Package 'Superpower'

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Title Simulation-Based Power Analysis for Factorial Designs

Version 0.0.3

Description Functions to perform simulations of ANOVA designs of up to three factors. Calculates the observed power and average observed effect size for all main effects and interactions in the ANOVA, and all simple comparisons between conditions. Includes functions for analytic power calculations and additional helper functions that compute effect sizes for ANOVA designs, observed error rates in the simulations, and functions to plot power curves. Please see Lakens, D., & Caldwell, A. R. (2019). ``Simulation-Based Power-Analysis for Factorial ANOVA Designs''. <doi:10.31234/osf.io/baxsf>.

URL https://arcaldwell49.github.io/SuperpowerBook/

BugReports https://github.com/arcaldwell49/Superpower/issues

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R topics documented:

`ANOVA_design` *Design function used to specify the parameters to be used in simulations*

Description

Design function used to specify the parameters to be used in simulations

Usage

```
ANOVA_design(
  design,
  n,
  mu,
  sd,
  r = 0,
  labelnames = NULL,
  plot = Superpower_options("plot")
)
```

Arguments

`design`	String specifying the ANOVA design.
`n`	Sample size in each condition
`mu`	Vector specifying mean for each condition
`sd`	standard deviation for all conditions (or a vector specifying the sd for each condition)
`r`	Correlation between dependent variables (single value or matrix)
`labelnames`	Optional vector to specifying factor and condition names (recommended, if not used factors and levels are indicated by letters and numbers)
`plot`	Should means plot be printed (defaults to TRUE)

Value

Returns single list with simulated data, design, design list, factor names, formulas for ANOVA, means, sd, correlation, sample size per condition, correlation matrix, covariance matrix, design string, labelnames, labelnameslist, factor names, meansplot

"dataframe" A sample dataframe of what data could look like given the proposed parameters.

"design" aov The design string, e.g. "2b*2w".

"design_list" The list of variables in the design.

"frml1" The first formula created for this design.

"frml2" The second formula created for this design.

"mu" Vector of means.

"sd" Vector of standard deviations.

"r" Common correlation coefficient.

"n" Sample size per cell. Can be entered as a single value or list of sample sizes for each condition. If unequal n is entered then the design can only be passed onto ANOVA_power.

"cor_mat" The correlation matrix.

"sigmatrix" The variance-covariance matrix.

"design_factors" Total number of within-subjects factors.

"labelnames" List of the label names.

"labelnameslist" Secondary list of labelnames

"factornames" List of the factor titles.

"meansplot" Plot of the experimental design.

Warnings

Varying the sd or r (e.g., entering multiple values) violates assumptions of homoscedascity and sphericity respectively

Examples

```
## Set up a within design with 2 factors, each with 2 levels,
## with correlation between observations of 0.8,
## 40 participants (who do all conditions), and standard deviation of 2
## with a mean pattern of 1, 0, 1, 0, conditions labeled 'condition' and
## 'voice', with names for levels of "cheerful", "sad", and "human", "robot"
ANOVA_design(design = "2w*2w", n = 40, mu = c(1, 0, 1, 0), sd = 2, r = 0.8,
      labelnames = c("condition", "cheerful", "sad", "voice", "human", "robot"))
```

ANOVA_exact *Simulates an exact dataset (mu, sd, and r represent empirical not population mean and covariance matrix) from the design to calculate power*

Description

Simulates an exact dataset (mu, sd, and r represent empirical not population mean and covariance matrix) from the design to calculate power

Usage

```
ANOVA_exact(
  design_result,
  correction = Superpower_options("correction"),
  alpha_level = Superpower_options("alpha_level"),
  verbose = Superpower_options("verbose"),
  emm = Superpower_options("emm"),
  emm_model = Superpower_options("emm_model"),
  contrast_type = Superpower_options("contrast_type"),
  emm_comp
)
```

Arguments

design_result	Output from the ANOVA_design function
correction	Set a correction of violations of sphericity. This can be set to "none", "GG" Greenhouse-Geisser, and "HF" Huynh-Feldt
alpha_level	Alpha level used to determine statistical significance
verbose	Set to FALSE to not print results (default = TRUE)
emm	Set to FALSE to not perform analysis of estimated marginal means
emm_model	Set model type ("multivariate", or "univariate") for estimated marginal means
contrast_type	Select the type of comparison for the estimated marginal means. Default is pairwise. See ?emmeans::‘contrast-methods‘ for more details on acceptable methods.
emm_comp	Set the comparisons for estimated marginal means comparisons. This is a factor name (a), combination of factor names (a+b), or for simple effects a | sign is needed (a|b)

Value

Returns dataframe with simulation data (power and effect sizes!), anova results and simple effect results, plot of exact data, and alpha_level. Note: Cohen's f = sqrt(pes/1-pes) and the noncentrality parameter is = f^2*df(error) "dataframe" A dataframe of the simulation result.

