Package ‘ERP’

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Type Package

Title Significance Analysis of Event-Related Potentials Data

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Description The functions provided in the package ERP are designed for the significance analysis of ERP data in a linear model framework. The possible procedures are either the collection of FDR or FWER controlling methods available in the generic function p.adjust, the same collection combined with a factor modeling of the time dependence among tests (see Sheu, Perthame, Lee and Causeur, 2016) and the Guthrie and Buchwald (1991) test.

License GPL (>= 2)

Imports fdrtool,mnormt

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ERP-package *Significance analysis of ERP data*

Description

The package provides multiple testing procedures designed for Event-Related Potentials (ERP) data in a linear model framework. These procedures are reviewed and compared in Sheu, Perthame, Lee and Causeur (2016). Some of the methods gathered in the package are the classical FDR- and FWER-controlling procedures, also available using function p.adjust. The package also implements the Guthrie-Buchwald procedure (Guthrie and Buchwald, 1991), which accounts for the auto-correlation among t-tests to control erroneous detections of short intervals. The Adaptive Factor-Adjustment method is an extension of the method described in Causeur, Chu, Hsieh and Sheu (2012). It assumes a factor model for the correlation among tests and combines adptatively the estimation of the signal and the updtating of the dependence modelling (see Sheu et al., 2016 for further details).

Details

Package:	ERP
Type:	Package
Version:	1.0
Date:	2014-04-01
License:	GPL (>=2)

Apart from the function erpplot, which is just a wrapper for matplot to display the ERP curves, all the functions in the package implement multiple testing procedures of ERP data in a linear model framework (F-tests for the comparison of two nested models). The function gbtest implements the Guthrie-Buchwald procedure (see Guthrie and Buchwald, 1991). The function erptest can be used for the classical FDR- and FWER-controlling multiple testing of ERP data: especially the Benjamini-Hochberg (see Benjamini and Hochberg, 1995) and Benjamini-Yekutieli (see Benjamini and Yekutieli, 2001) procedures, with the possible extension proposed by Storey and Tibshirani (2003) including a non-parametric estimation of the proportion of true nulls. The function erpavetest first partition of the entire interval of ERP observations into a predetermined number equally-spaced intervals before performing siginificance testing using the averaged ERPs.

Author(s)

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References

Benjamini, Y., and Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. Journal of the Royal Statistical Society Series B, 289-300.

Benjamini, Y., and Yekutieli, D. (2001). The control of the false discovery rate in multiple testing under dependency. Annals of Statistics 29, 1165-1188.

Causeur, D., Chu, M.-C., Hsieh, S. and Sheu, C.-F. (2012). A factor-adjusted multiple testing procedure for ERP data analysis. Behavior Research Methods, 44, 635-643.

Friguet, C., Kloareg, M. and Causeur, D. (2009). A factor model approach to multiple testing under dependence. Journal of the American Statistical Association, 104, 1406-1415.

Guthrie, D. and Buchwald, J.S. (1991). Significance testing of difference potentials. Psychophysiology, 28, 240-244.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics, 6, 65-70.

Hommel, G. (1988). A stagewise rejective multiple test procedure based on a modified Bonferroni test. Biometrika, 75, 383-386.

Hochberg, Y. (1988). A sharper Bonferroni procedure for multiple tests of significance. Biometrika, 75, 800-803.

Shaffer, J. P. (1995). Multiple hypothesis testing. Annual Review of Psychology, 46, 561-576.

Sarkar, S. (1998). Some probability inequalities for ordered MTP2 random variables: a proof of Simes conjecture. Annals of Statistics, 26, 494-504.

Sarkar, S., and Chang, C. K. (1997). Simes' method for multiple hypothesis testing with positively dependent test statistics. Journal of the American Statistical Association, 92, 1601-1608.

Sheu, C.-F., Perthame, E., Lee Y.-S. and Causeur, D. (2016). Accounting for time dependence in large-scale multiple testing of event-related potentials data. To appear in Annals of Applied Statistics.

Wright, S. P. (1992). Adjusted P-values for simultaneous inference. Biometrics, 48, 1005-1013.

