Cluster mass EEG

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We will explain and apply in R the **Permutation-Based Cluster-Mass** method proposed by Maris and Oostenveld, 2007 and developed in R by Frossard and Renaud, 2018, using EEG data. The Cluster-Mass is computed considering the time series of one channel (**Temporal Cluster-Mass**) and the time series of multiple channels (**Spatial-Temporal Cluster-Mass**). Finally the **All-Resolution Inference** from Rosenblatt et al. 2018 is applied in order to compute the lower bound for the true discovery proportion inside the clusters computed.

Packages

First of all, you need to install and load the following packages:

```
#devtools::install_github("angeella/ARIeeg")
#devtools::install_github("bnicenboim/eeguana")
#devtools::install_github("jaromilfrossard/permuco")
library(ARIeeg)
library(dplyr)
library(eeguana)
library(ggplot2)
library(tidyr)
library(purrr)
library(abind)
library(permuco4brain)
library(permuco)
library(hommel)
library(plotly)
library(tidyverse)
```

Data

The Dataset from the package `ARIeeg` is an **ERP experiment** composed by:

- 20 Subjects,
- 32 Channels
- Stimuli: pictures. Conditions:
  1. (f): fear (face)
  2. (h): happiness (face)
  3. (d): disgust (face)
  4. (n): neutral (face)
  5. (o): object

We have one observation for each subject and each stimulus. You can load it using:

```
load(system.file("extdata", "data_eeg_emotion.RData", package = "ARIeeg"))
```

We transform the data as `eeg_lst` class object from the package `eeguana`:

```
data = utilsTOlst(data=dati)
is_eeg_lst(data)
```

```
## [1] TRUE
```

and we drop off the final 5 channels:

```
chan_to_rm <- c("RM"   ,  "EOGvo" ,"EOGvu"
                , "EOGhl", "EOGhr")
data <-
  data %>%
  select(-one_of(chan_to_rm))
```

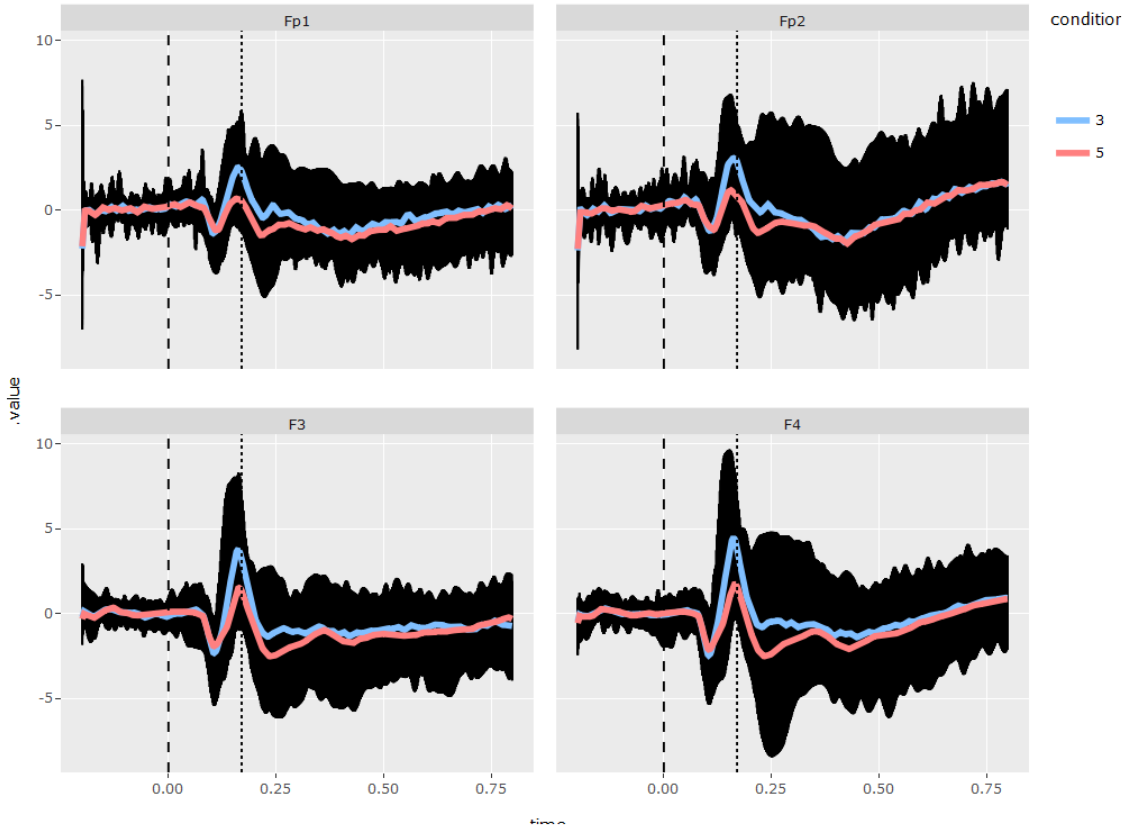
Finally, we segment the data and select two conditions, i.e., **disgust face** and **object**:

```
data_seg <- data %>%
  eeg_segment(.description %in% c(3,5),
              lim = c(min(dati$timings$time), max(dati$timings$time))
  ) %>% eeg_baseline()  %>%
  mutate(
    condition =
      description
  ) %>%
  select(-c(type,description))
```