"aov_result" aov object returned from aov_car.

"aov_result" emmeans object returned from emmeans.

"main_result" The power analysis results for ANOVA level effects.

"pc_results" The power analysis results for the pairwise (t-test) comparisons.

"emm_results" The power analysis results of the pairwise comparison results.

"manova_results" Default is "NULL". If a within-subjects factor is included, then the power of the multivariate (i.e. MANOVA) analyses will be provided.

"alpha_level" The alpha level, significance cut-off, used for the power analysis.

"plot" A plot of the dataframe from the simulation; should closely match the meansplot in ANOVA_design

Warnings

Varying the sd or r (e.g., entering multiple values) violates assumptions of homoscedascity and sphericity respectively

Examples

```
## Set up a within design with 2 factors, each with 2 levels,
## with correlation between observations of 0.8,
## 40 participants (who do all conditions), and standard deviation of 2
## with a mean pattern of 1, 0, 1, 0, conditions labeled 'condition' and
## 'voice', with names for levels of "cheerful", "sad", amd "human", "robot"
design_result <- ANOVA_design(design = "2w*2w", n = 40, mu = c(1, 0, 1, 0),
      sd = 2, r = 0.8, labelnames = c("condition", "cheerful",
      "sad", "voice", "human", "robot"))
exact_result <- ANOVA_exact(design_result, alpha_level = 0.05)
```

ANOVA_power *Simulation function used to estimate power*

Description

Simulation function used to estimate power

Usage

```
ANOVA_power(
  design_result,
  alpha_level = Superpower_options("alpha_level"),
  correction = Superpower_options("correction"),
  p_adjust = "none",
  nsims = 1000,
  seed = NULL,
  verbose = Superpower_options("verbose"),
  emm = Superpower_options("emm"),
```

```
  emm_model = Superpower_options("emm_model"),
  contrast_type = Superpower_options("contrast_type"),
  emm_p_adjust = "none",
  emm_comp = NULL
)
```

Arguments

`design_result`	Output from the ANOVA_design function
`alpha_level`	Alpha level used to determine statistical significance
`correction`	Set a correction of violations of sphericity. This can be set to "none", "GG" Greenhouse-Geisser, and "HF" Huynh-Feldt
`p_adjust`	Correction for multiple comparisons. This will adjust p values for ANOVA/MANOVA level effects; see ?p.adjust for options
`nsims`	number of simulations to perform
`seed`	Set seed for reproducible results
`verbose`	Set to FALSE to not print results (default = TRUE)
`emm`	Set to FALSE to not perform analysis of estimated marginal means
`emm_model`	Set model type ("multivariate", or "univariate") for estimated marginal means
`contrast_type`	Select the type of comparison for the estimated marginal means. Default is pairwise. See ?emmeans::‘contrast-methods‘ for more details on acceptable methods.
`emm_p_adjust`	Correction for multiple comparisons; default is "none". See ?summary.emmGrid for more details on acceptable methods.
`emm_comp`	Set the comparisons for estimated marginal means comparisons. This is a factor name (a), combination of factor names (a+b), or for simple effects a | sign is needed (a|b)

Value

Returns dataframe with simulation data (p-values and effect sizes), anova results (type 3 sums of squares) and simple effect results, and plots of p-value distribution.

`"sim_data"` Output from every iteration of the simulation

`"main_result"` The power analysis results for ANOVA effects.

`"pc_results"` The power analysis results for pairwise comparisons.

`"manova_results"` Default is "NULL". If a within-subjects factor is included, then the power of the multivariate (i.e. MANOVA) analyses will be provided.

`"emm_results"` The power analysis results of the estimated marginal means.

`"plot1"` Distribution of p-values from the ANOVA results.

`"plot2"` Distribution of p-values from the pairwise comparisons results.

`"correction"` The correction for sphericity applied to the simulation results.

`"p_adjust"` The p-value adjustment applied to the simulation results for ANOVA/MANOVA omnibus tests and t-tests.