Examples

```
### simulated ERPs for 20 subjects (rows) and 251 ERPs measured at
### every 4 milliseconds plus a behavior score (columns)

data(simerp)

### Plot raw ERP curves

erpplot(simerp[,1:251],frames=seq(0,1001,4),xlab="Time (ms)",
   ylab=expression(ERP),col="black",main="Simulated ERP")

### Test of averaged ERPs over a pre-determined number of equal intervals

frames = seq(0,1001,4)

tests = erpavetest(simerp[,1:251],design=model.matrix(~y,data=simerp))
plot(frames,sign(tests$signal)*sqrt(tests$r2),type="l",
```

```
   xlab="Time (ms)",ylab="Correlation",ylim=c(-1,1))
points(frames[tests$significant],rep(-1,length(tests$significant)),
   pch=16,col="blue")
abline(v=frames[tests$breaks],lty=2,col="darkgray")
title("Simulation")

### Guthrie-Buchwald test

tests = gbtest(simerp[,1:251],design=model.matrix(~y,data=simerp),nbsamples=500)
plot(frames,sign(tests$signal)*sqrt(tests$r2),type="l",xlab="Time (ms)",
   ylab="Correlation",ylim=c(-1,1))
points(frames[tests$significant],rep(-1,length(tests$significant)),
   pch=16,col="blue")
title("Simulation")

### Benjamini-Hochberg Significance testing

tests = erptest(simerp[,1:251],design=model.matrix(~y,data=simerp))
plot(frames,sign(tests$signal)*sqrt(tests$r2),type="l",xlab="Time (ms)",
   ylab="Correlation",ylim=c(-1,1))
points(frames[tests$significant],rep(-1,length(tests$significant)),
   pch=16,col="blue")
title("Simulation")

### AFA significance testing

tests = erpfatest(simerp[,1:251],design=model.matrix(~y,data=simerp),nbf=5,min.err=1e-01,maxiter=10)
plot(frames,sign(tests$signal)*sqrt(tests$r2),type="l",xlab="Time (ms)",
   ylab="Correlation",ylim=c(-1,1))
points(frames[tests$significant],rep(-1,length(tests$significant)),
   pch=16,col="blue")
title("Simulation")
```

`erpavetest` *Significance testing of averaged ERPs. The entire ERP recording time is first partitioned into a pre-determined number of equal intervals. The averaged ERPs for each time intervals are the input for analysis.*

Description

The function first calculates averaged ERP values within a predetermined number of equally-spaced intervals then tests for significance of the relationship between averaged ERPs and covariates in a linear model framework.

Usage

```
erpavetest(dta, design, design0 = NULL, nintervals = 10, method = "none", alpha = 0.05)
```

Arguments

`dta`	Data frame containing the ERP curves: each column corresponds to a time frame and each row to a curve.
`design`	Design matrix of the full model for the relationship between the ERP and the experimental variables. Typically the output of the function model.matrix
`design0`	Design matrix of the null model. Typically a submodel of the full model, obtained by removing columns from design. Default is NULL, corresponding to the model with no covariates.
`nintervals`	Number of intervals in the partition of the whole interval of observation. Default is 10.
`method`	FDR- or FWER- controlling multiple testing procedures as available in the function p.adjust. Default is "none".
`alpha`	The FDR or FWER control level. Default is 0.05

Value

`pval`	p-values of the tests.
`correctedpval`	Corrected p-values, for the multiplicity of tests. Depends on the multiple testing method (see function p.adjust).
`significant`	Indices of the time points for which the test is positive.
`segments`	Factor giving the membership of timepoints to each interval in the partition.
`breaks`	Breakpoints of the partition.
`test`	F-statistics.
`df1`	Residual degrees of freedom for the full model.
`df0`	Residual degrees of freedom for the null model.
`signal`	Estimated signal: a pxT matrix, where p is the difference between the numbers of parameters in the full and null models and T the number of frames.
`r2`	R-squared values for each of the T linear models.