Some plot to understand the global mean difference between the two conditions:

```
A<-data_seg %>%
  select(Fp1,Fp2, F3, F4) %>%
  ggplot(aes(x = .time, y = .value)) +
  geom_line(aes(group = condition))  +
  stat_summary(
    fun = "mean", geom = "line", alpha = 1, size = 1.5,
    aes(color = condition),show.legend = TRUE
  ) +
  facet_wrap(~.key) +
  geom_vline(xintercept = 0, linetype = "dashed") +
  geom_vline(xintercept = .17, linetype = "dotted") +
  theme(legend.position = "bottom")+
  scale_color_manual(labels = c("Disgust", "Object"), values = c("#80bfff", "#ff8080"))
p<-ggplotly(A)
tmpFile <- tempfile(fileext = ".png")
export(p, file = tmpFile)
```

```
## Warning: 'export' is deprecated.
## Use 'orca' instead.
## See help("Deprecated")
```



Theory

Multiple testing problem?

The aim is to test if the difference of brain signal during the two conditions is different from 0 for each time points, i.e., 500. If the full set of channels is considered, we have also test for each channel, i.e., 27, returning a total number of tests equals $500 \cdot 27$. Therefore, we have 500 or $500 \cdot 27$ statistical tests to perform at group-level, so considering the **random subject effect**. The multiple testing problem is then obvious, and correction methods as Bonferroni or similar don't capture the time(-spatial) correlation structure of the statistical tests, the cluster mass method, proposed by Maris and Oostenveld, 2007, is then used. It is based on **permutation theory**, and it gains some power respect to other procedure correcting at level of (spatial-)temporal cluster instead of at level of single tests. It is similar to the cluster mass in the fMRI framework, but in this case, the *voxels*, i.e., the single object of the analysis, are expressed in terms of time-points or in terms of combination time-points/channels. The method is then able to gain some power respect to some traditional conservative FWER correction method exploiting the (spatial-)temporal structure of the data.

Repeated Measures Anova Model

The cluster mass method is based on the **Repeated Measures Anova**, i.e.,

$$y = 1_{N\times 1}\mu + \eta X^{\eta} + \pi X^{\pi} + \eta\pi X^{\eta\pi} + \epsilon$$

