Package ‘MANOVA.RM’

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Type Package

Title Analysis of Multivariate Data and Repeated Measures Designs

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Depends R (>= 3.5.0)

Description Implemented are various tests for semi-parametric repeated measures and general MANOVA designs that do neither assume multivariate normality nor covariance homogeneity, i.e., the procedures are applicable for a wide range of general multivariate factorial designs. Furthermore, post-hoc comparisons are provided for the multivariate analyses.


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Imports plyr (>= 1.8.3), MASS (>= 7.3-43), Matrix (>= 1.2-2), magic (>= 1.5-6), plotrix (>= 3.5-12), parallel, methods, ellipse, multcomp

LazyData TRUE

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RoxygenNote 6.0.1

VignetteBuilder knitr, rmarkdown

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**conf.reg**

The `conf.reg()` function calculates confidence regions for contrasts in multivariate factorial designs. In the two-dimensional case, confidence ellipsoids can be plotted via the generic `plot()` function.

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**Description**

The `conf.reg()` function calculates confidence regions for contrasts in multivariate factorial designs. In the two-dimensional case, confidence ellipsoids can be plotted via the generic `plot()` function.

**Usage**

```
conf.reg(object, nullhypo)
```

**Arguments**

- `object` A MANOVA object.
- `nullhypo` In scenarios with more than one factor, the null hypothesis, i.e., the contrast of interest must be specified.
Value

A confreg object containing the following components:

- **center**: The center of the confidence ellipsoid.
- **scale**: The scaling factors for the axis of the confidence ellipsoid calculated as \( \sqrt{\lambda \times c/N} \), where \( \lambda \) are the eigenvalues, \( c \) denotes the bootstrap quantile and \( N \) is the total sample size. See Friedrich and Pauly (2018) for details.
- **eigenvectors**: The corresponding eigenvectors, which determine the axes of the ellipsoid.

References


Examples

```r
data(EEG)
EEG_mod <- MANOVA(resp ~ sex * diagnosis,
                 data = EEG, subject = "id", resampling = "paramBS",
                 alpha = 0.05, iter = 100, CPU = 1)
conf.reg(EEG_mod, nullhypo = "sex")
```

---

**EEG**

*EEG Measurements in Patients with Alzheimer’s Disease (long format)*

Description

At the Department of Neurology, University Clinic of Salzburg, 160 patients were diagnosed with either AD, MCI, or SCC, based on neuropsychological diagnostics. This data set contains z-scores for brain rate and Hjorth complexity, each measured at frontal, temporal and central electrode positions and averaged across hemispheres. In addition to standardization, complexity values were multiplied by -1 in order to make them more easily comparable to brain rate values: For brain rate we know that the values decrease with age and pathology, while Hjorth complexity values are known to increase with age and pathology. The three between-subjects factors considered were sex (men vs. women), diagnosis (AD vs. MCI vs. SCC), and age (< 70 vs. >= 70 years). Additionally, the within-subjects factors region (frontal, temporal, central) and feature (brain rate, complexity) structure the response vector.

Usage

```r
data(EEG)
```
**Format**

A data frame with 960 rows and 7 variables:

- **resp** EEG measurements
- **sex** sex of the patient
- **age** age of the patient, coded as 0 for less than 70 years and 1 for >= 70 years
- **diagnosis** neuropsychological diagnosis, AD for Alzheimer’s Disease, MCI for mild cognitive impairment or SCC for subjective cognitive complaints without clinically significant deficits
- **region** brain region of the EEG measurements, one of "temporal", "frontal" and "central"
- **feature** feature of the EEG measurements, either "brainrate" or "complexity"
- **id** Subject id

**Source**


**Description**

At the Department of Neurology, University Clinic of Salzburg, 160 patients were diagnosed with either AD, MCI, or SCC, based on neuropsychological diagnostics. This data set contains z-scores for brain rate and Hjorth complexity, each measured at frontal, temporal and central electrode positions and averaged across hemispheres. In addition to standardization, complexity values were multiplied by -1 in order to make them more easily comparable to brain rate values: For brain rate we know that the values decrease with age and pathology, while Hjorth complexity values are known to increase with age and pathology. The three between-subjects factors considered were sex (men vs. women), diagnosis (AD vs. MCI vs. SCC), and age (< 70 vs. >= 70 years). Additionally, the within-subjects factors region (frontal, temporal, central) and feature (brain rate, complexity) structure the response vector.