Author(s)

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See Also

`erptest`, `erpfatest`, `gbtest`, `p.adjust`, `pval.estimate.eta0`

Examples

```
require(mnormt)
require(fdrtool)

data(erpcz)
data(simerp)
```

```
# Paired t-tests for the comparison of ERP curves between two groups

tests = erpavetest(erpcz[,1:251],design=model.matrix(~Subject+Instruction,data=erpcz),
   design0=model.matrix(~Subject,data=erpcz))

frames = seq(0,1001,4)
plot(frames,tests$signal,type="l",xlab="Time (ms)",ylab="Difference ERP curves")
points(frames[tests$significant],rep(0,length(tests$significant)),pch=16,col="blue")
abline(v=frames[tests$breaks],lty=2,col="darkgray")
title("Paired comparison at electrode CZ")

# Tests for significance of correlations

tests = erpavetest(simerp[,1:251],design=model.matrix(~y,data=simerp))

plot(frames,sign(tests$signal)*sqrt(tests$r2),type="l",
   xlab="Time (ms)",ylab="Correlation",ylim=c(-1,1))
points(frames[tests$significant],rep(-1,length(tests$significant)),
   pch=16,col="blue")
abline(v=frames[tests$breaks],lty=2,col="darkgray")
title("Simulation")
```

---

erpcz — *ERP dataset from a directed forgetting experiment as presented in detail in Sheu, Perthame, Lee and Causeur (2016)*

Description

The experiment was conducted using an experimental paradigm similar to that described in Lee, Lee and Fawcett (2013). The objective of the study was to examine the electrophysiological process associated with directed forgetting.

Usage

```
data(erpcz)
```

Format

40 ERP curves obtained at electrode CZ for 20 subjects in two experimental conditions (TBR and TBF), each curve lasting for one thousand milliseconds (ms) with one record per 4ms. The last two columns, Subject and Instruction, provide the subject identifier and the group membership respectively.

Details

In the study phase of the experiment, 20 participants were instructed (with a ‘+’ or ‘X’ cue, respectively) to either remember or forget a stimulus word that was presented on a computer screen. ERPs were recorded throughout each of 90 trials - half for to-be-remembered (TBR) and half for to-be-forgotten (TBF). ERPs from nine electrode positions - 3 each from frontal, central and posterior regions - during the study phase were analyzed. The curent dataset provides the ERP curves at electrode CZ (central on the miline). The corresponding experimental covariates (subject and instruction) are provided in the last two columns.

Source

Sheu, C.-F., Perthame, E., Lee Y.-S. and Causeur, D. 2016. Accounting for time dependence in large-scale multiple testing of event-related potential data. To appear in Annals of Applied Statistics.

References

Lee, Y-S., Lee, H.M., Fawcett, J.-M. (2013). Intentional forgetting reduces color-naming interference: evidence from item-method directed forgetting. Journal of Experimental Psychology. Learning, Memory and Cognition, 39 (1), 220-236.

Examples

```
data(erpcz)
erpplot(erpcz[,1:251],frames=seq(0,1001,4),xlab="Time (ms)",
   ylab="ERP",main="ERP at electrode CZ")
```

---

erpfatest — *Adaptive Factor-Adjustement for multiple testing of ERP data*

Description

An adaptive factor-adjusted FDR- and FWER-controlling multiple testing procedures for ERP data. The procedure is described in detail in Sheu, Perthame, Lee, and Causeur (2016).

Usage

```
erpfatest(dta, design, design0 = NULL, method = "BH", nbf = NULL, nbfmax = 15,
   alpha = 0.05, pi0 = 1, wantplot = FALSE, s0 = NULL, min.err = 0.001,
   maxiter = 5, verbose = FALSE)
```

Arguments

`dta`	Data frame containing the ERP measurements: each column corresponds to a time frame and each row to a curve.
`design`	Design matrix of the full model for the relationship between the ERP and the experimental variables. Typically the output of the function model.matrix
`design0`	Design matrix of the null model. Typically a submodel of the full model, obtained by removing columns from design. Default is NULL, corresponding to the model with no covariates.