where $1_{N\times 1}$ is a matrix with ones and

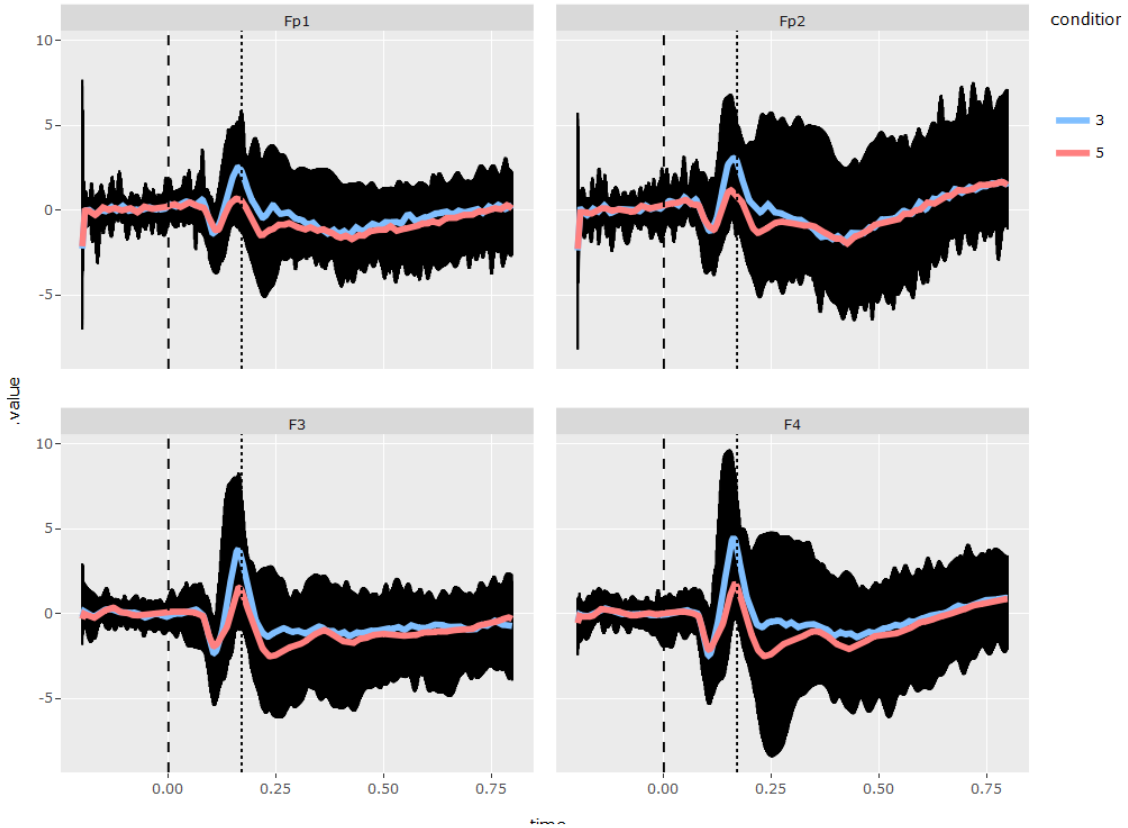


Figure 1: global ERP respect two conditions, i.e., disgust face and object.

1. μ is the **intercept**;
2. $y \in \mathbb{R}^{N\times 1}$ is the response variables, i.e., the **signal**, in our case $N = n_{subj} \times n_{stimuli} = 40$;
3. $X^{\eta} \in \mathbb{R}^{N\times n_{stimuli}}$ is the **design matrix** describing the **fixed effect** regarding the stimuli, and $\eta \in \mathbb{R}^{n_{stimuli}\times 1}$ the corresponding parameter of interest;
4. $X^{\pi} \in \mathbb{R}^{N\times n_{subj}}$ is the **design matrix** describing the **random effect** regarding the subjects, and $\pi \in \mathbb{R}^{n_{subj}\times 1}$ the corresponding parameter.
5. $X^{\eta\pi}$ is the **design matrix** describing the **interaction effects** between subjects and conditions;
6. $\epsilon \in \mathbb{R}^{N\times 1}$ is the **error term** with 0 mean and variance $\sigma^2 I_N$.

Therefore, $y \sim (1\mu + X^{\eta}\eta, \Sigma)$, $\pi \sim (0, \sigma^2_{\pi} I_{nsubj})$ and $\eta\pi \sim (0, \text{cov}(\eta\pi))$.

We want to make inference on η, such that $H_0 : \eta = 0$ vs $H_1 : \eta \neq 0$. We do that using the **F statistic**, i.e.,

$$F = \frac{y^{\top} H_{X^{\eta}} y/(n_{stimuli} - 1)}{y^{\top} H_{X^{\eta\pi}} y/(n_{stimuli} - 1)(n_{subj} - 1)}$$

where H_X is the **projection matrix**, i.e., $H_X = X(X^{\top}X)^{-1}X^{\top}$. In order to compute this test, we use an alternative definition of F based on the residuals:

$$F_r = \frac{r^{\top} H_{X^{\eta}} r/(n_{stimuli} - 1)}{r^{\top} H_{X^{\eta\pi}} r/(n_{stimuli} - 1)(n_{subj} - 1)}$$

where $r = (H_{X^{\eta}} + H_{X^{\eta\pi}})y$. For further details, see Kherad Pajouh and Renaud, 2014.

