Package 'multiplestressR'

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Title Additive and Multiplicative Null Models for Multiple Stressor
Data

Version 0.1.1

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Description An implementation of the additive (Gurevitch et al., 2000 <doi:10.1086/303337>)
and multiplicative (Lajeunesse, 2011 <doi:10.1890/11-0423.1>) factorial null models for
multiple stressor data (Burgess et al., 2021 <doi:10.1101/2021.07.21.453207>). Effect sizes
are able to be calculated for either null model, and subsequently classified into one of
four different interaction classifications (e.g., antagonistic or synergistic interactions).
Analyses can be conducted on data for single experiments through to large meta-
analytical datasets.
Minimal input (or statistical knowledge) is required, with any output easily understood.
Summary figures are also able to be easily generated.

URL https://benjburgess.github.io/multiplestressR/

Imports ggplot2, patchwork, viridis

License GPL (>= 3)

Encoding UTF-8

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R topics documented:

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classify_interactions   *Classify Interactions (for either null model)*

Description

Using the output from either the [effect_size_additive](#) or [effect_size_multiplicative](#) functions, interactions can be assigned classifications (e.g., antagonisms or synergisms) based on the frameworks used by *Burgess et al. (2021)*, or *Jackson et al. (2016)*.

Usage

```
classify_interactions(
  effect_size_dataframe,
  assign_reversals,
  remove_directionality
)
```

Arguments

effect_size_dataframe

Output from either the [effect_size_additive](#) or [effect_size_multiplicative](#) functions.

assign_reversals

Specify whether reversals should be distinguished from antagonisms (see *Jackson et al. (2016)* (TRUE or FALSE; default = TRUE)

remove_directionality

Specify whether directionality should be removed from the effect sizes. This is most pertinent where subsequent analyses will involve conducting a formal meta-analysis (set value to TRUE). (TRUE or FALSE; default = FALSE)

Value

The function returns a dataset containing i) the same results as from either the [effect_size_additive](#) or [effect_size_multiplicative](#) functions.

ii) the classification of any interactions (see below)

iii) if remove_directionality = TRUE; effect sizes, and confidence intervals will be adjusted (see below)

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For ii), interactions are classified in the following method.

a) if the confidence intervals for any effect size overlap zero then the interaction is assigned a *null* classification.

This is analogous to the classification of *additive* which other studies (e.g., *Jackson et al. (2016)*) may use.

Note that this is given precedence over the process described in b).

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b) if the confidence intervals for any effect size do not overlap zero then *Expected* and *Observed* effects are calculated.

Where the additive null model has been used:

$$Expected = X_a + X_b - 2 * X_c$$

$$Observed = X_i - X_c$$

Where the multiplicative null model has been used:

$$Expected = ln(X_a) + ln(X_b) - 2 * ln(X_c)$$

$$Observed = ln(X_i) - ln(X_c)$$

Here X_c, X_a, X_b, and X_i correspond to the means of the control, stressor A, stressor B, and stressors A and B treatments respectively.

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A *synergistic* classification is assigned where:

an effect size is positive *and Expected* is greater than zero.

or

an effect size is negative *and Expected* is less than zero.

—

An *antagonistic* classification is assigned where:

an effect size is negative *and both Expected and Observed* are greater than zero.

or

an effect size is positive *and both Expected and Observed* are less than zero.

—

A *reversal* classification is assigned where:

an effect size is negative *and Expected* is greater than zero but *Observed* is less than zero.

or

an effect size is positive *and Expected* is less than zero but *Observed* is greater than zero.

If *assign_reversals* = FALSE, then where a reversal would be assigned using the above method, it is simply assigned an *antagonistic* classification instead.

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If *remove_directionality* = TRUE, then the following method is implemented.

Where an interaction has an *Expected* value <0, the corresponding effect size for this interaction has its polarity changed (i.e., ES = -ES).

Confidence intervals for these altered effect sizes are likewise updated.

The remove of directionality is only likely to be of concern for meta-analyses.

