levels of the non-focal predictors are taken into account. It would answer the question, "What is the predicted value of the response at meaningful values or levels of my focal terms for an 'average' observation in my data?". It refers to randomly picking a subject of your sample and the result you get on average.

• "empirical" (or "counterfactual"): non-focal predictors are averaged over the observations in the sample. The response is predicted for each subject in the data and predicted values are then averaged across all subjects, aggregated/grouped by the focal terms. In particular, averaging is applied to counterfactual predictions (Dickerman and Hernan 2020). There is a more detailed description in this vignette.

Counterfactual predictions are useful, insofar as the results can also be transferred to other contexts. It answers the question, "What is the predicted value of the response at meaningful values or levels of my focal terms for the 'average' observation in the population?". It does not only refer to the actual data in your sample, but also "what would be if" we had more data, or if we had data from a different population. This is where "counterfactual" refers to.

You can set a default-option for the margin argument via options(), e.g. options(ggeffects_margin = "empirical"), so you don’t have to specify your "default" marginalization method each time you call predict_response(). Use options(ggeffects_margin = NULL) to remove that setting.

The condition argument can be used to fix non-focal terms to specific values.

Marginal Means and Adjusted Predictions at Specific Values

Meaningful values of focal terms can be specified via the terms argument. Specifying meaningful or representative values as string pattern is the preferred way in the ggeffects package. However, it is also possible to use a list() for the focal terms if prefer the "classical" R way. terms can also be a data (or reference) grid provided as data frame. All options are described in this vignette.

Indicating levels in square brackets allows for selecting only certain groups or values resp. value ranges. The term name and the start of the levels in brackets must be separated by a whitespace character, e.g. terms = c("age", "education [1,3]"). Numeric ranges, separated with colon, are also allowed: terms = c("education", "age [30:60]"). The stepsize for ranges can be adjusted using by, e.g. terms = "age [30:60 by=5]".

The terms argument also supports the same shortcuts as the values argument in values_at(). So terms = "age [meansd]" would return predictions for the values one standard deviation below the mean age, the mean age and one SD above the mean age. terms = "age [quart2]" would calculate predictions at the value of the lower, median and upper quartile of age.

Furthermore, it is possible to specify a function name. Values for predictions will then be transformed, e.g. terms = "income [exp]". This is useful when model predictors were transformed for fitting the model and should be back-transformed to the original scale for predictions. It is also possible to define own functions (see this vignette).

Instead of a function, it is also possible to define the name of a variable with specific values, e.g. to define a vector v = c(1000, 2000, 3000) and then use terms = "income [v]".
predict_response

You can take a random sample of any size with \texttt{sample=n}, e.g. \texttt{terms = "income [sample=8]"}, which will sample eight values from all possible values of the variable income. This option is especially useful for plotting predictions at certain levels of random effects group levels, where the group factor has too many levels to be completely plotted. For more details, see this vignette.

Finally, numeric vectors for which no specific values are given, a "pretty range" is calculated (see \texttt{pretty_range()}), to avoid memory allocation problems for vectors with many unique values. If a numeric vector is specified as second or third term (i.e. if this focal term is used for "stratification"), representative values (see \texttt{values_at()}) are chosen (unless other values are specified), which are typically the mean value, as well as one standard deviation below and above the mean. If all values for a numeric vector should be used to compute predictions, you may use e.g. \texttt{terms = "age [all]"}. See also package vignettes.

To create a pretty range that should be smaller or larger than the default range (i.e. if no specific values would be given), use the \texttt{n} tag, e.g. \texttt{terms="age [n=5]"} or \texttt{terms="age [n=12]"}. Larger values for \texttt{n} return a larger range of predicted values.

Bayesian Regression Models

\texttt{predict_response()} also works with Stan-models from the \texttt{rstanarm} or \texttt{brms}-packages. The predicted values are the median value of all drawn posterior samples. Standard errors are the median absolute deviation of the posterior samples. The confidence intervals for Stan-models are Bayesian predictive intervals. By default, the predictions are based on \texttt{rstantools::posterior_epred()} and hence have the limitations that the uncertainty of the error term (residual variance) is not taken into account. The recommendation is to use the posterior predictive distribution (\texttt{rstantools::posterior_predict()}), i.e. setting \texttt{interval = "prediction"}.

Zero-Inflated and Zero-Inflated Mixed Models with brms

Models of class \texttt{brmsfit} always condition on the zero-inflation component, if the model has such a component. Hence, there is no \texttt{type = "zero_inflated"} nor \texttt{type = "zi_random"} for \texttt{brmsfit}-models, because predictions are based on draws of the posterior distribution, which already account for the zero-inflation part of the model.

