Package ‘BFpack’

July 21, 2025

Type Package

Title Flexible Bayes Factor Testing of Scientific Expectations

Version 1.5.0

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Description Implementation of default Bayes factors
for testing statistical hypotheses under various statistical models. The package is
intended for applied quantitative researchers in the
social and behavioral sciences, medical research,
and related fields. The Bayes factor tests can be
executed for statistical models such as
univariate and multivariate normal linear models,
correlation analysis, generalized linear models, special cases of
linear mixed models, survival models, relational
event models. Parameters that can be tested are
location parameters (e.g., group means, regression coefficients),
variances (e.g., group variances), and measures of
association (e.g,. polychoric/polyserial/biserial/tetrachoric/product
moments correlations), among others.
The statistical underpinnings are
described in
O'Hagan (1995) <DOI:10.1111/j.2517-6161.1995.tb02017.x>,
De Santis and Spezzaferri (2001) <DOI:10.1016/S0378-3758(00)00240-8>,
Mulder and Xin (2022) <DOI:10.1080/00273171.2021.1904809>,
Mulder and Gelissen (2019) <DOI:10.1080/02664763.2021.1992360>,
Mulder (2016) <DOI:10.1016/j.jmp.2014.09.004>,
Mulder and Fox (2019) <DOI:10.1214/18-BA1115>,
Mulder and Fox (2013) <DOI:10.1007/s11222-011-9295-3>,
Boeing-Messing, van Assen, Hofman, Hoijtink, and Mulder (2017) <DOI:10.1037/met0000116>,
Hoijtink, Mulder, van Lissa, and Gu (2018) <DOI:10.1037/met0000201>,
Gu, Mulder, and Hoijtink (2018) <DOI:10.1111/bmsp.12110>,
Hoijtink, Gu, and Mulder (2018) <DOI:10.1111/bmsp.12145>, and
Hoijtink, Gu, Mulder, and Rosseel (2018) <DOI:10.1037/met0000187>. When using the
packages, please refer to the package Mulder et al. (2021) <DOI:10.18637/jss.v100.i18>
and the relevant methodological papers.

License GPL (>= 3)

URL https://github.com/jomulder/BFpack

BugReports https://github.com/jomulder/BFpack/issues

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NeedsCompilation yes

RoxygenNote 7.3.2

Depends R (>= 3.0.0), bain

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Suggests testthat, polycor, survival, pscl, metafor, knitr, rmarkdown, lmtest

VignetteBuilder knitr

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Contents

`BFpack-package` *BFpack: Flexible Bayes factor testing of scientific expectations*

Description

The R package **BFpack** provides tools for exploratory and confirmatory Bayesian hypothesis testing using Bayes factors and posterior probabilities under common statistical models. The main function 'BF' needs a fitted model 'x' as input argument. Depending on the class of the fitted model, a standard hypothesis test is executed by default. For example, if 'x' is a fitted regression model of class 'lm' then posterior probabilities are computed of whether each separate coefficient is zero, negative, or positive (assuming equal prior probabilities). If one has specific hypotheses with equality and/or order constraints on the parameters under the fitted model 'x' then these can be formulated using the 'hypothesis' argument (a character string), possibly together prior probabilities for the hypotheses via the 'prior' argument (default all hypotheses are equally likely a priori), and the 'complement' argument which is a logical stating whether the complement hypotheses should be included in the case ('TRUE' by default).

Use compilation for Fortran functions

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References

Mulder, J., D.R. Williams, Gu, X., A. Tomarken, F. Böing-Messing, J.A.O.C. Olsson-Collentine, Marlyne Meyerink, J. Menke, J.-P. Fox, Y. Rosseel, E.J. Wagenmakers, H. Hoijtink., and van Lissa, C. (submitted). BFpack: Flexible Bayes Factor Testing of Scientific Theories in R. https://arxiv.org/abs/1911.07728

Mulder, J., van Lissa, C., Gu, X., Olsson-Collentine, A., Boeing-Messing, F., Williams, D. R., Fox, J.-P., Menke, J., et al. (2019). BFpack: Flexible Bayes Factor Testing of Scientific Expectations. (Version 0.2.1) https://CRAN.R-project.org/package=BFpack

See Also

Useful links:

- https://github.com/jomulder/BFpack
- Report bugs at https://github.com/jomulder/BFpack/issues