`method`	FDR- or FWER- controlling multiple testing procedures as available in the function p.adjust. Default is "BH", for the Benjamini-Hochberg procedure (see Benjamini and Hochberg, 1995).
`nbf`	Number of factors in the residual covariance model. Default is NULL: the number of factors is determined by minimization of the variance inflation criterion as suggested in Friguet et al. (2009).
`nbfmax`	Only required if nbf=NULL. The largest possible number of factors.
`alpha`	The FDR or FWER control level. Default is 0.05
`pi0`	An estimate of the proportion of true null hypotheses, which can be plugged into an FDR controlling multiple testing procedure to improve its efficiency. Default is 1, corresponding to the classical FDR controlling procedures. If NULL, the proportion is estimated using the function pval.estimate.eta0 of package fdrtool, with the method proposed by Storey and Tibshirani (2003).
`wantplot`	If TRUE, a diagnostic plot is produced to help choosing the number of factors. Only active if nbf=NULL.
`s0`	Prior knowledge of the time frames for which no signal is expected. For example, s0=c(1:50, 226:251) specifies that the first 50 time frames and time frames between 226 and 251 are known not to contain ERP signal. s0 can also be specified by giving the lower and upper fraction of the entire time interval in which the signal is to be searched for. For example: s0=c(0.2, 0.9) means that ERP signals are not expected for for the first 20 percent and last 10 percent of the time frames measured. Defaul is NULL and it initiates a data-driven determination of s0.
`min.err`	Control parameter for convergence of the iterative algorithm. Default is 1e-03.
`maxiter`	Maximum number of iterations in algorithms. Default is 5.
`verbose`	If TRUE, details are printed along the iterations of the algorithm. Default is FALSE.

Details

The method is described in Sheu et al. (2016). It combines a decorrelation step based on a regression factor model as in Leek and Storey (2008), Friguet et al. (2009) or Sun et al. (2012) with an adaptive estimation of the ERP signal. The multiple testing corrections of the p-values are described in the help documentation of the function p.adjust of package stats.

Value

`pval`	p-values of the Adaptive Factor-Adjusted tests.
`correctedpval`	Corrected p-values, for the multiplicity of tests. Depends on the multiple testing method (see function p.adjust).
`significant`	Indices of the time points for which the test is positive.
`pi0`	Value for pi0: if the input argument pi0 is NULL, the output is the estimated proportion of true null hypotheses using the method by Storey and Tibshirani (2003).
`test`	Factor-Adjusted F-statistics.

df1	Residual degrees of freedom for the full model.
df0	Residual degrees of freedom for the null model.
nbf	Number of factors for the residual covariance model.
signal	Estimated signal: a pxT matrix, where p is the difference between the numbers of parameters in the full and null models and T the number of frames.
r2	R-squared values for each of the T linear models.

Author(s)

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References

Causeur, D., Chu, M.-C., Hsieh, S., Sheu, C.-F. 2012. A factor-adjusted multiple testing procedure for ERP data analysis. Behavior Research Methods, 44, 635-643.

Friguet, C., Kloareg, M., Causeur, D. 2009. A factor model approach to multiple testing under dependence. Journal of the American Statistical Association, 104, 1406-1415.

Leek, J.T., Storey, J.D. 2008. A general framework for multiple testing dependence. Proceedings of the National Academy of Sciences of the United States of America, 105, 18718-18723.

Sheu, C.-F., Perthame, E., Lee Y.-S. and Causeur, D. 2016. Accounting for time dependence in large-scale multiple testing of event-related potential data. To appear in Annals of Applied Statistics.

Storey, J. D., Tibshirani, R. 2003. Statistical significance for genome-wide experiments. Proceedings of the National Academy of Sciences of the United States of America, 100, 9440-9445.

Sun, Y., Zhang, N.R., Owen, A.B. 2012. Multiple hypothesis testing adjusted for latent variables, with an application to the AGEMAP gene expression data. The Annals of Applied Statistics, 6, no. 4, 1664-1688.