References

Burgess, B. J., Purves, D., Mace, G., & Murrell, D. J. (2021). Classifying ecosystem stressor interactions: Theory highlights the data limitations of the additive null model and the difficulty in revealing ecological surprises. *Global Change Biology*.

Jackson, M. C., Loewen, C. J., Vinebrooke, R. D., & Chimimba, C. T. (2016). Net effects of multiple stressors in freshwater ecosystems: a meta-analysis. *Global Change Biology*, 22(1), 180-189.

Examples

```
#loading up an example dataset from the multiplestressR package
df <- multiplestressR::survival

#calculating effect sizes
df <- effect_size_additive(Control_N          = df$Sample_Size_Control,
                           Control_SD         = df$Standard_Deviation_Control,
                           Control_Mean       = df$Mean_Control,
                           StressorA_N        = df$Sample_Size_Temperature,
                           StressorA_SD       = df$Standard_Deviation_Temperature,
                           StressorA_Mean     = df$Mean_Temperature,
                           StressorB_N        = df$Sample_Size_pH,
                           StressorB_SD       = df$Standard_Deviation_pH,
                           StressorB_Mean     = df$Mean_pH,
                           StressorsAB_N      = df$Sample_Size_Temperature_pH,
                           StressorsAB_SD     = df$Standard_Deviation_Temperature_pH,
                           StressorsAB_Mean   = df$Mean_Temperature_pH,
                           Significance_Level = 0.05);

#classifying interactions
df <- classify_interactions(effect_size_dataframe = df,
                  assign_reversals = TRUE,
                  remove_directionality = TRUE)
```

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critical_effect_size_additive

Critical Effect Sizes (for the additive null model)

Description

The critical effect size for a given experimental design (i.e., number of replicates per treatment).

Usage

```
critical_effect_size_additive(
  Control_N,
  StressorA_N,
  StressorB_N,
  StressorsAB_N,
  Small_Sample_Correction,
  Significance_Level
)
```

Arguments

Control_N   Sample size of the control treatment (numeric)

StressorA_N   Sample size of stressor A treatment (numeric)

StressorB_N   Sample size of stressor B treatment (numeric)

StressorsAB_N   Sample size of stressors A and B treatment (numeric)

Small_Sample_Correction

        Whether the correction for small sample sizes should be enacted (TRUE or FALSE; default is TRUE)

Significance_Level

        The value of alpha for which confidence intervals are calculated (numeric, between 0 and 1; default is 0.05)

Details

The critical effect size represents the minimum effect size required for a significant result to be returned (see Burgess et al. (2021)).

For the additive null model, the critical effect size is directly related to treatment sample sizes.

Value

The function returns the critical effect size (for the additive null model; see effect_size_additive) for a given experimental design.

References

Burgess, B. J., Jackson, M. C., & Murrell, D. J. (2021). Multiple stressor null models frequently fail to detect most interactions due to low statistical power. *bioRxiv*.

Examples

```
critical_effect_size_additive(Control_N    = 4,
                              StressorA_N  = 4,
                              StressorB_N  = 4,
                              StressorsAB_N = 4)

critical_effect_size_additive(Control_N    = 3,
                              StressorA_N  = 3,
                              StressorB_N  = 3,
                              StressorsAB_N = 3,
                              Small_Sample_Correction = FALSE,
                              Significance_Level = 0.10)
```

---

effect_size_additive   *Additive Null Model*

Description

Calculate the additive null model for one, or more, experiments.