Examples

```
## Not run:
# EXAMPLE 1. One-sample t test
ttest1 <- t_test(therapeutic, mu = 5)
print(ttest1)
# confirmatory Bayesian one sample t test
```

```
BF1 <- BF(ttest1, hypothesis = "mu = 5")
summary(BF1)
# exploratory Bayesian one sample t test
BF(ttest1)

# EXAMPLE 2. ANOVA
aov1 <- aov(price ~ anchor * motivation,data = tvprices)
BF1 <- BF(aov1, hypothesis = "anchorrounded = motivationlow;
                              anchorrounded < motivationlow")
summary(BF1)

# EXAMPLE 3. Logistic regression
fit <- glm(sent ~ ztrust + zfWHR + zAfro + glasses + attract + maturity +
   tattoos, family = binomial(), data = wilson)
BF1 <- BF(fit, hypothesis = "ztrust > zfWHR > 0;
                             ztrust > 0 & zfWHR = 0")
summary(BF1)

# EXAMPLE 4. Correlation analysis
set.seed(123)
cor1 <- cor_test(memory[1:20,1:3])
BF1 <- BF(cor1)
summary(BF1)
BF2 <- BF(cor1, hypothesis = "Wmn_with_Im > Wmn_with_Del > 0;
                              Wmn_with_Im = Wmn_with_Del = 0")
summary(BF2)

## End(Not run)
```

`actors` *Actors from a small hypothetical network*

Description

The related data files 'events', 'same_location', 'same_culture' contain information on the event sequence and the two event statistics respectively.

Usage

```
data(actors)
```

Format

dataframe (25 rows, 4 columns)

actors$id	`integer`	ID of the employee, corresponding to the sender and receiver IDs in the events dataframe
actors$location	`numeric`	Location of the actor, ranging from 1-4
actors$culture	`character`	Categorical variable, indicating the culture of the employee

`attention` *Multiple Sources of Attentional Dysfunction in Adults With Tourette's Syndrome*

Description

Data from a psychological study comparing attentional performances of Tourette's syndrome (TS) patients, ADHD patients, and controls. These data were simulated using the sufficient statistics from Silverstein, Como, Palumbo, West, and Osborn (1995).

Usage

```
data(attention)
```

Format

A data.frame with 51 rows and 2 columns.

Details

accuracy	`numeric`	Participant's accuracy in the attentional task
group	`factor`	Participant's group membership (TS patient, ADHD patient, or control)

References

Silverstein, S. M., Como, P. G., Palumbo, D. R., West, L. L., & Osborn, L. M. (1995). Multiple sources of attentional dysfunction in adults with Tourette's syndrome: Comparison with attention deficit-hyperactivity disorder. Neuropsychology, 9(2), 157-164. doi:10.1037/0894-4105.9.2.157

bartlett_test *Bartlett Test of Homogeneity of Variances*

Description

Performs Bartlett's test of the null that the variances in each of the groups (samples) are the same.

Usage

```
bartlett_test(x, g, ...)

## Default S3 method:
bartlett_test(x, g, ...)
```

Arguments

x	a numeric vector of data values, or a list of numeric data vectors representing the respective samples, or fitted linear model objects (inheriting from class "lm").
g	a vector or factor object giving the group for the corresponding elements of x. Ignored if x is a list.
...	further arguments to be passed to or from methods.

Details

x must be a numeric data vector, and g must be a vector or factor object of the same length as x giving the group for the corresponding elements of x.

Value

A list with class "bartlett_htest" containing the following components:

statistic	Bartlett's K-squared test statistic.
parameter	the degrees of freedom of the approximate chi-squared distribution of the test statistic.
p.value	the p-value of the test.
conf.int	a confidence interval for the mean appropriate to the specified alternative hypothesis.
method	the character string "Bartlett test of homogeneity of variances".
data.name	a character string giving the names of the data.
vars	the sample variances across groups (samples).
n	the number of observations per group (sample)

Bain t_test

In order to allow users to enjoy the functionality of bain with the familiar stats-function `bartlett.test`, we have had to make minor changes to the function `bartlett.test.default`. All rights to, and credit for, the function `bartlett.test.default` belong to the R Core Team, as indicated in the original license below. We make no claims to copyright and incur no liability with regard to the changes implemented in `bartlett_test`.

References

Bartlett, M. S. (1937). Properties of sufficiency and statistical tests. Proceedings of the Royal Society of London Series A 160, 268–282. DOI: 10.1098/rspa.1937.0109.

Examples

```
require(graphics)

plot(count ~ spray, data = InsectSprays)
bartlett_test(InsectSprays$count, InsectSprays$spray)
```

`BF.default` — *Bayes factors for Bayesian exploratory and confirmatory hypothesis testing*

Description

The `BF` function can be used for hypothesis testing and model selection using the Bayes factor. By default exploratory hypothesis tests are performed of whether each model parameter equals zero, is negative, or is positive. Confirmatory hypothesis tests can be executed by specifying hypotheses with equality and/or order constraints on the parameters of interest. Depending on the class of the fitted model different Bayes factors are used as described in the output.