See Also

erpavetest, erptest, gbtest, p.adjust, pval.estimate.eta0

Examples

```
require(mnormt)
require(fdrtool)

data(erpcz)
data(simerp)

# Paired t-tests for the comparison of ERP curves between two groups

tests = erpfatest(erpcz[,1:251],design=model.matrix(~Subject+Instruction,data=erpcz),
   design0=model.matrix(~Subject,data=erpcz),nbf=3,s0=c(1:50,226:251),min.err=1e-01)

frames = seq(0,1001,4)
plot(frames,tests$signal,type="l",xlab="Time (ms)",ylab="Difference ERP curves")
points(frames[tests$significant],rep(0,length(tests$significant)),pch=16,col="blue")
```

```
title("Paired comparison at electrode CZ")

# Tests for significance of correlations

tests = erpfatest(simerp[,1:251],design=model.matrix(~y,data=simerp),
   nbf=5,min.err=1e-01,maxiter=10)
plot(frames,sign(tests$signal)*sqrt(tests$r2),type="l",
   xlab="Time (ms)",ylab="Correlation",ylim=c(-1,1))
points(frames[tests$significant],rep(-1,length(tests$significant)),
   pch=16,col="blue")
title("Simulation")
```

`erpplot` *Plot of ERP curves.*

Description

Wrapper for matplot (package graphics) to display ERP curves.

Usage

```
erpplot(dta, frames = NULL, ylim = NULL, ...)
```

Arguments

`dta`	Data frame containing the ERP curves: each column corresponds to a time frame and each row to a curve.
`frames`	Sequence of time frames. Default is NULL, in which case frames is just the sequence of intergers between one and the total number of frames.
`ylim`	Limits for the y-axis. Default is NULL (set into the function).
`...`	Graphical parameters (see par) and any further arguments of plot, typically plot.default, may also be supplied as arguments to this function. Hence, the high-level graphics control arguments described under par and the arguments to title may be supplied to this function.

Value

The function generates a plot, but does not return any other numerical outputs.

Author(s)

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See Also

`matplot`

Examples

```
data(erpcz)
erpplot(erpcz[,1:251],frames=seq(0,1001,4),xlab="Time (ms)",
   ylab="ERP",main="ERP at electrode CZ")

data(simerp)
erpplot(simerp[,1:251],frames=seq(0,1001,4),xlab="Time (ms)",
   ylab="ERP",main="Simulated ERP")
```

---

erptest *FDR- and FWER-controlling Multiple testing of ERP data*

Description

Classical FDR- and FWER-controlling multiple testing procedures for ERP data in a linear model framework.

Usage

```
erptest(dta, design, design0 = NULL, method = "BH", alpha = 0.05, pi0 = 1)
```

Arguments

`dta`	Data frame containing the ERP curves: each column corresponds to a time frame and each row to a curve.
`design`	Design matrix of the full model for the relationship between the ERP and the experimental variables. Typically the output of the function model.matrix
`design0`	Design matrix of the null model. Typically a submodel of the full model, obtained by removing columns from design. Default is NULL, corresponding to the model with no covariates.
`method`	FDR- or FWER- controlling multiple testing procedures as available in the function p.adjust. Default is "BH", for the Benjamini-Hochberg procedure (see Benjamini and Hochberg, 1995).
`alpha`	The FDR or FWER control level. Default is 0.05
`pi0`	An estimate of the proportion of true null hypotheses, which can be plugged into an FDR controlling multiple testing procedure to improve its efficiency. Default is 1, corresponding to the classical FDR controlling procedures. If NULL, the proportion is estimated using the function pval.estimate.eta0 of package fdrtool, with the method proposed by Storey and Tibshirani (2003).

Details

The multiple testing corrections of the p-values are described in the help documentation of the function p.adjust du package stats.

Value

`pval`	p-values of the tests.
`correctedpval`	Corrected p-values, for the multiplicity of tests. Depends on the multiple testing method (see function p.adjust).
`significant`	Indices of the time points for which the test is positive.
`pi0`	Value for pi0: if the input argument pi0 is NULL, the output is the estimated proportion of true null hypotheses using the method by Storey and Tibshirani (2003).
`test`	F-statistics.
`df1`	Residual degrees of freedom for the full model.
`df0`	Residual degrees of freedom for the null model.
`signal`	Estimated signal: a pxT matrix, where p is the difference between the numbers of parameters in the full and null models and T the number of frames.
`r2`	R-squared values for each of the T linear models.