Usage

```
effect_size_additive(
  Control_N,
  Control_SD,
  Control_Mean,
  StressorA_N,
  StressorA_SD,
  StressorA_Mean,
  StressorB_N,
  StressorB_SD,
  StressorB_Mean,
  StressorsAB_N,
  StressorsAB_SD,
  StressorsAB_Mean,
  Small_Sample_Correction,
  Significance_Level
)
```

Arguments

Control_N	Sample size of the control treatment (numeric)
Control_SD	Standard deviation of the control treatment (numeric)
Control_Mean	Mean value of the control treatment (numeric)
StressorA_N	Sample size of stressor A treatment (numeric)
StressorA_SD	Standard deviation of stressor A treatment (numeric)

StressorA_Mean Mean value of stressor A treatment (numeric)

StressorB_N   Sample size of stressor B treatment (numeric)

StressorB_SD   Standard deviation of stressor B treatment (numeric)

StressorB_Mean Mean value of stressor B treatment (numeric)

StressorsAB_N   Sample size of stressors A and B treatment (numeric)

StressorsAB_SD Standard deviation of stressors A and B treatment (numeric)

StressorsAB_Mean

        Mean value of stressors A and B treatment (numeric)

Small_Sample_Correction

        Whether the correction for small sample sizes should be enacted (TRUE or FALSE; default is TRUE)

Significance_Level

        The value of alpha for which confidence intervals are calculated (numeric, between 0 and 1; default is 0.05)

Details

The form of the additive null model used here is taken from *Gurevitch et al. (2000)*.

Interaction effect sizes, variances, and confidence intervals are calculated.

Here, the factorial form of Hedges' d is calculated.

Value

The function returns a dataframe containing

i. effect sizes

ii. effect size variances

iii. upper and lower confidence intervals

iv. user specified numeric parameters

The equations used to calculate effect sizes, effect size variances, and confidence intervals are described in *Burgess et al. (2021)*.

Note that the parameter *Small_Sample_Correction* determines whether the correction for sample sizes is to be used within the function. This correction (see *Borenstein et al. (2009)*) tends towards 1 as sample sizes increase. Hence it is most applicable where small sample sizes are used.

References

Borenstein, M., Cooper, H., Hedges, L., & Valentine, J. (2009). Effect sizes for continuous data. *The Handbook of Research Synthesis and Meta-Analysis*, 2, 221-235.

Burgess, B. J., Jackson, M. C., & Murrell, D. J. (2021). Multiple stressor null models frequently fail to detect most interactions due to low statistical power. *bioRxiv*.

Gurevitch, J., Morrison, J. A., & Hedges, L. V. (2000). The interaction between competition and predation: a meta-analysis of field experiments. *The American Naturalist*, 155(4), 435-453.

Examples

```
df <- effect_size_additive(Control_N = 4,
                     Control_SD = 0.114,
                     Control_Mean = 0.90,
                     StressorA_N = 4,
                     StressorA_SD = 0.11,
                     StressorA_Mean = 0.77,
                     StressorB_N = 3,
                     StressorB_SD = 0.143,
                     StressorB_Mean = 0.72,
                     StressorsAB_N = 4,
                     StressorsAB_SD = 0.088,
                     StressorsAB_Mean = 0.55,
                     Small_Sample_Correction = TRUE,
                     Significance_Level = 0.05)

#loading up an example dataset from the multiplestressR package
df <- multiplestressR::survival

#calculating effect sizes
df <- effect_size_additive(Control_N        = df$Sample_Size_Control,
                           Control_SD       = df$Standard_Deviation_Control,
                           Control_Mean     = df$Mean_Control,
                           StressorA_N      = df$Sample_Size_Temperature,
                           StressorA_SD     = df$Standard_Deviation_Temperature,
                           StressorA_Mean   = df$Mean_Temperature,
                           StressorB_N      = df$Sample_Size_pH,
                           StressorB_SD     = df$Standard_Deviation_pH,
                           StressorB_Mean   = df$Mean_pH,
                           StressorsAB_N    = df$Sample_Size_Temperature_pH,
                           StressorsAB_SD   = df$Standard_Deviation_Temperature_pH,
                           StressorsAB_Mean = df$Mean_Temperature_pH,
                           Significance_Level = 0.05);
```

---

effect_size_multiplicative
                              Multiplicative Null Model

Description

Calculate the multiplicative null model for one, or more, experiments.