Usage

```
## Default S3 method:
BF(
  x,
  hypothesis = NULL,
  prior.hyp.explo = NULL,
  prior.hyp.conf = NULL,
  prior.hyp = NULL,
  complement = TRUE,
  log = FALSE,
  cov.prob = 0.95,
  Sigma,
  n,
  ...
)

## S3 method for class 'lm'
BF(
  x,
  hypothesis = NULL,
  prior.hyp.explo = NULL,
  prior.hyp.conf = NULL,
  prior.hyp = NULL,
  complement = TRUE,
  log = FALSE,
  cov.prob = 0.95,
  BF.type = NULL,
  iter = 10000,
  ...
)

## S3 method for class 'rma.uni'
BF(
  x,
  hypothesis = NULL,
  prior.hyp.explo = NULL,
  prior.hyp.conf = NULL,
  prior.hyp = NULL,
  complement = TRUE,
  log = FALSE,
  cov.prob = 0.95,
  BF.type,
  iter = 20000,
  ...
)

## S3 method for class 't_test'
BF(
```

```
  x,
  hypothesis = NULL,
  prior.hyp.explo = NULL,
  prior.hyp.conf = NULL,
  prior.hyp = NULL,
  complement = TRUE,
  log = FALSE,
  cov.prob = 0.95,
  BF.type = NULL,
  iter = 1e+06,
  ...
)
```

Arguments

`x` An R object containing the outcome of a statistical analysis. An R object containing the outcome of a statistical analysis. Currently, the following objects can be processed: t_test(), bartlett_test(), lm(), aov(), manova(), cor_test(), lmer() (only for testing random intercep variances), glm(), coxph(), survreg(), polr(), zeroinfl(), rma(), ergm(), bergm(), or named vector objects. In the case `x` is a named vector, the arguments `Sigma` and `n` are also needed. See vignettes for elaborations.

`hypothesis` A character string containing the constrained (informative) hypotheses to evaluate in a confirmatory test. The default is NULL, which will result in standard exploratory testing under the model `x`.

`prior.hyp.explo` The prior probabilities of the hypotheses in the exploratory tests. Except for objects of class `aov` (for (M)ANOVA, etc.), this argument should be a vector with three elements reflecting the prior probability of a zero effect, a negative effect, and a positive effect, respectively. For objects of class `aov`, the argument should be a list where the first element should be a vector of length 3 specifying the prior probabilities of each parameter being zero, negative, or positive, the second element should be a vector of length 2 specifying the prior probabilities of a model where is no main effect for a factor and the full model, and the third element should be a vector of length 2 specifying the prior probabilities of a model where is no interaction effect (if present) for two factors and the full model. The default (`NULL`) specifies equal prior probabilities for each hypothesis per exploratory test.

`prior.hyp.conf` The prior probabilities of the constrained hypotheses in the confirmatory test.

`prior.hyp` Deprecated. Please use the argument `prior.hyp.conf`.

`complement` a logical specifying whether the complement should be added to the tested hypothesis under `hypothesis`.

`log` a logical specifying whether the Bayes factors should be computed on a log scale. Default is `FALSE`.

`cov.prob` coverage probability of the Bayesian credibility interval in the `estimates` element of the output object. The argument is only used for objects for which a

	Bayesion estimation algorithm is used, such as a `cor_test` or `rma.uni` object. The default coverage probability is 0.95.
`Sigma`	An approximate posterior covariance matrix (e.g,. error covariance matrix) of the parameters of interest. This argument is only required when `x` is a named vector.
`n`	The (effective) sample size that was used to acquire the estimates in the named vector `x` and the error covariance matrix `Sigma`. This argument is only required when `x` is a named vector.
`...`	Parameters passed to and from other functions.
`BF.type`	For certain object classes of `x`, different types of Bayes factor tests are supported. This can be specified using this argument. For models of class 'lm' and 't_test', setting this argument to `'FBF'` the fractional Bayes factor (O'Hagan, 1995) is used and setting this argument to `'AFBF'` the adjusted fractional Bayes factor (Mulder, 2014) is used. The default for these model classes is the fractional Bayes factor. For models of class 'rma.uni' (meta-analyses), 'BF.type' controls the prior that is used for the test. Certain defaults are provided for a standardized effect (`BF.type="stand.effect"`), a normal prior with mean 0 and sd 0.5 is used, for log odds (`BF.type="log.odds"`), a Student prior with mean 0, scale 2.36, and 13.1 degrees of freedom is used (corresponding to uniform priors on the success probabilities), for a correlation (`BF.type="correlation"`), a logistic prior is used for the Fisher transformed correlation having scale 0.5 (corresponding to a uniform prior for the correlation in (-1,1)), for a unit-information prior (`BF.type="unit.info"`), the total sample size `sum(ni)` is used to scale a normal unit information prior, and for a manually specified prior `BF.type` needs to be an object of class `prior` from the `metaBMA` package.
`iter`	Number of iterations that are used to compute the Monte Carlo estimates. Only used for certain hypothesis tests of class `mlm` (multivariate regression) where constraints are formulated across different dependent variables as well as different predictors.