**Usage**

data(EEGwide)

**Format**

A data frame with 160 rows and 9 variables:

- **brainrate_temporal** EEG measurements for brainrate in temporal regions
- **brainrate_frontal** EEG measurements for brainrate in frontal regions
brainrate_central  EEG measurements for brainrate in central regions
complexity_temporal  EEG measurements for complexity in temporal regions
complexity_frontal  EEG measurements for complexity in frontal regions
complexity_central  EEG measurements for complexity in central regions
sex  sex of the patient
age  age of the patient
diagnosis  neuropsychological diagnosis, AD for Alzheimer’s Disease, MCI for mild cognitive impairment or SCC for subjective cognitive complaints without clinically significant deficits
AgeGroup  categorized age, coded as 0 for less than 70 years and 1 for >= 70 years

Source


GUI.MANova

A graphical user interface for the MANOVA() function

Description

This function provides a graphical user interface for calculating statistical tests for multivariate data.

Usage

GUI.MANova()

Details

The function produces a GUI for the calculation of the test statistics. Data can be loaded via the "load data" button. The formula, number of resampling iterations (default: 10,000) and the significance level alpha (default: 0.05) need to be specified. Furthermore, the column name specifying the subjects in the data needs to be provided. For the resampling methods, the user can choose between a parametric bootstrap approach (see e.g. Konietschke et al. (2015)) and a Wild bootstrap using Rademacher weights (see e.g. Bathke et al. (2016)).
GUI.MANOVAnwide

A graphical user interface for the MANOVA.wide() function

Description

This function provides a graphical user interface for calculating statistical tests for multivariate data.

Usage

GUI.MANOVAnwide()

Details

The function produces a GUI for the calculation of the test statistics. Data can be loaded via the "load data" button. The formula, number of resampling iterations (default: 10,000) and the significance level alpha (default: 0.05) need to be specified. For the resampling methods, the user can choose between a parametric bootstrap approach (see e.g. Konietschke et al. (2015)) and a Wild bootstrap using Rademacher weights (see e.g. Bathke et al. (2016)).

GUI.RM

A graphical user interface for the RM() function

Description

This function provides a graphical user interface for calculating statistical tests in repeated measures designs.

Usage

GUI.RM()

Details

The function produces a GUI for the calculation of the test statistics and for plotting. Data can be loaded via the "load data" button. The formula, number of resampling iterations (default: 10,000) and the significance level alpha (default: 0.05) need to be specified. Furthermore, the number of sub-plot factors and the column name specifying the subjects in the data need to be provided. For the resampling methods, the user can choose between a permutation approach (Friedrich et al. (2017)), a parametric bootstrap approach (Konietschke et al. (2015)) and a Wild bootstrap using Rademacher weights (Bathke et al. (2016)). If the plot option is chosen, an additional window opens containing information on the plots.
The MANOVA function calculates the Wald-type statistic (WTS) and a modified ANOVA-type statistic (MATS) as well as resampling versions of these test statistics for semi-parametric multivariate data.

**Usage**

```r
call { MANOVA(formula, data, subject, iter = 10000, alpha = 0.05, 
    resampling = "paramBS", CPU, seed, nested.levels.unique = FALSE, 
    dec = 3) }
```

**Arguments**

- **formula**: A model formula object. The left hand side contains the response variable and the right hand side contains the factor variables of interest. An interaction term must be specified.
- **data**: A data.frame, list or environment containing the variables in `formula`. Data must be in long format and must not contain missing values.
- **subject**: The column name of the subjects in the data.
- **iter**: The number of iterations used for calculating the resampled statistic. The default option is 10,000.
- **alpha**: A number specifying the significance level; the default is 0.05.
- **resampling**: The resampling method to be used, one of "paramBS" (parametric bootstrap approach) and "WildBS" (wild bootstrap approach with Rademacher weights).
- **CPU**: The number of cores used for parallel computing. If omitted, cores are detected via `detectCores`.
- **seed**: A random seed for the resampling procedure. If omitted, no reproducible seed is set.
- **nested.levels.unique**: A logical specifying whether the levels of the nested factor(s) are labeled uniquely or not. Default is FALSE, i.e., the levels of the nested factor are the same for each level of the main factor. For an example and more explanations see the GFD package and the corresponding vignette.
- **dec**: Number of decimals the results should be rounded to. Default is 3.