Author(s)

David Causeur - david.causeur@agrocampus-ouest.fr

References

Benjamini, Y., and Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. Journal of the Royal Statistical Society Series B, 289-300.

Benjamini, Y., and Yekutieli, D. (2001). The control of the false discovery rate in multiple testing under dependency. Annals of Statistics 29, 1165-1188.

Holm, S. (1979). A simple sequentially rejective multiple test procedure. Scandinavian Journal of Statistics, 6, 65-70.

Hommel, G. (1988). A stagewise rejective multiple test procedure based on a modified Bonferroni test. Biometrika, 75, 383-386.

Hochberg, Y. (1988). A sharper Bonferroni procedure for multiple tests of significance. Biometrika, 75, 800-803.

Shaffer, J. P. (1995). Multiple hypothesis testing. Annual Review of Psychology, 46, 561-576.

Sarkar, S. (1998). Some probability inequalities for ordered MTP2 random variables: a proof of Simes conjecture. Annals of Statistics, 26, 494-504.

Sarkar, S., and Chang, C. K. (1997). Simes' method for multiple hypothesis testing with positively dependent test statistics. Journal of the American Statistical Association, 92, 1601-1608.

Sheu, C.-F., Perthame, E., Lee Y.-S. and Causeur, D. (2016). Accounting for time dependence in large-scale multiple testing of event-related potential data. To appear in Annals of Applied Statistics.

Wright, S. P. (1992). Adjusted P-values for simultaneous inference. Biometrics, 48, 1005-1013.

See Also

`erpavetest`, `erpfatest`, `gbtest`, `p.adjust`, `pval.estimate.eta0`

Examples

```
require(mnormt)
require(fdrtool)

data(erpcz)
data(simerp)

# Paired comparison of ERP curves

tests = erptest(erpcz[,1:251],design=model.matrix(~Subject+Instruction,data=erpcz),
   design0=model.matrix(~Subject,data=erpcz))

frames = seq(0,1001,4)
plot(frames,tests$signal,type="l",xlab="Time (ms)",
   ylab="Difference ERP curves")
points(frames[tests$significant],rep(0,length(tests$significant)),
   pch=16,col="blue")
title("Paired comparison at electrode CZ")

# Independent two-group comparison of ERP curves

tests = erptest(erpcz[,1:251],design=model.matrix(~Instruction,data=erpcz))

frames = seq(0,1001,4)
plot(frames,tests$signal,type="l",xlab="Time (ms)",
   ylab="Difference ERP curves")
points(frames[tests$significant],rep(0,length(tests$significant)),
   pch=16,col="blue")
title("Independent comparison at electrode CZ")

# Tests for significance of correlations

tests = erptest(simerp[,1:251],design=model.matrix(~y,data=simerp))
plot(frames,sign(tests$signal)*sqrt(tests$r2),type="l",xlab="Time (ms)",
   ylab="Correlation",ylim=c(-1,1))
points(frames[tests$significant],rep(-1,length(tests$significant)),
   pch=16,col="blue")
title("Simulation")
```

`gbtest` *The Guthrie-Buchwald procedure for significance analysis of ERP data*

Description

Monte-Carlo implementation of the Guthrie-Buchwald procedure (see Guthrie and Buchwald, 1991) which accounts for the auto-correlation among test statistics to control erroneous detections of short intervals.

Usage

```
gbtest(dta, design, design0 = NULL, graphthresh = 0.05, nbsamples = 1000)
```

Arguments

- `dta` Data frame containing the ERP curves: each column corresponds to a time frame and each row to a curve.
- `design` Design matrix of the full model for the relationship between the ERP and the experimental variables. Typically the output of the function model.matrix
- `design0` Design matrix of the null model. Typically a submodel of the full model, obtained by removing columns from design. Default is NULL, corresponding to the model with no covariates.
- `graphthresh` Graphical threshold (see Guthrie and Buchwald, 1991). Default is 0.05. As the FDR control level, the smaller is the graphical threshold, the more conservative is the procedure.
- `nbsamples` Number of samples in the Monte-Carlo method to estimate the residual covariance. Default is 1000.