Details

The function requires a fitted modeling object. Current analyses that are supported: `t_test`, `bartlett_test`, `aov`, `manova`, `lm`, `mlm`, `glm`, `hetcor`, `lmer`, `coxph`, `survreg`, `ergm`, `bergm`, `zeroinfl`, `rma` and `polr`.

For testing parameters from the results of t_test(), lm(), aov(), manova(), and bartlett_test(), hypothesis testing is done using adjusted fractional Bayes factors are computed (using minimal fractions). For testing measures of association (e.g., correlations) via `cor_test()`, Bayes factors are computed using joint uniform priors under the correlation matrices. For testing intraclass correlations (random intercept variances) via `lmer()`, Bayes factors are computed using uniform priors for the intraclass correlations. For all other tests, approximate adjusted fractional Bayes factors (with minimal fractions) are computed using Gaussian approximations, similar as a classical Wald test.

Value

The output is an object of class `BF`. The object has elements:

- BFtu_exploratory: The Bayes factors of the constrained hypotheses against the unconstrained hypothesis in the exploratory test.
- BFtu_main (only for aov objects with predictors of class factor): The Bayes factors of a constrained model where all levels of a factor are assumed to have the same effect on the outcome variable versus an unconstrained (full) model with no constraints.
- BFtu_interaction (only for aov objects with interaction effects with predictors of class factor): The Bayes factors of a constrained model where the effect of the dummy variables corresponding to an interaction effects are assumed to be zero versus an unconstrained (full) model with no constraints.
- PHP_exploratory: The posterior probabilities of the constrained hypotheses in the exploratory test.
- PHP_main (only for aov objects with predictors of class factor): The posterior probabilities a constrained model where all levels of a factor are assumed to have the same effect on the outcome variable versus an unconstrained (full) model with no constraints.
- PHP_interaction (only for aov objects with interaction effects with predictors of class factor): The posterior probabilities of a constrained model where the effect of the dummy variables corresponding to an interaction effects are assumed to be zero versus an unconstrained (full) model with no constraints.
- BFtu_confirmatory: The Bayes factors of the constrained hypotheses against the unconstrained hypothesis in the confirmatory test using the hypothesis argument.
- PHP_confirmatory: The posterior probabilities of the constrained hypotheses in the confirmatory test using the hypothesis argument.
- BFmatrix_confirmatory: The evidence matrix which contains the Bayes factors between all possible pairs of hypotheses in the confirmatory test.
- BFtable_confirmatory: The Specification table (output when printing the summary of a BF for a confirmatory test) which contains the different elements of the extended Savage Dickey density ratio where
  - The first column 'complex=' quantifies the relative complexity of the equality constraints of a hypothesis (the prior density at the equality constraints in the extended Savage Dickey density ratio).
  - The second column 'complex>' quantifies the relative complexity of the order constraints of a hypothesis (the prior probability of the order constraints in the extended Savage Dickey density ratio).
  - The third column 'fit=' quantifies the relative fit of the equality constraints of a hypothesis (the posterior density at the equality constraints in the extended Savage Dickey density ratio).
  - The fourth column 'fit>' quantifies the relative fit of the order constraints of a hypothesis (the posterior probability of the order constraints in the extended Savage Dickey density ratio)
  - The fifth column 'BF=' contains the Bayes factor of the equality constraints against the unconstrained hypothesis.
  - The sixth column 'BF>' contains the Bayes factor of the order constraints against the unconstrained hypothesis.
  - The seventh column 'BF' contains the Bayes factor of the constrained hypothesis against the unconstrained hypothesis.

  - The eighth column 'PHP' contains the posterior probabilities of the hypotheses.

- prior.hyp.explo: The prior probabilities of the constrained hypotheses in the exploratory tests.
- prior.hyp.conf: The prior probabilities of the constrained hypotheses in the confirmatory test.
- hypotheses: The tested constrained hypotheses in a confirmatory test.
- estimates: Descriptives of unconstrained estimates based on flat priors (also for rma.uni objects for Bayesian meta-analyses).
- model: The input model x.
- bayesfactor: The type of Bayes factor that is used for this model.
- parameter: The type of parameter that is tested.
- log: logical whether the Bayes factors were reported on a log scale.
- fraction_number_groupIDs (only for objects of class lm): The number of 'group identifiers' that were identified based on the number of unique combinations of levels of predictor variables of class factor in the data. These group identifiers are used to automatically specify the minimal fractions that are used to compute (adjusted) fractional Bayes factors.
- fraction_groupID_observations (only for objects of class lm): A vector that specifies to which 'group identifier' an observation belongs. The group identifiers are constructed based on the unique combination of the levels based on the predictor variables of class factor of the observations.
- call: The call of the BF function.