**Details**

The MANOVA() function provides the Wald-type statistic (WTS) as well as the modified ANOVA-type statistic (MATS) for multivariate designs with metric data as described in Konietschke et al. (2015) and Friedrich and Pauly (2018), respectively. The MATS is invariant under scale transformations of the components and applicable to designs with singular covariance matrices. Both tests
are applicable for non-normal error terms, different sample sizes and/or heteroscedastic variances. They are implemented for designs with an arbitrary number of crossed factors or for nested designs. In addition to the asymptotic p-values, the function also provides p-values based on resampling approaches.

Value

A MANOVA object containing the following components:

Descriptive

Some descriptive statistics of the data for all factor level combinations. Displayed are the number of individuals per factor level combination and the vector of means (one column per dimension).

Covariance

The estimated covariance matrix.

WTS

The value of the WTS along with degrees of freedom of the central chi-square distribution and p-value.

MATS

The value of the MATS.

resampling

p-values for the test statistic based on the chosen resampling approach.

NOTE

The number of resampling iterations has been set to 100 in the examples due to run time restrictions on CRAN. Usually it is recommended to use at least 1000 iterations. For more information and detailed examples also refer to the package vignette.

References


See Also

RM

Examples

data(EEG)
EEG_mod <- MANOVA(resp ~ sex * diagnosis,
                 data = EEG, subject = "id", resampling = "paramBS",
                 alpha = 0.05, iter = 100, CPU = 1)
The MANOVA.wide function calculates the Wald-type statistic (WTS) and a modified ANOVA-type statistic (MATS) as well as resampling versions of these test statistics for semi-parametric multivariate data provided in wide format.

Usage

MANOVA.wide(formula, data, iter = 10000, alpha = 0.05, resampling = "paramBS", CPU, seed, nested.levels.unique = FALSE, dec = 3)

Arguments

- **formula**: A model formula object. The left hand side contains the matrix of response variables and the right hand side contains the factor variables of interest. An interaction term must be specified.
- **data**: A data.frame, list or environment containing the variables in formula. Data must be in wide format. Note: Lines containing missing values will be removed.
- **iter**: The number of iterations used for calculating the resampled statistic. The default option is 10,000.
- **alpha**: A number specifying the significance level; the default is 0.05.
- **resampling**: The resampling method to be used, one of "paramBS" (parametric bootstrap approach) and "WildBS" (wild bootstrap approach with Rademacher weights). The Wild Bootstrap is calculated for all test statistics.
- **CPU**: The number of cores used for parallel computing. If omitted, cores are detected via detectCores.
- **seed**: A random seed for the resampling procedure. If omitted, no reproducible seed is set.
- **nested.levels.unique**: A logical specifying whether the levels of the nested factor(s) are labeled uniquely or not. Default is FALSE, i.e., the levels of the nested factor are the same for each level of the main factor. For an example and more explanations see the GFD package and the corresponding vignette.
- **dec**: Number of decimals the results should be rounded to. Default is 3.

Value

See MANOVA
NOTE

The number of resampling iterations has been set to 100 in the examples due to run time restrictions on CRAN. Usually it is recommended to use at least 1000 iterations.

See Also

MANOVA

Examples

```r
#Example on producing plastic film from Krzanowski (1998, p. 381), see \code{\link{manova.summary}}
tear <- c(6.5, 6.2, 5.8, 6.5, 6.5, 6.9, 7.2, 6.9, 6.1, 6.3,
          6.7, 6.6, 7.2, 7.1, 6.8, 7.1, 7.0, 7.2, 7.5, 7.6)
gloss <- c(9.5, 9.9, 9.6, 9.6, 9.2, 9.1, 10.0, 9.9, 9.5, 9.4,
         9.1, 9.3, 8.3, 8.4, 8.5, 9.2, 8.8, 9.7, 10.1, 9.2)
opacity <- c(4.4, 6.4, 3.0, 4.1, 0.8, 5.7, 2.0, 3.9, 1.9, 5.7,
            2.8, 4.1, 3.8, 1.6, 3.4, 8.4, 5.2, 6.9, 2.7, 1.9)
rate <- gl(2, 10, labels = c("Low", "High"))
additive <- gl(2, 5, length = 20, labels = c("Low", "High"))
example <- data.frame(tear, gloss, opacity, rate, additive)
fit <- MANOVA.wide(cbind(tear, gloss, opacity) ~ rate * additive,
data = example, iter = 100, CPU = 1)
summary(fit)
```

Description

The MANOVARM package provides two important functions: MANOVA() and RM() which will be explained in detail below.