Usage

```
effect_size_multiplicative(
  Control_N,
  Control_SD,
```

```
    Control_Mean,
    StressorA_N,
    StressorA_SD,
    StressorA_Mean,
    StressorB_N,
    StressorB_SD,
    StressorB_Mean,
    StressorsAB_N,
    StressorsAB_SD,
    StressorsAB_Mean,
    Significance_Level
)
```

Arguments

`Control_N`	Sample size of the control treatment (numeric)
`Control_SD`	Standard deviation of the control treatment (numeric)
`Control_Mean`	Mean value of the control treatment (numeric)
`StressorA_N`	Sample size of stressor A treatment (numeric)
`StressorA_SD`	Standard deviation of stressor A treatment (numeric)
`StressorA_Mean`	Mean value of stressor A treatment (numeric)
`StressorB_N`	Sample size of stressor B treatment (numeric)
`StressorB_SD`	Standard deviation of stressor B treatment (numeric)
`StressorB_Mean`	Mean value of stressor B treatment (numeric)
`StressorsAB_N`	Sample size of stressors A and B treatment (numeric)
`StressorsAB_SD`	Standard deviation of stressors A and B treatment (numeric)
`StressorsAB_Mean`	
	Mean value of stressors A and B treatment (numeric)
`Significance_Level`	
	The value of alpha for which confidence intervals are calculated (numeric, between 0 and 1; default is 0.05)

Details

The form of the multiplicative null model used here is taken from *Lajeunesse (2011)*.

Interaction effect sizes, variances, and confidence intervals are calculated.

Here, the factorial form of the response ratio is calculated.

Value

The function returns a dataframe containing

i. effect sizes

ii. effect size variances

iii. upper and lower confidence intervals

iv. user specified numeric parameters

The equations used to calculate effect sizes, effect size variances, and confidence intervals are described in *Burgess et al. (2021)*.

References

Burgess, B. J., Jackson, M. C., & Murrell, D. J. (2021). Multiple stressor null models frequently fail to detect most interactions due to low statistical power. *bioRxiv*.

Lajeunesse, M. J. (2011). On the meta-analysis of response ratios for studies with correlated and multi-group designs. *Ecology*, 92(11), 2049-2055.

Examples

```
effect_size_multiplicative(Control_N = 4,
                           Control_SD = 0.114,
                           Control_Mean = 0.90,
                           StressorA_N = 4,
                           StressorA_SD = 0.11,
                           StressorA_Mean = 0.77,
                           StressorB_N = 3,
                           StressorB_SD = 0.143,
                           StressorB_Mean = 0.72,
                           StressorsAB_N = 4,
                           StressorsAB_SD = 0.088,
                           StressorsAB_Mean = 0.55,
                           Significance_Level = 0.05)

#loading up an example dataset from the multiplestressR package
df <- multiplestressR::survival

#calculating effect sizes
df <- effect_size_multiplicative(Control_N        = df$Sample_Size_Control,
                          Control_SD       = df$Standard_Deviation_Control,
                          Control_Mean     = df$Mean_Control,
                          StressorA_N      = df$Sample_Size_Temperature,
                          StressorA_SD     = df$Standard_Deviation_Temperature,
                          StressorA_Mean   = df$Mean_Temperature,
                          StressorB_N      = df$Sample_Size_pH,
                          StressorB_SD     = df$Standard_Deviation_pH,
                          StressorB_Mean   = df$Mean_pH,
                          StressorsAB_N    = df$Sample_Size_Temperature_pH,
                         StressorsAB_SD    = df$Standard_Deviation_Temperature_pH,
                          StressorsAB_Mean = df$Mean_Temperature_pH,
                          Significance_Level = 0.05);

#classifying interactions
df <- classify_interactions(effect_size_dataframe = df,
                   assign_reversals = TRUE,
                   remove_directionality = TRUE)
```

---

summary_plots   *Generate Summary Figures*

Description

Using the output from `classify_interactions` function, summary figures can be created using this function.

Usage

```
summary_plots(
  effect_size_dataframe,
  Small_Sample_Correction,
  Significance_Level
)
```

Arguments

effect_size_dataframe

> Output from the `classify_interactions` function.