Methods (by class)

- BF(default): S3 method for a named vector 'x'
- BF(lm): S3 method for an object of class 'lm'
- BF(rma.uni): BF S3 method for an object of class 'rma.uni'
- BF(t_test): BF S3 method for an object of class 't_test'

References

Mulder, Williams, Gu, Tomarken, Böing-Messing, Olsson-Collentine, Meyerink, Menke, Fox, Rosseel, Wagenmakers, Hoijtink, and van Lissa (2021). BFpack: Flexible Bayes Factor Testing of Scientific Theories in R. Journal of Statistical Software, 100. <https://doi.org/10.18637/jss.v100.i18>

Mulder and Xin (2022). Bayesian Testing of Scientific Expectations under Multivariate Normal Linear Models. <https://doi.org/10.1080/00273171.2021.1904809>

Mulder and Gelissen (2021). Bayes factor testing of equality and order constraints on measures of association in social research. Journal of Applied Statistics, 50. <https://doi.org/10.1080/02664763.2021.1992360>

Mulder and Fox (2019). Bayes Factor Testing of Multiple Intraclass Correlations. Bayesian Analysis, 14. <http://doi.org/10.1214/18-BA1115>

Hoijtink, Mulder, van Lissa, and Gu (2018). A tutorial on testing hypotheses using the Bayes factor. Psychological Methods, 24(5), 539–556. <http://doi.org/10.1037/met0000201>

Boeing-Messing, van Assen, Hofman, Hoijtink, and Mulder (2017). Bayesian evaluation of constrained hypotheses on variances of multiple independent groups. Psycholological Methods, 22(2), 262-287. <https://doi.org/10.1037/met0000116>

van Aert and Mulder (2021). Bayesian hypothesis testing and estimation under the marginalized random-effects meta-analysis model. Psychonomic Bulletin and Review, 29, 55–69. <https://doi.org/10.3758/s13423-021-01918-9>

Examples

```
# EXAMPLE 1. One-sample t test
ttest1 <- t_test(therapeutic, mu = 5)
print(ttest1)
# confirmatory Bayesian one sample t test
BF1 <- BF(ttest1, hypothesis = "mu = 5")
summary(BF1)
# exploratory Bayesian one sample t test
BF(ttest1)

# EXAMPLE 2. ANOVA
aov1 <- aov(price ~ anchor * motivation,data = tvprices)
BF1 <- BF(aov1, hypothesis = "anchorrounded = motivationlow;
                              anchorrounded < motivationlow")
summary(BF1)

# EXAMPLE 3. linear regression
lm1 <- lm(mpg ~ cyl + hp + wt, data = mtcars)
BF(lm1, hypothesis = "wt < cyl < hp = 0")

# EXAMPLE 4. Logistic regression
fit <- glm(sent ~ ztrust + zfWHR + zAfro + glasses + attract + maturity +
   tattoos, family = binomial(), data = wilson)
BF1 <- BF(fit, hypothesis = "ztrust > zfWHR > 0;
                             ztrust > 0 & zfWHR = 0")
summary(BF1)

# EXAMPLE 5. Correlation analysis
set.seed(123)
cor1 <- cor_test(memory[1:20,c(1,2,6)])
BF1 <- BF(cor1)
summary(BF1)
BF2 <- BF(cor1, hypothesis = "Rat_with_Im > Rat_with_Del > 0;
                             Rat_with_Im = Rat_with_Del = 0")
summary(BF2)
# correlations can also be computed between continuous/ordinal variables
memory_test <- memory[1:20,c(1,2,6)]
memory_test[,3] <- as.ordered(memory_test[,3])
cor2 <- cor_test(memory_test)
BF(cor2)

# EXAMPLE 6. Bayes factor testing on a named vector
# A Poisson regression model is used to illustrate the computation
# of Bayes factors with a named vector as input
```

```
poisson1 <- glm(formula = breaks ~ wool + tension,
  data = datasets::warpbreaks, family = poisson)
# extract estimates, error covariance matrix, and sample size:
estimates <- poisson1$coefficients
covmatrix <- vcov(poisson1)
samplesize <- nobs(poisson1)
# compute Bayes factors on equal/order constrained hypotheses on coefficients
BF1 <- BF(estimates, Sigma = covmatrix, n = samplesize, hypothesis =
"woolB > tensionM > tensionH; woolB = tensionM = tensionH")
summary(BF1)
```

`cor_test` *Bayesian correlation analysis*

Description

Estimate the unconstrained posterior for the correlations using a joint uniform prior (Mulder and Gelissen, 2023) or a marginally uniform prior (Barnard et al., 2000, Mulder, 2016). Correlation matrices are sampled from the posterior using the MCMC algorithm of Talhouk et al. (2012).

Usage

```
cor_test(
  ...,
  formula = NULL,
  iter = 10000,
  burnin = 2000,
  nugget.scale = 0.999
)
```

Arguments

`...`	matrices (or data frames) of dimensions n (observations) by p (variables) for different groups (in case of multiple matrices or data frames).
`formula`	an object of class `formula`. This allows for including control variables in the model (e.g., ~ `education`).
`iter`	total number of iterations from posterior. The total is split across three chains. By default, the total number of iterations is 10000, implying 3333 iterations per chain.
`burnin`	number of iterations for burnin (default is 2000).
`nugget.scale`	a scalar to avoid computational issues due to posterior draws for the corralations too close to 1 in absolute value. Posterior draws for the correlations are multiplied with this nugget.scale. So `nugget.scale` should be close to 1 (the default is .999). If the traceplots show that draws are stuck at 1 or -1 too long try a slightly smaller `nugget.scale`.