Zero-Inflated and Zero-Inflated Mixed Models with \texttt{glmmTMB}

If \texttt{model} is of class \texttt{glmmTMB}, \texttt{hurdle}, \texttt{zeroinfl} or \texttt{zerotrunc}, and \texttt{margin} is not set to "empirical", simulations from a multivariate normal distribution (see \texttt{MASS::mvrnorm}) are drawn to calculate \texttt{mu*(1-p)}. Confidence intervals are then based on quantiles of these results. For \texttt{type = "zi_random"}, prediction intervals also take the uncertainty in the random-effect parameters into account (see also \texttt{Brooks et al. 2017}, pp.391-392 for details).

An alternative for models fitted with \texttt{glmmTMB} that take all model uncertainties into account are simulations based on \texttt{simulate()}, which is used when \texttt{type = "simulate"} (see \texttt{Brooks et al. 2017}, pp.392-393 for details).

Finally, if \texttt{margin = "empirical"}, the returned predictions are already conditioned on the zero-inflation part (and possible random effects) of the model, thus these are most comparable to the \texttt{type = "simulate"} option. In other words, if all model components should be taken into account for predictions, you should consider using \texttt{margin = "empirical"}. 
MixMod-models from GLMMadaptive

Predicted values for the fixed effects component (type = "fixed" or type = "zero_inflated") are based on predict(..., type = "mean_subject"), while predicted values for random effects components (type = "random" or type = "zi_random") are calculated with predict(..., type = "subject_specific") (see ?GLMMadaptive::predict.MixMod for details). The latter option requires the response variable to be defined in the newdata-argument of predict(), which will be set to its typical value (see values_at()).

Multinomial Models

polr, clm models, or more generally speaking, models with ordinal or multinominal outcomes, have an additional column response.level, which indicates with which level of the response variable the predicted values are associated.

Averaged model predictions (package MuMIn)

For averaged model predictions, i.e. when the input model is an object of class “averaging” (MuMIn::model.avg()), predictions are made with the full averaged coefficients.

Note

Printing Results

The print() method gives a clean output (especially for predictions by groups), and indicates at which values covariates were held constant. Furthermore, the print() method has several arguments to customize the output. See this vignette for details.

Limitations

The support for some models, for example from package MCMCglmm, is not fully tested and may fail for certain models. If you encounter any errors, please file an issue at Github.

References


Examples

```r
library(sjlabelled)
data(efc)
fit <- lm(barthtot ~ c12hour + neg_c_7 + c161sex + c172code, data = efc)
predict_response(fit, terms = "c12hour")
predict_response(fit, terms = c("c12hour", "c172code"))
# more compact table layout for printing
```
```r
out <- predict_response(fit, terms = c("c12hour", "c172code", "c161sex"))
print(out, collapse_table = TRUE)

# specified as formula
predict_response(fit, terms = ~ c12hour + c172code + c161sex)

# only range of 40 to 60 for variable 'c12hour'
predict_response(fit, terms = "c12hour [40:60]")

# terms as named list
predict_response(fit, terms = list(c12hour = 40:60))

# covariate "neg_c_7" is held constant at a value of 11.84 (its mean value).
# To use a different value, use "condition"
predict_response(fit, terms = "c12hour [40:60]", condition = c(neg_c_7 = 20))

# to plot ggeffects-objects, you can use the 'plot()-function.
# the following examples show how to build your ggplot by hand.

# plot predicted values, remaining covariates held constant
library(ggplot2)
mydf <- predict_response(fit, terms = "c12hour")
ggplot(mydf, aes(x, predicted)) +
  geom_line() +
  geom_ribbon(aes(ymin = conf.low, ymax = conf.high), alpha = 0.1)

# three variables, so we can use facets and groups
mydf <- predict_response(fit, terms = c("c12hour", "c161sex", "c172code"))
ggplot(mydf, aes(x = x, y = predicted, colour = group)) +
  stat_smooth(method = "lm", se = FALSE) +
  facet_wrap(~ facet, ncol = 2)

# select specific levels for grouping terms
mydf <- predict_response(fit, terms = c("c12hour", "c172code [1,3]", "c161sex"))
ggplot(mydf, aes(x = x, y = predicted, colour = group)) +
  stat_smooth(method = "lm", se = FALSE) +
  facet_wrap(~ facet) +
  labs(
    y = get_y_title(mydf),
    x = get_x_title(mydf),
    colour = get_legend_title(mydf)
  )

# level indication also works for factors with non-numeric levels
# and in combination with numeric levels for other variables
data(efc)
ecfc$c172code <- sjlabelled::as_label(efc$c172code)
fit <- lm(barthtot ~ c12hour + neg_c_7 + c161sex + c172code, data = efc)
predict_response(fit, terms = c("c12hour",
  "c172code [low level of education, high level of education]",
  "c161sex [1]"))
```
# when "terms" is a named list
predict_response(fit, terms = list(
  c12hour = seq(0, 170, 30),
  c172code = c("low level of education", "high level of education"),
  c161sex = 1)
)