"emm_p_adjust" The p-value adjustment applied to the simulation results for the estimated marginal means.

"nsims" The number of simulations run.

"alpha_level" The alpha level, significance cut-off, used for the power analysis.

References

too be added

Examples

```
## Set up a within design with 2 factors, each with 2 levels,
## with correlation between observations of 0.8,
## 40 participants (who do all conditions), and standard deviation of 2
## with a mean pattern of 1, 0, 1, 0, conditions labeled 'condition' and
## 'voice', with names for levels of "cheerful", "sad", amd "human", "robot"
design_result <- ANOVA_design(design = "2w*2w", n = 40, mu = c(1, 0, 1, 0),
      sd = 2, r = 0.8, labelnames = c("condition", "cheerful",
      "sad", "voice", "human", "robot"))
power_result <- ANOVA_power(design_result, alpha_level = 0.05,
      p_adjust = "none", seed = 2019, nsims = 10)
```

---

mu_from_ES

Convenience function to calculate the means for between designs with one factor (One-Way ANOVA). Can be used to determine the means that should yield a specified effect sizes (expressed in Cohen's f).

Description

Convenience function to calculate the means for between designs with one factor (One-Way ANOVA). Can be used to determine the means that should yield a specified effect sizes (expressed in Cohen's f).

Usage

```
mu_from_ES(K, ES)
```

Arguments

K	Number of groups (2, 3, or 4)
ES	Effect size (eta-squared)

Value

Returns vector of means

References

Albers, C., & Lakens, D. (2018). When power analyses based on pilot data are biased: Inaccurate effect size estimators and follow-up bias. Journal of Experimental Social Psychology, 74, 187–195. https://doi.org/10.1016/j.jesp.2017.09.004

Examples

```
## Medium effect size (eta-squared), 2 groups
ES <- 0.0588
K <- 2
mu_from_ES(K = K, ES = ES)
```

---

plot_power — *Convenience function to plot power across a range of sample sizes.*

Description

Convenience function to plot power across a range of sample sizes.

Usage

```
plot_power(
  design_result,
  alpha_level = Superpower_options("alpha_level"),
  min_n = 7,
  max_n = 100,
  plot = Superpower_options("plot"),
  emm = Superpower_options("emm"),
  emm_model = Superpower_options("emm_model"),
  contrast_type = Superpower_options("contrast_type"),
  emm_comp
)
```

Arguments

design_result	Output from the ANOVA_design function
alpha_level	Alpha level used to determine statistical significance
min_n	Minimum sample size in power curve.
max_n	Maximum sample size in power curve.
plot	Should power plot be printed automatically (defaults to FALSE)
emm	Set to FALSE to not perform analysis of estimated marginal means
emm_model	Set model type ("multivariate", or "univariate") for estimated marginal means
contrast_type	Select the type of comparison for the estimated marginal means
emm_comp	Set the comparisons for estimated marginal means comparisons. This is a factor name (a), combination of factor names (a+b), or for simple effects a | sign is needed (a|b)

Value

Returns plot with power curves for the ANOVA, and a dataframe with the summary data.

"plot_ANOVA" Plot of power curves from ANOVA results.

"plot_MANOVA" Plot of power curves from MANOVA results. Returns NULL if no within-subject factors.

"plot_emm" Plot of power curves from MANOVA results. Returns NULL if emm = FALSE.

"power_df" The tabulated ANOVA power results.

"power_df_manova" The tabulated MANOVA power results. Returns NULL if no within-subject factors.

"power_df_emm" The tabulated Estimated Marginal Means power results. Returns NULL if emm = FALSE.

"effect_sizes" Effect sizes (partial eta-squared) from ANOVA results.

"effect_sizes_manova" Effect sizes (Pillai's Trace) from MANOVA results. Returns NULL if no within-subject factors.

"effect_sizes_emm" Effect sizes (cohen's f) estimated marginal means results. Returns NULL if emm = FALSE.

References

too be added

Examples

```
design_result <- ANOVA_design(design = "3b",
                              n = 20,
                              mu = c(0,0,0.3),
                              sd = 1,
                              labelnames = c("condition",
                              "cheerful", "neutral", "sad"))

plot_power(design_result, min_n = 50, max_n = 70)
```

---

power_oneway_between *Analytic power calculation for one-way between designs.*

Description

Analytic power calculation for one-way between designs.