MANOVA and MANOVA.wide function

The MANOVA() and MANOVA.wide() functions provide the Wald-type statistic (WTS) as well as a modified ANOVA-type statistic (MATS) as in Friedrich and Pauly (2018) for multivariate designs with metric data as described in Konietschke et al. (2015). These are applicable for non-normal error terms, different sample sizes and/or heteroscedastic variances. The MATS can even handle designs involving singular covariance matrices. The tests are implemented for designs with an arbitrary number of crossed factors or for nested designs. In addition to the asymptotic p-values, they also provide p-values based on resampling approaches (parametric or wild bootstrap). The difference between the two functions is the format of the data: For MANOVA(), the data needs to be in long format, while MANOVA.wide() is for data in wide format. For further details, see MANOVA and MANOVA.wide.
**RM function**

The RM() function provides the Wald-type statistic (WTS) as well as the ANOVA-type statistic (ATS) for repeated measures designs with metric data as described in Friedrich et al. (2017). These are even applicable for non-normal error terms and/or heteroscedastic variances. It is implemented for designs with an arbitrary number of whole-plot and sub-plot factors and allows for different sample sizes. In addition to the asymptotic p-values, it also provides p-values based on resampling approaches (Permutation, parametric bootstrap, Wild bootstrap). For further details, see RM.

**References**


---

**o2cons**

*Oxygen Consumption of Leukocytes*

**Description**

A dataset containing measurements on the oxygen consumption of leukocytes in the presence and absence of inactivated staphylococci.

**Usage**

`data(o2cons)`

**Format**

A data frame with 144 rows and 5 variables:

- **O2** oxygen consumption of leukocytes in µl
- **Staphylococci** whether or not inactivated staphylococci were added, 1 denotes yes, 0 no
- **Time** the measurements were taken after 6, 12 and 18 minutes
- **Group** the treatment group, either P for Placebo or V for Verum
- **Subject** the subject id
Source

---

**plot.RM**
*Plot function for an RM object*

**Description**
Generic plot function for RM objects: Returns a plot of the mean values along with confidence intervals for a factor (combination) specified by the user.

**Usage**
```r
## S3 method for class 'RM'
plot(x, CI.info = FALSE, ...)
```

**Arguments**
- `x`: An object of class RM
- `CI.info`: If CI.info = TRUE, the mean values and confidence limits of the considered contrast are printed.
- `...`: Additional parameters to be passed to plot()

**Details**
An additional argument `factor` can be used to specify the factor(s) used for plotting in two- and higher-way layouts. See the examples for details.

---

**print.MANOVA**
*Display MANOVA object*

**Description**
Returns a short summary of the results (test statistics with p-values)

**Usage**
```r
## S3 method for class 'MANOVA'
print(x, ...)
```

**Arguments**
- `x`: A MANOVA object
- `...`: Additional parameters (currently not used)
print.RM

Display an RM object

Description

Returns a short summary of the results (test statistics with p-values)

Usage

```r
## S3 method for class 'RM'
print(x, ...)
```

Arguments

- `x`: An RM object
- `...`: Additional parameters (currently not used)

RM

Tests for Repeated Measures in Semi-Parametric Factorial Designs

Description

The RM() function calculates the Wald-type statistic (WTS), the ANOVA-type statistic (ATS) as well as resampling versions of these test statistics for semi-parametric repeated measures designs.

Usage

```r
RM(formula, data, subject, no.subf = 1, iter = 10000, alpha = 0.05,
   resampling = "Perm", CPU, seed, CI.method = "t-quantile", dec = 3)
```

Arguments

- `formula`: A model formula object. The left hand side contains the response variable and the right hand side contains the factor variables of interest. An interaction term must be specified. The time variable must be the last factor in the formula.
- `data`: A data.frame, list or environment containing the variables in formula. Data must be in long format and must not contain missing values.
- `subject`: The column name of the subjects in the data.
- `no.subf`: The number of sub-plot factors in the data, default is 1.
- `iter`: The number of iterations used for calculating the resampled statistic. The default option is 10,000.
- `alpha`: A number specifying the significance level; the default is 0.05.
resampling  The resampling method to be used, one of "Perm" (randomly permute all ob-
ervations), "paramBS" (parametric bootstrap approach) and "WildBS" (wild
bootstrap approach with Rademacher weights). Except for the Wild Bootstrap,
all methods are applied to the WTS only.