# use categorical value on x-axis, use axis-labels, add error bars
dat <- predict_response(fit, terms = c("c172code", "c161sex"))
ggplot(dat, aes(x, predicted, colour = group)) +
  geom_point(position = position_dodge(0.1)) +
  geom_errorbar(
    aes(ymin = conf.low, ymax = conf.high),
    position = position_dodge(0.1)
  ) +
  scale_x_discrete(breaks = 1:3, labels = get_x_labels(dat))

# 3-way-interaction with 2 continuous variables
data(efc)
# make categorical
efc$c161sex <- as_factor(efc$c161sex)
fit <- lm(neg_c_7 ~ c12hour * barthtot * c161sex, data = efc)
# select only levels 30, 50 and 70 from continuous variable Barthel-Index
dat <- predict_response(fit, terms = c("c12hour", "barthtot [30,50,70]", "c161sex"))
ggplot(dat, aes(x = x, y = predicted, colour = group)) +
  stat_smooth(method = "lm", se = FALSE, fullrange = TRUE) +
  facet_wrap(~facet) +
  labs(
    colour = get_legend_title(dat),
    x = get_x_title(dat),
    y = get_y_title(dat),
    title = get_title(dat)
  )

# or with ggeffects' plot-method
plot(dat, show_ci = FALSE)

# predictions for polynomial terms
data(efc)
fit <- glm(
  tot_sc_e ~ c12hour + e42dep + e17age + I(e17age^2) + I(e17age^3),
  data = efc,
  family = poisson()
)
predict_response(fit, terms = "e17age")
**pretty_range**

**Description**

Creates an evenly spaced, pretty sequence of numbers for a range of a vector.

**Usage**

```
pretty_range(x, n = NULL, length = NULL)
```

**Arguments**

- `x` (A numeric vector.)
- `n` (Numeric value, indicating the size of how many values are used to create a pretty sequence. If `x` has a large value range (> 100), `n` could be something between 1 to 5. If `x` has a rather small amount of unique values, `n` could be something between 10 to 20. If `n = NULL`, `pretty_range()` automatically tries to find a pretty sequence.)
- `length` (Integer value, as alternative to `n`, defines the number of intervals to be returned.)

**Value**

A numeric vector with a range corresponding to the minimum and maximum values of `x`. If `x` is missing, a function, pre-programmed with `n` and `length` is returned. See examples.

**Examples**

```r
data(iris)
# pretty range for vectors with decimal points
pretty_range(iris$Petal.Length)

# pretty range for large range, increasing by 50
pretty_range(1:1000)

# increasing by 20
pretty_range(1:1000, n = 7)

# return 10 intervals
pretty_range(1:1000, length = 10)

# same result
pretty_range(1:1000, n = 2.5)

# function factory
range_n_5 <- pretty_range(n = 5)
range_n_5(1:1000)
```
residualize_over_grid  Compute partial residuals from a data grid

Description
This function computes partial residuals based on a data grid, where the data grid is usually a data frame from all combinations of factor variables or certain values of numeric vectors. This data grid is usually used as newdata argument in predict(), and can be created with new_data().

Usage
residualize_over_grid(grid, model, ...)

## S3 method for class 'data.frame'
residualize_over_grid(grid, model, predictor_name, ...)

## S3 method for class 'ggeffects'
residualize_over_grid(grid, model, protect_names = TRUE, ...)

Arguments
grid       A data frame representing the data grid, or an object of class ggeffects, as returned by predict_response().
model      The model for which to compute partial residuals. The data grid grid should match to predictors in the model.
...        Currently not used.
predictor_name The name of the focal predictor, for which partial residuals are computed.
protect_names Logical, if TRUE, preserves column names from the ggeffects objects that is used as grid.

Value
A data frame with residuals for the focal predictor.