Usage

```
power_oneway_between(design_result, alpha_level = 0.05)
```

Arguments

`design_result`	Output from the ANOVA_design function
`alpha_level`	Alpha level used to determine statistical significance

Value

mu = means

sigma = standard deviation

n = sample size

alpha_level = alpha level

Cohen_f = Cohen f

f_2 = Cohen's f^2

lambda = lambda

F_critical = Critical F-value

power = power

df1 = degrees of freedom for the effect

df2 = degrees of freedom of the error

eta_p_2 = partial eta-squared

mean_mat = matrix of the means

References

too be added

Examples

```
## Set up a within design with one factor with 2 levels,
## 40 participants (woh do all conditions), and standard deviation of 2
## with a mean pattern of 1, 0, 1, conditions labeled 'condition'
## with names for levels of "cheerful", "neutral", "sad"
design_result <- ANOVA_design(design = "3b", n = 40, mu = c(1, 0, 1),
      sd = 2, labelnames = c("condition", "cheerful", "neutral", "sad"))
power_result <- power_oneway_between(design_result, alpha_level = 0.05)
```

`power_oneway_within` *Analytic power calculation for one-way within designs.*

Description

Analytic power calculation for one-way within designs.

Usage

```
power_oneway_within(design_result, alpha_level = 0.05)
```

Arguments

`design_result` Output from the ANOVA_design function

`alpha_level` Alpha level used to determine statistical significance

Value

mu = means

sigma = standard deviation

n = sample size

alpha_level = alpha level

Cohen_f = Cohen's f

f_2 = Cohen's f squared

lambda = lambda

F_critical = Critical F-value

power = power

df1 = degrees of freedom for the effect

df2 = degrees of freedom of the error

eta_p_2 = partial eta-squared

mean_mat = matrix of the means

References

too be added

Examples

```
## Set up a within design with 3 factors,
## with correlation between observations of 0.8,
## 40 participants (who do all conditions), and standard deviation of 2
## with a mean pattern of 1, 0, 1, conditions labeled 'condition' and
## 'voice', with names for levels of "cheerful", "neutral", "sad".
design_result <- ANOVA_design(design = "3w", n = 40, r = 0.8,
      mu = c(1, 0, 1), sd = 2,
      labelnames = c("condition", "cheerful", "neutral", "sad"))
power_result <- power_oneway_within(design_result, alpha_level = 0.05)
```

power_threeway_between
Analytic power calculation for three-way between designs.

Description

Analytic power calculation for three-way between designs.

Usage

```
power_threeway_between(design_result, alpha_level = 0.05)
```

Arguments

design_result	Output from the ANOVA_design function
alpha_level	Alpha level used to determine statistical significance (default to 0.05)