So, let the group of permutation, including the identity transformation, $\mathcal{P}$, we use $r^{\star} = Pr$, where $P \in \mathcal{P}$ to compute the null distribution of our test, i.e., $\mathcal{R}$, and then the p-value, i.e.,

$$\text{p-value} = \frac{1}{B} \sum_{F_r^{\star} \in \mathcal{R}} \mathbb{I}(|F_r^{\star}| \geq |F_r|)$$

if the two-tailed is considered, where $F_r^{\star} = f(r^{\star})$.

We have this model for each time point $t \in \{1, \ldots, 500\}$ and each channel, so finally we will have $n_{\text{time-points}} \times n_{\text{channels}}$ statistical tests/p-values (raw).

Temporal Cluster mass

This method has been proposed by Maris and Oostenveld, 2007 and is commonly implemented in specialised software of EEG data analysis. It relies on a continuity argument that implies that an effect will appear into clusters of adjacent timeframes. Based on all time-specific statistics, we form these clusters using a threshold τ as follows

All the adjacent time points for which the statistics are above this threshold define one cluster C_i for $i \in \{1, \ldots, n_C\}$, where n_C is the number of clusters found. We assign to each time point in the same cluster C_i, the same cluster-mass statistic $m_i = f(C_i)$ where f is a function that aggregates the statistics of the whole cluster into a scalar; typically the sum of the F statistics or the sum of squared of the t statistics. The cluster-mass null distribution $\mathcal{M}$ is computed by repeating the process described above for each permutation. The contribution of a permutation to the cluster-mass null distribution is the maximum over all cluster-masses for this permutation. To test the significance of an observed cluster Ci, we compare its cluster-mass $m_i = f(C_i)$ with the cluster-mass null distribution $\mathcal{M}$. The p-value of the effect at each time within a cluster C_i is the p value associated with this cluster, i.e.

$$p_i = \frac{1}{n_P} \sum_{m_i^{\star} \in \mathcal{M}} 1\{m_i^{\star} \geq m_i\}$$

where $m_i^{\star}$ is computed considering the permuted statistic. This method makes sense for EEG data analysis because if a difference of cerebral activity is believed to happen at a time s for a given factor, it is very likely that the time $s + 1$ (or $s - 1$) will show this difference too.