Partial Residuals
For generalized linear models (glms), residualized scores are computed as \( \text{inv.link(link(Y) + r)} \) where \( Y \) are the predicted values on the response scale, and \( r \) are the working residuals.

For (generalized) linear mixed models, the random effect are also partialled out.

References
test_predictions

Examples

```r
library(ggeffects)
set.seed(1234)
x <- rnorm(200)
z <- rnorm(200)
# quadratic relationship
y <- 2 * x + x^2 + 4 * z + rnorm(200)
d <- data.frame(x, y, z)
model <- lm(y ~ x + z, data = d)
pr <- predict_response(model, c("x [all]", "z"))
head(residualize_over_grid(pr, model))
```

Description

Function to test differences of adjusted predictions for statistical significance. This is usually called contrasts or (pairwise) comparisons, or "marginal effects". `hypothesis_test()` is an alias.

Usage

```r
test_predictions(object, ...)

hypothesis_test(object, ...)
```

```r
## Default S3 method:
test_predictions(
  object,
  terms = NULL,
  by = NULL,
  test = "pairwise",
  equivalence = NULL,
  scale = "response",
  p_adjust = NULL,
  df = NULL,
  ci_level = 0.95,
  collapse_levels = FALSE,
  margin = "mean_reference",
  engine = "marginaleffects",
  verbose = TRUE,
  ...
)
```

```r
## S3 method for class 'ggeffects'
```
test_predictions(
  object,
  by = NULL,
  test = "pairwise",
  equivalence = NULL,
  scale = "response",
  p_adjust = NULL,
  df = NULL,
  collapse_levels = FALSE,
  engine = "marginaleffects",
  verbose = TRUE,
  ...
)

Arguments

object A fitted model object, or an object of class ggeffects. If object is of class ggeffects, arguments terms, margin and ci_level are taken from the ggeffects object and don’t need to be specified.

... Arguments passed down to data_grid() when creating the reference grid and to marginaleffects::predictions() resp. marginaleffects::slopes(). For instance, arguments type or transform can be used to back-transform comparisons and contrasts to different scales. vcov can be used to calculate heteroscedasticity-consistent standard errors for contrasts. See examples at the bottom of this vignette for further details.

To define a heteroscedasticity-consistent variance-covariance matrix, you can either use the same arguments as for predict_response() etc., namely vcov_fun, vcov_type and vcov_args. These are then transformed into a matrix and passed down to the vcov argument in marginaleffects. Or you directly use the vcov argument. See ?marginaleffects::slopes for further details.

terms If object is an object of class ggeffects, the same terms argument is used as for the predictions, i.e. terms can be ignored. Else, if object is a model object, terms must be a character vector with the names of the focal terms from object, for which contrasts or comparisons should be displayed. At least one term is required, maximum length is three terms. If the first focal term is numeric, contrasts or comparisons for the slopes of this numeric predictor are computed (possibly grouped by the levels of further categorical focal predictors).

by Character vector specifying the names of predictors to condition on. Hypothesis test is then carried out for focal terms by each level of by variables. This is useful especially for interaction terms, where we want to test the interaction within "groups". by is only relevant for categorical predictors.

test Hypothesis to test, defined as character string. Can be one of:
  • "pairwise" (default), to test pairwise comparisons.
  • "contrast" to test simple contrasts (i.e. each level is tested against the average over all levels).
  • "exclude" to test simple contrasts (i.e. each level is tested against the average over all other levels, excluding the contrast that is being tested).
• "interaction" to test interaction contrasts (difference-in-difference contrasts).
• "consecutive" to test contrasts between consecutive levels of a predictor.
• "polynomial" to test orthogonal polynomial contrasts, assuming equally-spaced factor levels.
• A character string with a custom hypothesis, e.g. "b2 = b1". This would test if the second level of a predictor is different from the first level. Custom hypotheses are very flexible. It is also possible to test interaction contrasts (difference-in-difference contrasts) with custom hypotheses, e.g. "(b2 - b1) = (b4 - b3)". See also section Introduction into contrasts and pairwise comparisons.
• A data frame with custom contrasts. See 'Examples'.
• NULL, in which case simple contrasts are computed.