Value

list of class `cor_test`:

- `meanF` posterior means of Fisher transform correlations
- `covmF` posterior covariance matrix of Fisher transformed correlations
- `correstimates` posterior estimates of correlation coefficients
- `corrdraws` list of posterior draws of correlation matrices per group
- `corrnames` names of all correlations

References

Barnard, J., McCulloch, R., & Meng, X. L. (2000). Modeling covariance matrices in terms of standard deviations and correlations, with application to shrinkage. Statistica Sinica, 1281-1311. <https://www.jstor.org/stable/24306780>

Joe, H. (2006). Generating random correlation matrices based on partial correlations. Journal of Multivariate Analysis, 97(10), 2177-2189. <https://doi.org/10.1016/j.jmva.2005.05.010>

Mulder, J., & Gelissen, J. P. (2023). Bayes factor testing of equality and order constraints on measures of association in social research. Journal of Applied Statistics, 50(2), 315-351. <https://doi.org/10.1080/02664763.2021

Mulder, J. (2016). Bayes factors for testing order-constrained hypotheses on correlations. Journal of Mathematical Psychology, 72, 104-115. <https://doi.org/10.1016/j.jmp.2014.09.004>

Talhouk, A., Doucet, A., & Murphy, K. (2012). Efficient Bayesian inference for multivariate probit models with sparse inverse correlation matrices. Journal of Computational and Graphical Statistics, 21(3), 739-757. <https://doi.org/10.1080/10618600.2012.679239>

Examples

```
# Bayesian correlation analysis of the 6 variables in 'memory' object
# we consider a correlation analysis of the first three variable of the memory data.
fit <- cor_test(BFpack::memory[,1:3])

# Bayesian correlation of variables in memory object in BFpack while controlling
# for the Cat variable
fit <- cor_test(BFpack::memory[,c(1:4)],formula = ~ Cat)

# Example of Bayesian estimation of polyserial correlations
memory_example <- memory[,c("Im","Rat")]
memory_example$Rat <- as.ordered(memory_example$Rat)
fit <- cor_test(memory_example)

# Bayesian correlation analysis of first three variables in memory data
# for two different groups
HC <- subset(BFpack::memory[,c(1:3,7)], Group == "HC")[,-4]
SZ <- subset(BFpack::memory[,c(1:3,7)], Group == "SZ")[,-4]
fit <- cor_test(HC,SZ)
```

`Fcor` *Student t approximations of Fisher transformed correlations*

Description

Approximated degrees of freedom and approximated scale of the Fisher transformed correlations depending on the dimension of the vector of dependent variables P based on a joint uniform prior.

Usage

```
data(Fcor)
```

Format

A data.frame with 3 columns.

Details

nu	`numeric`	Approximated degrees of freedom
sigma	`numeric`	Approximated scale
P	`integer`	Dimension of vector of dependent variables

`fmri` *fMRI data*

Description

fMRI data assessing relation between individual differences in the ability to recognize faces and cars and thickness of the superficial, middle, and deep layers of the fusiform face area, as assessed by high-resolution fMRI recognition (Williams et al, 2019, under review)

Usage

```
data(fmri)
```

Format

A data.frame with 13 rows and 6 columns.

Details

Subject	`numeric`	Particicpant ID number
Face	`numeric`	Standardized score on face recognition battery
Vehicle	`numeric`	Standardized score on vehicle recognition battery
Superficial	`numeric`	Depth in mm of superficial layer of FFA
Middle	`numeric`	Depth in mm of middle layer of FFA
Bform	`numeric`	Depth in mm of deep layer of FFA

References

McGuigin, R.W., Newton, A.T., Tamber-Rosenau, B., Tomarken, A.J, & Gauthier, I. (under review). Thickness of deep layers in the fusiform face area predicts face recognition.

`memory` *Memory data on health and schizophrenic patients*

Description

Data set from study assessing differences between schizophrenic patients and healthy control participants in patterns of correlations among 6 verbal memory tasks (Ichinose et al., 2019).

Im	`numeric`	Percent correct on immediate recall of 3 word lists
Del	`numeric`	Percent correct on delayed recall of 3 word lists
Wmn	`numeric`	Number correct on letter-number span test of auditory working memory
Cat	`numeric`	Number correct on category fluency task
Fas	`numeric`	Number correct on letter fluency task
Rat	`numeric`	Number correct on remote associates task
Group	`factor`	Participant Group (HC = Healthy Control; SZ = Schizophrenia)

Usage

```
data(memory)
```

Format

A data.frame with 40 rows and 8 columns.