Small_Sample_Correction

> Whether the correction for small sample sizes should be enacted (TRUE or FALSE; default is TRUE) *Note that if the multiplicative null model (see `effect_size_multiplicative`) was implemented, this parameter is not used and can be ignored. If the additive null model (see `effect_size_additive`) was implemented, then this parameter should be assigned the same value as in that analysis.*

Significance_Level

> The value of alpha for which confidence intervals are calculated (numeric, between 0 and 1; default is 0.05) *Note that if the multiplicative null model (see `effect_size_multiplicative`) was implemented, this parameter is not used and can be ignored. If the additive null model (see `effect_size_additive`) was implemented, then this parameter should be assigned the same value as in that analysis.*

Details

The figures include:

a) The proportions of the different interaction classifications from the dataset

b) Median sample sizes plotted against effect size (different interaction classifications are highlighted). Where the additive null model was used in the analysis, lines for critical effect sizes are plotted (see `critical_effect_size_additive` function).

c) Density of different median sample sizes.

d) Inverse of effect size variance plotted against effect size (i.e., one iteration of a funnel plot).

e) Effect size standard error (i.e., the square root of the effect size variance) plotted against effect size (i.e., one iteration of a funnel plot)).

Note that c - e) are most useful for researchers conducting a meta-analysis.

Value

The function returns a series of figures each of which is outlined above.

Examples

```
#loading up an example dataset from the multiplestressR package
df <- multiplestressR::survival

#calculating effect sizes
df <- effect_size_additive(Control_N        = df$Sample_Size_Control,
                           Control_SD       = df$Standard_Deviation_Control,
                           Control_Mean     = df$Mean_Control,
                           StressorA_N      = df$Sample_Size_Temperature,
                           StressorA_SD     = df$Standard_Deviation_Temperature,
                           StressorA_Mean   = df$Mean_Temperature,
                           StressorB_N      = df$Sample_Size_pH,
                           StressorB_SD     = df$Standard_Deviation_pH,
                           StressorB_Mean   = df$Mean_pH,
                           StressorsAB_N    = df$Sample_Size_Temperature_pH,
                           StressorsAB_SD   = df$Standard_Deviation_Temperature_pH,
                           StressorsAB_Mean = df$Mean_Temperature_pH,
                           Significance_Level = 0.05);

#classifying interactions
df <- classify_interactions(effect_size_dataframe = df,
                  assign_reversals = TRUE,
                  remove_directionality = TRUE);

#generate summary plots
df_plots <- summary_plots(effect_size_dataframe = df,
                  Significance_Level = 0.05)
```

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survival	*Survival data for 250 populations exposed to the stressors of temperature and pH.*

Description

A generated dataset on the survival rates of 250 populations (each composed of 100 individuals) exposed to the stressors of temperature and pH. The dataset uses a factorial design comprising four treatments: i) Control conditions; ii) Exposed to temperature; iii) Exposed to pH; iv) Exposed to both temperature and pH. This generated dataset is used in the examples for each function in the multiplestressR package. Please note that this is a generated dataset and does not reflect data from actual ecological experiments.

Usage

```
survival
```

Format

A data frame with 250 rows and 12 variables:

Sample_Size_Control Number of samples for the control treatment

Standard_Deviation_Control standard deviation for mean survival of the control treatment

Mean_Control mean survival (as a proportion) for the control treatment

Sample_Size_Temperature Number of samples for the temperature treatment

Standard_Deviation_Temperature standard deviation for mean survival of the temperature treatment

Mean_Temperature mean survival (as a proportion) for the temperature treatment

Sample_Size_pH Number of samples for the pH treatment

Standard_Deviation_pH standard deviation for mean survival of the pH treatment

Mean_pH mean survival (as a proportion) for the pH treatment

Sample_Size_Temperature_pH Number of samples for the combined temperature and pH treatment

Standard_Deviation_Temperature_pH standard deviation for mean survival of the combined temperature and pH treatment

Mean_Temperature_pH mean survival (as a proportion) for the combined temperature and pH treatment

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