Technical details about the packages used as back-end to calculate contrasts and pairwise comparisons are provided in the section Packages used as back-end to calculate contrasts and pairwise comparisons below.

equivalence

ROPE’s lower and higher bounds. Should be "default" or a vector of length two (e.g., c(-0.1, 0.1)). If "default", bayestestR::rope_range() is used. Instead of using the equivalence argument, it is also possible to call the equivalence_test() method directly. This requires the parameters package to be loaded. When using equivalence_test(), two more columns with information about the ROPE coverage and decision on H0 are added. Furthermore, it is possible to plot() the results from equivalence_test(). See bayestestR::equivalence_test() resp. parameters::equivalence_test.lm() for details.

scale

Character string, indicating the scale on which the contrasts or comparisons are represented. Can be one of:

• "response" (default), which would return contrasts on the response scale (e.g. for logistic regression, as probabilities);
• "link" to return contrasts on scale of the linear predictors (e.g. for logistic regression, as log-odds);
• "probability" (or "probs") returns contrasts on the probability scale, which is required for some model classes, like MASS::polr();
• "oddsratios" to return contrasts on the odds ratio scale (only applies to logistic regression models);
• "irr" to return contrasts on the odds ratio scale (only applies to count models);
• or a transformation function like "exp" or "log", to return transformed (exponentiated respectively logarithmic) contrasts; note that these transformations are applied to the response scale.

Note: If the scale argument is not supported by the provided object, it is automatically changed to a supported scale-type (a message is printed when verbose = TRUE).

p_adjust

Character vector, if not NULL, indicates the method to adjust p-values. See stats::p.adjust() or stats::p.adjust.methods for details. Further possible adjustment methods are "tukey" or "sidak", and for johnson_neyman().
"fdr" (or "bh") and "esarey" (or its short-cut "es") are available options. Some caution is necessary when adjusting p-value for multiple comparisons. See also section P-value adjustment below.

df Degrees of freedom that will be used to compute the p-values and confidence intervals. If NULL, degrees of freedom will be extracted from the model using `insight::get_df()` with type = "wald".

ci_level Numeric, the level of the confidence intervals. If object is an object of class ggeffects, the same ci_level argument is used as for the predictions, i.e. ci_level can be ignored.

collapse_levels Logical, if TRUE, term labels that refer to identical levels are no longer separated by ",", but instead collapsed into a unique term label (e.g., "level a-level a" becomes "level a"). See 'Examples'.

margin Character string, indicates the method how to marginalize over non-focal terms. See `predict_response()` for details. If object is an object of class ggeffects, the same margin argument is used as for the predictions, i.e. margin can be ignored.

engine Character string, indicates the package to use for computing contrasts and comparisons. Usually, this argument can be ignored, unless you want to explicitly use another package than marginaleffects to calculate contrasts and pairwise comparisons. engine can be either "marginaleffects" (default) or "emmeans". The latter is useful when the marginaleffects package is not available, or when the emmeans package is preferred. Note that using emmeans as back-end is currently not as feature rich as the default (marginaleffects) and still in development. Setting engine = "emmeans" provides some additional test options: "interaction" to calculate interaction contrasts, "consecutive" to calculate contrasts between consecutive levels of a predictor, or a data frame with custom contrasts (see also test). There is an experimental option as well, engine = "ggeffects". However, this is currently work-in-progress and offers much less options as the default engine, "marginaleffects". It can be faster in some cases, though, and works for comparing predicted random effects in mixed models, or predicted probabilities of the zero-inflation component. If the marginal-effects package is not installed, the emmeans package is used automatically. If this package is not installed as well, engine = "ggeffects" is used.

verbose Toggle messages and warnings.

Value

A data frame containing predictions (e.g. for test = NULL), contrasts or pairwise comparisons of adjusted predictions or estimated marginal means.

Introduction into contrasts and pairwise comparisons

There are many ways to test contrasts or pairwise comparisons. A detailed introduction with many (visual) examples is shown in this vignette.
Simple workflow for pairwise comparisons

A simple workflow includes calculating adjusted predictions and passing the results directly to test_predictions(), e.g.:

```r
# 1. fit your model
model <- lm(mpg ~ hp + wt + am, data = mtcars)
# 2. calculate adjusted predictions
pr <- predict_response(model, "am")
pr
# 3. test pairwise comparisons
test_predictions(pr)
```

See also this vignette.

Packages used as back-end to calculate contrasts and pairwise comparisons

The test argument is used to define which kind of contrast or comparison should be calculated. The default is to use the marginaleffects package. Here are some technical details about the packages used as back-end. When test is...