References

Ichinose, M.C., Han, G., Polyn, S., Park, S., & Tomarken, A.J. (2019). Verbal memory performance discordance in schizophrenia: A reflection of cognitive dysconnectivity. Unpublished manuscript.

`mvt_test` *Multivariate Student t test*

Description

First step to performs a Bayesian multivariate one sample Student t test using the (adjusted) fractional Bayes factor using the `BF()` function.

Usage

```
mvt_test(X, Y, null = NULL, paired = FALSE, ...)
```

Arguments

`X`	a data matrix with the variables in the columns.
`Y`	an optional data matrix with the variables in the columns.
`null`	a vector of the null values of the variables.
`paired`	a logical indicating whether you want a multivariate paired t-test.
`...`	further arguments to be passed to or from methods.

Details

`X` must be a data matrix and `null` must be a vector of the assumed null values of the variables.

Value

An object that can be applied to the `BF()`.

References

Mulder, J. and Gu, X. (2023). Bayesian Testing of Scientific Expectations under Multivariate Normal Linear Models. Multivariate Behavioral Research, 57, 767-783. DOI: 10.1080/00273171.2021.1904809.

Examples

```
mvt_fmri <- mvt_test(fmri[,1:2],null = c(0,0))
BF(mvt_fmri)

# the same test can be executed via the lm() function
intercept <- rep(1,nrow(fmri))
lm1 <- lm(cbind(Face,Vehicle) ~ -1 + intercept, data=fmri)
BF(lm1,hypothesis="intercept_on_Face=intercept_on_Vehicle=0")
```

`relevents` *A sequence of innovation-related e-mail messages*

Description

A time-ordered sequence of 247 communication messages between 25 actors.

Usage

```
data(relevents)
```

Format

dataframe (247 rows, 3 columns)

relevents$time	`numeric`	Time of the e-mail message, in seconds since onset of the observation
relevents$sender	`integer`	ID of the sender, corresponding to the employee IDs in the actors dataframe
relevents$receiver	`integer`	ID of the receiver

Details

The related data files 'actors', 'same_location', 'same_culture' contain information on the actors and three event statistics respectively.

`same_culture` *Same culture event statistic*

Description

A matrix coding whether senders of events (in the rows) and receivers of events (in the column) have the background culture. Related to the 'events' data object, that contains a relational event sequence, and the 'actors' object, that contains information on the 25 actors involved in the relational event sequence.

Usage

```
data(same_culture)
```

Format

dataframe (25 rows, 4 columns)

same_culture	`integer`	Event statistic. Matrix with senders in the rows and receivers in the columns. The event statistic is

---

`same_location` *Same location event statistic*

Description

A matrix coding whether senders of events (in the rows) and receivers of events (in the column) have the same location. Related to the 'events' data object, that contains a relational event sequence, and the 'actors' object, that contains information on the 25 actors involved in the relational event sequence.

Usage

```
data(same_location)
```

Format

dataframe (25 rows, 4 columns)

same_location `integer` Event statistic. Matrix with senders in the rows and receivers in the columns. The event statistic i

---

`sivan` *Wason task performance and morality*

Description

Data from an experimental study, using the Wason selection task (Wason 1968) to examine whether humans have cognitive adaptations for detecting violations of rules in multiple moral domains. Moral domains are operationalized in terms of the five domains of the Moral Foundations Questionnaire (Graham et al. 2011). These data were simulated using the R-package `synthpop`, based on the characteristics of the original data.

Usage

```
data(sivan)
```

Format

A data.frame with 887 rows and 12 columns.

Details

sex	`factor`	Participant sex
age	`integer`	Participant age
nationality	`factor`	Participant nationality
politics	`integer`	How would you define your political opinions? Likert type scale, from 1 (Liberal) to 6 (Conservat
WasonOrder	`factor`	Was the Wason task presented before, or after the MFQ?
Harm	`numeric`	MFQ harm domain.
Fairness	`numeric`	MFQ fairness domain.
Loyalty	`numeric`	MFQ loyalty domain.
Purity	`numeric`	MFQ purity domain.
Tasktype	`ordered`	How was the Wason task framed?
GotRight	`factor`	Did the participant give the correct answer to the Wason task?

References

Sivan, J., Curry, O. S., & Van Lissa, C. J. (2018). Excavating the Foundations: Cognitive Adaptations for Multiple Moral Domains. Evolutionary Psychological Science, 4(4), 408–419. doi:10.1007/s40806-018-0154-8

`therapeutic` *Data come from an experimental study (Rosa, Rosa, Sarner, and Barrett, 1998) that were also used in Howell (2012, p.196). An experiment was conducted to investigate if Therapeutic Touch practitioners who were blindfolded can effectively identify which of their hands is below the experimenter¡¯s. Twenty-eight practitioners were involved and tested 10 times in the experiment. Researchers expected an average of 5 correct answers from each practitioner as it is the number by chance if they do not outperform others.*

Description

correct	`integer`	How many correct answers are from each practitioner)

Usage

```
data(therapeutic)
```

Format

A data.frame with 22 rows and 1 column.