CPU  The number of cores used for parallel computing. If omitted, cores are detected
via detectCores.

seed  A random seed for the resampling procedure. If omitted, no reproducible seed
is set.

CI.method  The method for calculating the quantiles used for the confidence intervals, either
"t-quantile" (the default) or "resampling" (the quantile of the resampled WTS).

dec  Number of decimals the results should be rounded to. Default is 3.

Details

The RM() function provides the Wald-type statistic as well as the ANOVA-type statistic for repeated
measures designs with metric data as described in Friedrich et al. (2017). These are even applicable
for non-normal error terms and/or heteroscedastic variances. It is implemented for designs with
an arbitrary number of whole-plot and sub-plot factors and allows for different sample sizes. In
addition to the asymptotic p-values, it also provides p-values based on resampling approaches.

Value

An RM object containing the following components:

Descriptive  Some descriptive statistics of the data for all factor level combinations. Dis-
played are the number of individuals per factor level combination, the mean and
100*(1-alpha)% confidence intervals (based on t-quantiles).

Covariance  The estimated covariance matrix.

WTS  The value of the WTS along with degrees of freedom of the central chi-square
distribution and corresponding p-value.

ATS  The value of the ATS, degrees of freedom of the central F distribution and the
corresponding p-value.

resampling  p-values for the test statistics based on the chosen resampling approach.

References


Testing Mean Differences among Groups: Multivariate and Repeated Measures Analysis with Mini-


See Also

GFD, nparLD, MANOVA
**Examples**

```r
data(o2cons)
## Not run:
oxy <- RM(O2 ~ Group * Staphylococci * Time, data = o2cons,
        subject = "Subject", no.subf = 2, iter = 1000, resampling = "Perm", CPU = 1)
summary(oxy)
plot(oxy, factor = "Group")

## For more details including the output of the examples also refer to the
## package vignette.

## using the EEG data, consider additional within-subjects factors 'brain region'
## and 'feature'

data(eeg)
EEG_model <- RM(resp ~ sex * diagnosis * feature * region,
                 data = eeg, subject = "id", no.subf = 2, resampling = "WildBS",
                 iter = 1000, alpha = 0.01, CPU = 4, seed = 987, dec = 2)
summary(EEG_model)
## Not run
```

---

**simCI**

*Simultaneous confidence intervals for contrasts in multivariate factorial designs.*

**Description**

Simultaneous confidence intervals for contrasts in multivariate factorial designs.

**Usage**

`simCI(object, contrast = c("pairwise", "user-defined"), contmat = NULL,
       type = NULL, base = 1, ...)`

**Arguments**

- `object` A MANOVA object.
- `contrast` The contrast matrix of interest, can either be "pairwise" or "user-defined".
- `contmat` If contrast = "user-defined", the contrast matrix must be specified here. Note that its rows must sum to zero.
- `type` If contrast is "pairwise", the type of the pairwise comparison must be specified here. Calculation is based on the contrMat function in package multcomp, see the corresponding help page for details on the types of contrasts available.
- `base` an interger specifying which group is considered the baseline group for Dunnett contrasts, see contrMat.
- `...` Not used yet.
Details

The simCI() function computes confidence intervals for the chosen contrasts of the multivariate mean vector based on the sum statistic. Details on the derivation of these confidence intervals can be found in Friedrich and Pauly (2018).

Value

Simultaneous confidence intervals for the chosen contrasts.

References


See Also

contrMat

summary.MANOVA  Summary of a MANOVA object

Description

Returns a summary of the results including mean vectors and sample sizes for all groups as well as test statistics with degrees of freedom and p-values

Usage

## S3 method for class 'MANOVA'
summary(object, ...)

Arguments

<table>
<thead>
<tr>
<th>Argument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>object</td>
<td>A MANOVA object</td>
</tr>
<tr>
<td>...</td>
<td>Additional parameters (currently not used)</td>
</tr>
</tbody>
</table>
summary.RM

Summarizing an RM object

Description

Returns a summary of the results including mean values, variances and sample sizes for all groups as well as test statistics with degrees of freedom and p-values.

Usage

```r
## S3 method for class 'RM'
summary(object, ...)
```

Arguments

- `object`: An RM object
- `...`: Additional parameters (currently not used)
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