- "pairwise" (default), pairwise comparisons are based on the marginaleffects package.
- "contrast" uses the emmeans package, i.e. emmeans::contrast(method = "eff") is called.
- "exclude" relies on the emmeans package, i.e. emmeans::contrast(method = "del.eff") is called.
- "polynomial" relies on the emmeans package, i.e. emmeans::contrast(method = "poly") is called.
- "interaction" uses the emmeans package, i.e. emmeans::contrast(interaction = ...) is called.
- "consecutive" also relies on the emmeans package, i.e. emmeans::contrast(method = "consec") is called.
- a character string with a custom hypothesis, the marginaleffects package is used.
- a data frame with custom contrasts, emmeans is used again.
- NULL calls functions from the marginaleffects package with hypothesis = NULL.
- If all focal terms are only present as random effects in a mixed model, or if predicted probabilities for the zero-inflation component of a model should be tested, functions from the ggeffects package are used. There is an example for pairwise comparisons of random effects in this vignette.

P-value adjustment for multiple comparisons

Note that p-value adjustment for methods supported by p.adjust() (see also p.adjust.methods), each row is considered as one set of comparisons, no matter which test was specified. That is, for instance, when test_predictions() returns eight rows of predictions (when test = NULL), and p.adjust = "bonferroni", the p-values are adjusted in the same way as if we had a test of pairwise comparisons (test = "pairwise") where eight rows of comparisons are returned. For methods "tukey" or "sidak", a rank adjustment is done based on the number of combinations of
levels from the focal predictors in terms. Thus, the latter two methods may be useful for certain tests only, in particular pairwise comparisons.

For `johnson_neyman()`, the only available adjustment methods are "fdr" (or "bh") (Benjamini & Hochberg 1995) and "esarey" (or "es") (Esarey and Sumner 2017). These usually return similar results. The major difference is that "fdr" can be slightly faster and more stable in edge cases, however, confidence intervals are not updated. Only the p-values are adjusted. "esarey" is slower, but confidence intervals are updated as well.

Global options to choose package for calculating comparisons

ggeffects_test_engine can be used as option to either use the `marginaleffects` package for computing contrasts and comparisons (default), or the `emmeans` package (e.g. `options(ggeffects_test_engine = "emmeans")`). The latter is useful when the `marginaleffects` package is not available, or when the `emmeans` package is preferred. You can also provide the engine directly, e.g. `test_predictions(..., engine = "emmeans")`. Note that using `emmeans` as backend is currently not as feature rich as the default (`marginaleffects`) and still in development.

If engine = "emmeans", the test argument can also be "interaction" to calculate interaction contrasts (difference-in-difference contrasts), "consecutive" to calculate contrasts between consecutive levels of a predictor, or a data frame with custom contrasts. If test is one of the latter options, and engine is not specified, the engine is automatically set to "emmeans".

If the `marginaleffects` package is not installed, the `emmeans` package is used automatically. If this package is not installed as well, engine = "ggeffects" is used.

Global Options to Customize Tables when Printing

The verbose argument can be used to display or silence messages and warnings. Furthermore, `options()` can be used to set defaults for the `print()` and `print_html()` method. The following options are available, which can simply be run in the console:

- `ggeffects_ci_brackets`: Define a character vector of length two, indicating the opening and closing parentheses that encompass the confidence intervals values, e.g. `options(ggeffects_ci_brackets = c("[", "]")).`  
- `ggeffectsCollapse_ci`: Logical, if TRUE, the columns with predicted values (or contrasts) and confidence intervals are collapsed into one column, e.g. `options(ggeffectsCollapse_ci = TRUE)`.  
- `ggeffectsCollapse_p`: Logical, if TRUE, the columns with predicted values (or contrasts) and p-values are collapsed into one column, e.g. `options(ggeffectsCollapse_p = TRUE)`. Note that p-values are replaced by asterisk-symbols (stars) or empty strings when `ggeffectsCollapse_p = TRUE`, depending on the significance level.  
- `ggeffectsCollapse_tables`: Logical, if TRUE, multiple tables for subgroups are combined into one table. Only works when there is more than one focal term, e.g. `options(ggeffectsCollapse_tables = TRUE)`.  
- `ggeffects_output_format`: String, either "text", "markdown" or "html". Defines the default output format from `predict_response()`. If "html", a formatted HTML table is created and printed to the view pane. "markdown" creates a markdown-formatted table inside Rmarkdown documents, and prints a text-format table to the console when used interactively. If "text" or NULL, a formatted table is printed to the console, e.g. `options(ggeffects_output_format = "html")`. 


• ggeffects_html_engine: String, either "tt" or "gt". Defines the default engine to use for printing HTML tables. If "tt", the tinytable package is used, if "gt", the gt package is used, e.g. options(ggeffects_html_engine = "gt").

Use options(<option_name> = NULL) to remove the option.