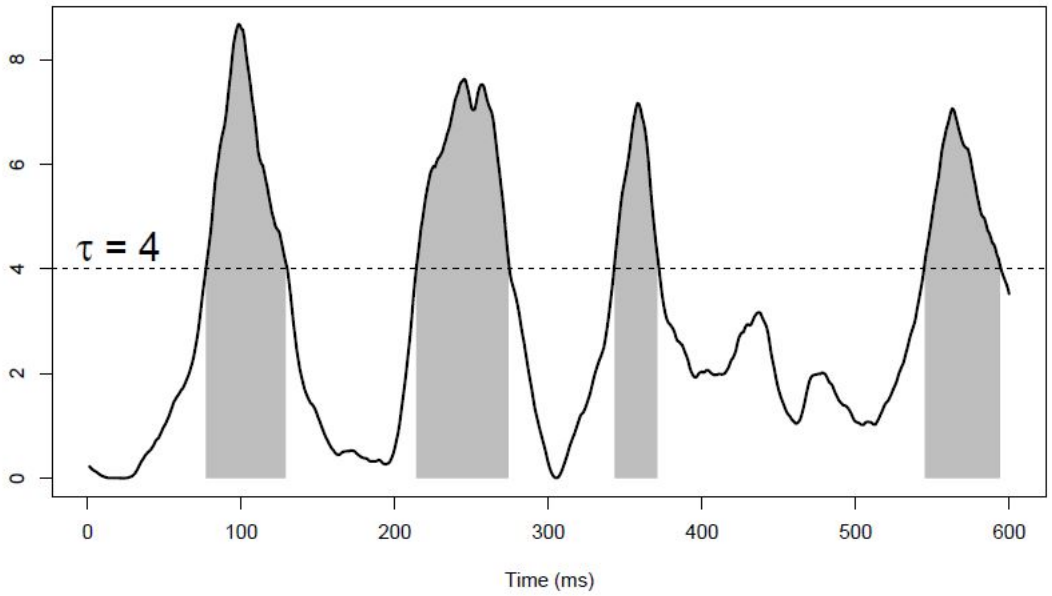


Figure 2: Example of cluster mass EEG from Frossard, 2019

Spatial-temporal Cluster mass

In this case, we will use the theory of graph, where the vertices represent the channels, and the edges represent the **adjacency** relationship. The adjacency must be defined using prior information, therefore the three-dimensional Euclidean distance between channels is used. Two channels are defined adjacent if their Euclidean distance is less than a threshold δ, where δ is the smallest euclidean distance that produces a connected graph. This is due to the fact that a connected graph implies no disconnected sub-graph. Having sub-graphs implies that some tests cannot, by design, be in the same cluster, which is not a useful assumption for this analysis. (Frossard and Renaud, 2018; Frossard, 2019).

Then, having the spatial adjacency definition, we need to define the temporal one. We reproduce this graph $n_{\text{time-points}}$ times, the edges between all pairs of two vertices (tests) are associated with the same electrode when they are temporally adjacent. The final graph has a total of vertices equals to the number of tests ($n_{\text{channels}} \times n_{\text{time-points}}$). The following figure represents the case of 64 channels and 3 temporal measures:

We then delete all the vertices in which statistics are below a threshold, e.g., the 95 percentile of the null distribution of the F statistics. So, we have a new graph composed of **multiple connected components**. Then, each connected component is interpreted as a spatial-temporal cluster. Finally, for each connected component, we compute the cluster-mass statistic using the sum (or sum of squares) of statistics of that particular connected component.

The cluster-mass null distribution is computed by permutations while maintaining spatial-temporal correlations among tests. Permutations must be performed without changing the position of electrodes nor mixing time-points. Concretely, after transforming the responses using the permutation method in Kherad Pajouh and Renaud, 2014, they are sorted in a three-dimensional array. It has the design (subjects $\times$ stimuli) in the first dimension, time in the second one and electrodes in the third one. Then, only the first dimension is permuted to create a re-sampled response (or 3D array). Doing so, it does not reorder time-points, neither electrodes, therefore, the spatial-temporal correlations are maintained within each permuted sample.

Application

In R, all of this is possible thanks to the permuco and permuco4brain packages developed by Frossard and Renaud, 2018.

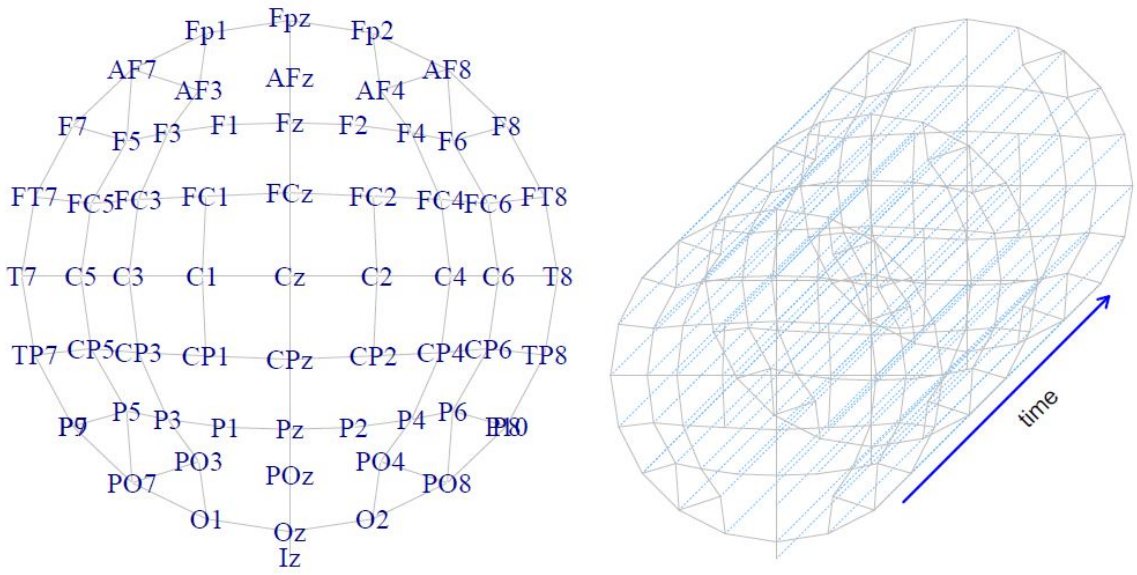


Figure 3: Example of graph of adjacency from Frossard, 2019

Temporal Cluster-Mass

So, we select one channel from our dataset, e.g. the Fp1:

```
Fp1 <- data_seg %>% select(Fp1)
```