Value

mu = means

sigma = standard deviation

n = sample size

alpha_level = alpha level

Cohen_f_A = Cohen's f for main effect A

Cohen_f_B = Cohen's f for main effect B

Cohen_f_C = Cohen's f for main effect C

Cohen_f_AB = Cohen's f for the A*B interaction

Cohen_f_AC = Cohen's f for the A*C interaction

Cohen_f_BC = Cohen's f for the B*C interaction

Cohen_f_ABC = Cohen's f for the A*B*C interaction

f_2_A = Cohen's f squared for main effect A

f_2_B = Cohen's f squared for main effect B

f_2_C = Cohen's f squared for main effect C

f_2_AB = Cohen's f squared for A*B interaction

f_2_AC = Cohen's f squared for A*C interaction

f_2_BC = Cohen's f squared for B*C interaction

f_2_ABC = Cohen's f squared for A*B*C interaction

lambda_A = lambda for main effect A

lambda_B = lambda for main effect B

lambda_C = lambda for main effect C

lambda_AB = lambda for A*B interaction
lambda_AC = lambda for A*C interaction
lambda_BC = lambda for B*C interaction
lambda_ABC = lambda for A*B*C interaction
critical_F_A = critical F-value for main effect A
critical_F_B = critical F-value for main effect B
critical_F_C = critical F-value for main effect C
critical_F_AB = critical F-value for A*B interaction
critical_F_AC = critical F-value for A*C interaction
critical_F_BC = critical F-value for B*C interaction
critical_F_ABC = critical F-value for A*B*C interaction
power_A = power for main effect A
power_B = power for main effect B
power_C = power for main effect C
power_AB = power for A*B interaction
power_AC = power for A*C interaction
power_BC = power for B*C interaction
power_ABC = power for A*B*C interaction
df_A = degrees of freedom for main effect A
df_B = degrees of freedom for main effect B
df_C = degrees of freedom for main effect C
df_AB = degrees of freedom for A*B interaction
df_AC = degrees of freedom for A*C interaction
df_BC = degrees of freedom for B*C interaction
df_ABC = degrees of freedom for A*B*C interaction
df_error = degrees of freedom for error term
eta_p_2_A = partial eta-squared for main effect A
eta_p_2_B = partial eta-squared for main effect B
eta_p_2_C = partial eta-squared for main effect C
eta_p_2_AB = partial eta-squared for A*B interaction
eta_p_2_AC = partial eta-squared for A*C interaction
eta_p_2_BC = partial eta-squared for B*C interaction
eta_p_2_ABC = partial eta-squared for A*B*C interaction
mean_mat = matrix of the means

References

to be added

Examples

```
design_result <- ANOVA_design(design = "2b*2b*2b", n = 40,
      mu = c(1, 0, 1, 0, 0, 1, 1, 0), sd = 2,
      labelnames = c("condition", "cheerful", "sad",
      "voice", "human", "robot", "color", "green", "red"))
power_result <- power_threeway_between(design_result, alpha_level = 0.05)
```

---

power_twoway_between *Analytic power calculation for two-way between designs.*

Description

Analytic power calculation for two-way between designs.

Usage

```
power_twoway_between(design_result, alpha_level = 0.05)
```

Arguments

design_result	Output from the ANOVA_design function
alpha_level	Alpha level used to determine statistical significance

Value

mu = means

sigma = standard deviation

n = sample size

alpha_level = alpha level

Cohen_f_A = Cohen's f for main effect A

Cohen_f_B = Cohen's f for main effect B

Cohen_f_AB = Cohen's f for the A*B interaction

f_2_A = Cohen's f squared for main effect A

f_2_B = Cohen's f squared for main effect B

f_2_AB = Cohen's f squared for A*B interaction

lambda_A = lambda for main effect A

lambda_B = lambda for main effect B

lambda_AB = lambda for A*B interaction

critical_F_A = critical F-value for main effect A

critical_F_B = critical F-value for main effect B

critical_F_AB = critical F-value for A*B interaction

power_A = power for main effect A

power_B = power for main effect B

power_AB = power for A*B interaction

df_A = degrees of freedom for main effect A

df_B = degrees of freedom for main effect B

df_AB = degrees of freedom for A*B interaction

df_error = degrees of freedom for error term

eta_p_2_A = partial eta-squared for main effect A

eta_p_2_B = partial eta-squared for main effect B

eta_p_2_AB = partial eta-squared for A*B interaction

mean_mat = matrix of the means

References

too be added

Examples

```
design_result <- ANOVA_design(design = "2b*2b", n = 40, mu = c(1, 0, 1, 0),
     sd = 2, labelnames = c("condition", "cheerful", "sad",
     "voice", "human", "robot"))
power_result <- power_twoway_between(design_result, alpha_level = 0.05)
```

`Superpower_options` *Set/get global Superpower options*

Description

Global Superpower options are used, for example, by `ANOVA_exact` (et al.) and `ANOVA_power`. But can be changed in each functions directly using an argument (which has precedence over the global options).

Usage

```
Superpower_options(...)
```

Arguments

`...`	One of four: (1) nothing, then returns all options as a list; (2) a name of an option element, then returns its' value; (3) a name-value pair which sets the corresponding option to the new value (and returns nothing), (4) a list with option-value pairs which sets all the corresponding arguments. The example show all possible cases.

Details

The following arguments are currently set:

- `verbose` should verbose (printed results) be set to true? Default is `TRUE`.
- `emm` Option to perform analysis of estimated marginal means. Default is `FALSE`.
- `emm_model` Model type ("multivariate", or "univariate") for estimated marginal means. Default is `"multivariate"`.
- `contrast_type` The type of comparison for the estimated marginal means. Default is `"pairwise"`. See ?emmeans::'contrast-methods' for more details on acceptable methods.
- `plot` Option to automatically print plots. Default is `FALSE`.
- `alpha_level` Alpha level used to determine statistical significance. Default is .05.
- `correction` Option to set a correction for sphericity violations. Default is no correction. This can be set to "none", "GG" Greenhouse-Geisser, and "HF" Huynh-Feldt

Value

depends on input, see above.

Note

All options are saved in the global R `options` with prefix `Superpower.`

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