References

See Also
There is also an equivalence_test() method in the parameters package (parameters::equivalence_test.lm()), which can be used to test contrasts or comparisons for practical equivalence. This method also has a plot() method, hence it is possible to do something like:

library(parameters)
predict_response(model, focal_terms) |> equivalence_test() |> plot()

Examples

data(efc)
  efc$c172code <- as.factor(efc$c172code)
  efc$c161sex <- as.factor(efc$c161sex)
  levels(efc$c161sex) <- c("male", "female")
  m <- lm(barthtot ~ c12hour + neg_c_7 + c161sex + c172code, data = efc)

  # direct computation of comparisons
  test_predictions(m, "c172code")

  # passing a `ggeffects` object
  pred <- predict_response(m, "c172code")
  test_predictions(pred)

  # test for slope
  test_predictions(m, "c12hour")

  # interaction - contrasts by groups
  m <- lm(barthtot ~ c12hour + c161sex * c172code + neg_c_7, data = efc)
  test_predictions(m, c("c161sex", "c172code"), test = NULL)

  # interaction - pairwise comparisons by groups
  test_predictions(m, c("c161sex", "c172code"))

  # equivalence testing
  test_predictions(m, c("c161sex", "c172code"), equivalence = c(-2.96, 2.96))
# equivalence testing, using the parameters package
pr <- predict_response(m, c("c161sex", "c172code"))
parameters::equivalence_test(pr)

# interaction - collapse unique levels
test_predictions(m, c("c161sex", "c172code"), collapse_levels = TRUE)

# p-value adjustment
test_predictions(m, c("c161sex", "c172code"), p_adjust = "tukey")

# not all comparisons, only by specific group levels
test_predictions(m, "c172code", by = "c161sex")

# specific comparisons
test_predictions(m, c("c161sex", "c172code"), test = "b2 = b1")

# interaction - slope by groups
m <- lm(barthtot ~ c12hour + neg_c_7 * c172code + c161sex, data = efc)
test_predictions(m, c("neg_c_7", "c172code"))

# Interaction and consecutive contrasts -----------------
# -------------------------------------------------------
data(coffee_data, package = "ggeffects")
m <- lm(alertness ~ time * coffee + sex, data = coffee_data)

# consecutive contrasts
test_predictions(m, "time", by = "coffee", test = "consecutive")

# interaction contrasts - difference-in-difference comparisons
pr <- predict_response(m, c("time", "coffee"), margin = "marginalmeans")
test_predictions(pr, test = "interaction")

# Custom contrasts --------------------------------------
# -------------------------------------------------------
wakeup_time <- data.frame(
  "wakeup vs later" = c(-2, 1, 1) / 2, # make sure each "side" sums to (+/-)1!
  "start vs end of day" = c(-1, 0, 1)
)
test_predictions(m, "time", by = "coffee", test = wakeup_time)

# Example: marginal effects -----------------------------
# -------------------------------------------------------
data(iris)
m <- lm(Petal.Width ~ Petal.Length + Species, data = iris)

# we now want the marginal effects for "Species". We can calculate
# the marginal effect using the "marginaleffects" package
marginaleffects::avg_slopes(m, variables = "Species")

# finally, test_predictions() returns the same. While the previous results
# report the marginal effect compared to the reference level "setosa",
# test_predictions() returns the marginal effects for all pairwise comparisons
test_predictions(m, "Species")
values_at

Calculate representative values of a vector

Description

This function calculates representative values of a vector, like minimum/maximum values or lower, median and upper quartile etc., which can be used for numeric vectors to plot adjusted predictions at these representative values.

Usage

values_at(x, values = "meansd")

representative_values(x, values = "meansd")

Arguments

x A numeric vector.
values Character vector, naming a pattern for which representative values should be calculated.

- "minmax": (default) minimum and maximum values (lower and upper bounds) of the moderator are used to plot the interaction between independent variable and moderator.
- "meansd": uses the mean value of the moderator as well as one standard deviation below and above mean value to plot the effect of the moderator on the independent variable.
- "zeromax": is similar to the "minmax" option, however, 0 is always used as minimum value for the moderator. This may be useful for predictors that don’t have an empirical zero-value, but absence of moderation should be simulated by using 0 as minimum.
- "fivenum": calculates and uses the Tukey’s five number summary (minimum, lower-hinge, median, upper-hinge, maximum) of the moderator value.
- "quart": calculates and uses the quartiles (lower, median and upper) of the moderator value, including minimum and maximum value.
- "quart2": calculates and uses the quartiles (lower, median and upper) of the moderator value, excluding minimum and maximum value.
- "terciles": calculates and uses the terciles (lower and upper third) of the moderator value, including minimum and maximum value.
- "terciles2": calculates and uses the terciles (lower and upper third) of the moderator value, excluding minimum and maximum value.
- an option to compute a range of percentiles is also possible, using "percentile", followed by the percentage of the range. For example, "percentile95" will calculate the 95% range of the variable.
• "all": uses all values of the moderator variable. Note that this option only applies to type = "eff", for numeric moderator values.