Details

The Guthrie-Buchwald method starts from a preliminary estimation of r, the lag-1 autocorrelation, among test statistics. Then, the null distribution of the lengths of the intervals $I_alpha = t : pvalue_t <= alpha $, where alpha is the so-called graphical threshold parameter of the method, is obtained using simulations of p-values p_t associated to auto-regressive t-test process of order 1 with mean 0 and auto-correlation r. Such an interval I_alpha is declared significant if its length exceeds the $(1-alpha)-$quantile of the null distribution. Note that the former method is designed to control erroneous detections of short significant intervals but not to control any type-I error rate.

Value

- `nbsignifintervals` Number of significant intervals.
- `intervals` List of length nbsignifintervals which components give the indices of each significant intervals.
- `significant` Indices of the time points for which the test is positive.
- `signal` Estimated signal: a pxT matrix, where p is the difference between the numbers of parameters in the full and null models and T the number of frames.
- `rho` Estimated lag-1 auto-correlation.
- `r2` R-squared values for each of the T linear models.

Author(s)

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References

Guthrie, D. and Buchwald, J.S. (1991). Significance testing of difference potentials. Psychophysiology, 28, 240-244.

Sheu, C.-F., Perthame, E., Lee Y.-S. and Causeur, D. (2016). Accounting for time dependence in large-scale multiple testing of event-related potentials data. To appear in Annals of Applied Statistics.

See Also

erpavetest, erpfatest, erptest

Examples

```
require(mnormt)
data(erpcz)
data(simerp)

# Paired comparison of ERP curves

tests = gbtest(erpcz[,1:251],design=model.matrix(~Subject+Instruction,data=erpcz),
   design0=model.matrix(~Subject,data=erpcz),nbsamples=500)

frames = seq(0,1001,4)
plot(frames,tests$signal,type="l",xlab="Time (ms)",
  ylab="Difference ERP curves")
points(frames[tests$significant],rep(0,length(tests$significant)),
   pch=16,col="blue")
title("Paired comparison at electrode CZ")

# Tests for significance of correlations

tests = gbtest(simerp[,1:251],design=model.matrix(~y,data=simerp),nbsamples=500)
plot(frames,sign(tests$signal)*sqrt(tests$r2),type="l",xlab="Time (ms)",
   ylab="Correlation",ylim=c(-1,1))
points(frames[tests$significant],rep(-1,length(tests$significant)),
   pch=16,col="blue")
title("Simulation")
```

---

simerp — *ERP dataset from a simulation study presented in detail in Sheu, Perthame, Lee and Causeur (2016)*

Description

The dataset contains 20 ERP curves (time frames every 4 ms from 0 to 1000 ms) and a variable y for behavioral score.

Usage

```
data(simerp)
```

Format

A sample of 20 simulated ERP curves, each curve lasting for one thousand milliseconds (ms) with one record per 4ms. The last column gives a behavioral score for the directed forgetting experiment described in Sheu, Perthame, Lee and Causeur (2016).

Details

The dataset is simulated under assumption of a multivariate regression model with normal residuals. The covariate, y, is a recognition score, as observed in a directed forgetting experiment described in Sheu, Perthame, Lee and Causeur (2016). Only the slope coefficients corresponding to time points in the interval [450 ms ; 550 ms] are true non-nulls, with a peak at 500 ms. The residual covariance of the model mimics the sample residual covariance of the ERP datasets collected in the directed forgetting experiment.

Source

Sheu, C.-F., Perthame, E., Lee Y.-S. and Causeur, D. 2016. Accounting for time dependence in large-scale multiple testing of event-related potential data. To appear in Annals of Applied Statistics.

Examples

```
data(simerp)
erpplot(simerp[,1:251],frames=seq(0,1001,4),xlab="Time (ms)",
   ylab="ERP",main="Simulated ERP")
```

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