1. Construct the y. We need to construct the three-dimensional **signal matrix**, having dimensions 40×500:

```
signal_Fp1 <- Fp1%>%
    signal_tbl()%>%
    group_by(.id)%>%
    nest()%>%
    mutate(data = map(data,~as.matrix(.x[-1])))%>%
    pull(data)%>%
    invoke(abind,.,along = 2)%>%
    aperm(c(2,1))
dim(signal_Fp1)
```

```
## [1]  40 500
```

2. Construct the $X_{\eta\pi}$, having dimensions 40×2:

```
design <-
  segments_tbl(Fp1)%>%
  select(.subj, condition)
dim(design)
```

```
## [1] 40  2
```

3. Define the **repeated measures ANOVA formula**:

```
f <- signal_Fp1 ~ condition + Error(.subj/(condition))
```

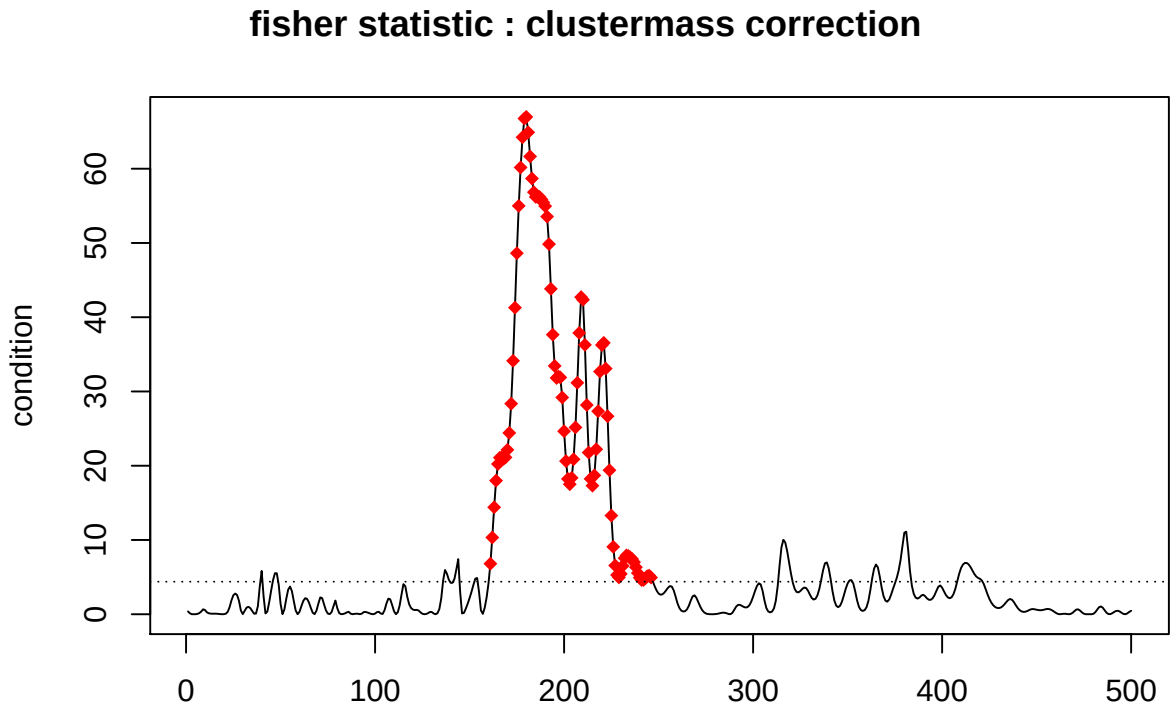
Thanks to the permuco package, we can apply the temporal cluster-Mass for the channel Fp1:

```
lm_Fp1 <- clusterlm(f,data = design)
print(lm_Fp1)
```

```
## Effect: condition.
## Alternative Hypothesis: two.sided.
## Statistic: fisher(1, 19).
## Resample Method: Rd_kheradPajouh_renaud.
## Number of Dependant Variables: 500.
## Type of Resample: .
## Number of Resamples: 5000.
## Multiple Comparisons Procedure: clustermass.
## Threshold: 4.38075.
## Mass Function: the sum.
## Table of clusters.
##
##    start end cluster mass P(>mass)
## 1     40  40     5.834359   0.8944
## 2     46  48    15.621750   0.8088
## 3    136 139    20.628700   0.7476
## 4    142 144    18.238758   0.7808
## 5    153 154     9.661613   0.8690
## 6    161 246  2403.135136   0.0004
## 7    314 320    56.329115   0.3590
## 8    336 341    35.300331   0.5582
## 9    351 352     9.153198   0.8844
## 10   363 367    29.083554   0.6384
## 11   376 383    63.884839   0.3088
## 12   408 421    80.330852   0.2472
```