Value

A numeric vector of length two or three, representing the required values from x, like minimum/maximum value or mean and +/- 1 SD. If x is missing, a function, pre-programmed with n and length is returned. See examples.

Examples

data(efc)
values_at(efc$c12hour)
values_at(efc$c12hour, "quart2")

mean_sd <- values_at(values = "meansd")
mean_sd(efc$c12hour)

vcov

Calculate variance-covariance matrix for adjusted predictions

Description

Returns the variance-covariance matrix for the predicted values from object.

Usage

## S3 method for class 'ggeffects'
vcov(
  object,
  vcov_fun = NULL,
  vcov_type = NULL,
  vcov_args = NULL,
  vcov.fun = vcov_fun,
  vcov.type = vcov_type,
  vcov.args = vcov_args,
  verbose = TRUE,
  ...
)

Arguments

  object An object of class "ggeffects", as returned by predict_response().
  vcov_fun Variance-covariance matrix used to compute uncertainty estimates (e.g., for confidence intervals based on robust standard errors). This argument accepts a covariance matrix, a function which returns a covariance matrix, or a string which identifies the function to be used to compute the covariance matrix.

• A (variance-covariance) matrix
• A function which returns a covariance matrix (e.g., `stats::vcov()`)
• A string which indicates the estimation type for the heteroscedasticity-consistent variance-covariance matrix, e.g. `vcov_fun = "HC0"`. Possible values are "HC0", "HC1", "HC2", "HC3", "HC4", "HC4m", and "HC5", which will then call the vcovHC()-function from the sandwich package, using the specified type. Further possible values are "CR0", "CR1", "CR1p", "CR1S", "CR2", and "CR3", which will call the vcovCR()-function from the clubSandwich package.
• A string which indicates the name of the vcov*()-function from the sandwich or clubSandwich packages, e.g. `vcov_fun = "vcovCL"`, which is used to compute (cluster) robust standard errors for predictions.

If NULL, standard errors (and confidence intervals) for predictions are based on the standard errors as returned by the predict()-function. Note that probably not all model objects that work with predict_response() are also supported by the sandwich or clubSandwich packages. See details in this vignette.

### `vcov_type`
Character vector, specifying the estimation type for the robust covariance matrix estimation (see `?sandwich::vcovHC` or `?clubSandwich::vcovCR` for details). Only used when `vcov_fun` is a character string indicating one of the functions from those packages. When `vcov_fun` is a function, a possible type argument must be provided via the `vcov_args` argument.

### `vcov_args`
List of named vectors, used as additional arguments that are passed down to `vcov_fun`.

### `vcov.fun, vcov.type, vcov.args`
Deprecated. Use `vcov_fun`, `vcov_type` and `vcov_args` instead.

### `verbose`
Toggle messages or warnings.

### `...`
Currently not used.

#### Details

The returned matrix has as many rows (and columns) as possible combinations of predicted values from the predict_response() call. For example, if there are two variables in the terms-argument of predict_response() with 3 and 4 levels each, there will be 3 x 4 combinations of predicted values, so the returned matrix has a 12 x 12 dimension. In short, `nrow(object)` is always equal to `nrow(vcov(object))`. See also 'Examples'.

#### Value

The variance-covariance matrix for the predicted values from object.

#### Examples

```r
data(efc)
model <- lm(barthtot ~ c12hour + neg_c_7 + c161sex + c172code, data = efc)
result <- predict_response(model, c("c12hour [meansd]", "c161sex"))
vcov(result)
```
# compare standard errors
sqrt(diag(vcov(result)))
as.data.frame(result)

# only two predicted values, no further terms
# vcov() returns a 2x2 matrix
result <- predict_response(model, "c161sex")
vcov(result)

# 2 levels for c161sex multiplied by 3 levels for c172code
# result in 6 combinations of predicted values
# thus vcov() returns a 6x6 matrix
result <- predict_response(model, c("c161sex", "c172code"))
vcov(result)
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