References

Howell, D. (2012). Statistical methods for psychology (8th ed.). Belmont, CA: Cengage Learning.

`timssICC` *Trends in International Mathematics and Science Study (TIMSS) 2011-2015*

Description

A stratified sample was drawn by country and school to obtain a balanced sample of p = 15 grade-4 students per school for each of four countries (The Netherlands (NL), Croatia (HR), Germany (DE), and Denmark (DK)) and two measurement occasions (2011, 2015). Achievement scores (first plausible value) of overall mathematics were considered. Performances of fourth and eight graders from more than 50 participating countries around the world can be found at (https://www.iea.nl/timss) The TIMSS achievement scale is centered at 500 and the standard deviation is equal to 100 scale score points. The TIMSS data set has a three-level structure, where students are nested within classrooms/schools, and the classrooms/schools are nested within countries. Only one classroom was sampled per school. Changes in the mathematics achievement can be investigated by examining the grouping of students in schools across countries. Changes in country-specific intraclass correlation coefficient from 2011 to 2015, representing heterogeneity in mathematic achievements within and between schools across years, can be tested. When detecting a decrease in average performance together with an increase of the intraclass correlation, a subset of schools performed worse. For a constant intraclass correlation across years the drop in performance applied to the entire population of schools. For different countries, changes in the intraclass correlation across years can be tested concurrently to examine also differences across countries.

Usage

```
data(timssICC)
```

Format

A data.frame with 16770 rows and 15 columns.

Details

math	`numeric`	math score child
groupNL11	`numeric`	Indicator for child from NL in 2011
groupNL15	`numeric`	Indicator for child from NL in 2015
groupHR11	`numeric`	Indicator for child from HR in 2011
groupHR15	`numeric`	Indicator for child from HR in 2015
groupDE11	`numeric`	Indicator for child from DE in 2011
groupDE15	`numeric`	Indicator for child from DE in 2015
groupDR11	`numeric`	Indicator for child from DK in 2011
groupDR15	`numeric`	Indicator for child from DK in 2015
gender	`numeric`	Female=0,Male=1

weight	`numeric`	Child sampling weight
yeargender	`numeric`	Interaction for occassion and gender
lln	`numeric`	total number of children in school-class
groupschool	`factor`	Nested indicator for school in country
schoolID	`factor`	Unique indicator for school

References

Mulder, J. & Fox, J.-P. (2019). Bayes factor testing of multiple intraclass correlations. Bayesian Analysis. 14, 2, p. 521-552.

`tvprices` *Precision of the Anchor Influences the Amount of Adjustment*

Description

Data from an experimental study where participants have to guess the price of a plasma tv. There were two experimental conditions. These data were simulated using the sufficient statistics from Janiszewski & Uy (2008).

Usage

```
data(tvprices)
```

Format

A data.frame with 59 rows and 3 columns.

Details

price	`numeric`	Participant z-scores of price
anchor	`factor`	Participant anchor
motivation	`factor`	motivation to change

References

Janiszewski, C., & Uy, D. (2008). Precision of the anchor influences the amount of adjustment. Psychological Science, 19(2), 121–127. doi:10.1111/j.1467-9280.2008.02057.x

wilson *Facial trustworthiness and criminal sentencing*

Description

Data from a correlational study in which the correlation between ratings of facial trustworthiness of inmates was correlated with whether they had received the death penalty or not (wilson and Rule, 2015). These data were simulated using the R-package synthpop, based on the characteristics of the original data.

Usage

```
data(wilson)
```

Format

A data.frame with 742 rows and 13 columns.

Details

stim	integer	Stimulus Number
sent	integer	Sentence: 1 = Death, 0 = Life
race	integer	Race: 1 = White, -1 = Black
glasses	integer	Glasses: 1 = Yes, 0 = No
tattoos	integer	Tattoos: 1 = Yes, 0 = No
ztrust	numeric	Trustworthiness
trust_2nd	numeric	Trustworthiness ratings with 2nd control group; Death targets are same as in primary analysis, Life ta
afro	numeric	raw Afrocentricity ratings.
zAfro	numeric	Afrocentricity ratings normalized within target race. Analyses in paper were done with this variable.
attract	numeric	Attractiveness
fWHR	numeric	facial width-to-height
afWHR	numeric	fWHR normalized within target race. Analyses in paper were done with this variable
maturity	numeric	Maturity

References

Wilson, J. P., & Rule, N. O. (2015). Facial Trustworthiness Predicts Extreme Criminal-Sentencing Outcomes. Psychological Science, 26(8), 1325–1331. doi: 10.1177/0956797615590992

Index