and the corresponding plot:

```
plot(lm_Fp1)
```



ARI in EEG cluster mass

However, our significant cluster says only that at least one test is different from 0, we don't know how many tests/time-points are significant (**spatial specificity paradox**). So, we can apply ARI to understand the lower bound of the number of true discovery proportion. The cluster is composed by the time points from 161 to 246, i.e., the size of the cluster is equal to 86.

```
praw <- lm_Fp1$multiple_comparison$condition$uncorrected$main[,2]
cluster <- c(161:246)

discoveries(hommel(praw), ix = cluster)
```

```
## [1] 57
```

Therefore, we have at least 62% of true active time points in the cluster computed.

Spatial-Temporal Cluster-Mass

1. Construct the y. We need to construct the three-dimensional **signal array**, having dimensions $40 \times 500 \times 27$:

```
signal <-
    data_seg%>%
    signal_tbl()%>%
    group_by(.id)%>%
    nest()%>%
    mutate(data = map(data,~as.matrix(.x[-1])))%>%
    pull(data)%>%
    invoke(abind,.,along = 3)%>%
    aperm(c(3,1,2))

dim(signal)
```

```
## [1]  40 500  27
```

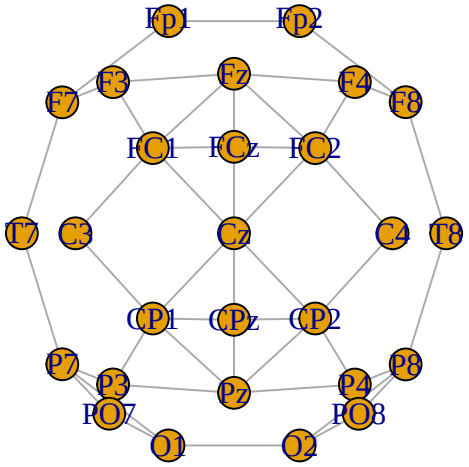
2. Construct the $X_{\eta\pi}$:

```
design <-
  segments_tbl(data_seg)%>%
  select(.subj, condition)
dim(design)
```

```
## [1] 40  2
```

3. Construct the **graph**, using $\delta = 53mm$:

```
graph <- position_to_graph(channels_tbl(data_seg), name = .channel, delta = 53,
                           x = .x, y = .y, z = .z)
plot(graph)
```



4. Define the **repeated measures ANOVA formula**:

```
f <- signal ~ condition + Error(.subj/(condition))
```

Finally, run the main function:

```
model <- permuco4brain::brainperm(formula = f,
                                  data = design,
                                  graph = graph,
                                  np = 5000,
                                  multcomp = "clustermass",
                                  return_distribution = TRUE)
```

```
## Computing Effect:
## 1 (condition) of 1. Start at 2020-05-21 08:05:41.
```

where np indicates the number of permutation.

Then, we can analyze the output:

```
print(model)
```

```
## Effect: condition.
## Alternative Hypothesis: two.sided.
## Statistic: fisher(1, 19).
## Resample Method: Rd_kheradPajouh_renaud.
## Number of Dependant Variables: 13500.
## Type of Resample: permutation.
## Number of Resamples: 5000.
## Multiple Comparisons Procedure: clustermass.
## Threshold: 4.38075.
## Mass Function: the sum.
## Table of clusters.
##
##    Cluster id First sample Last sample N. chan. Main chan. Main chan. length
```

```
##    1           1            1           4        3         Fz                4
##    2           2            2           6        2         O2                5
##    3           3            3           6        1         F7                4
##    4           4           10          10        1         F8                1
##    5           5           18          19        1         Pz                2
##    6           6           25          27        1         T7                3
##    7           7           29          30        1         F8                2
##    8           8           38          41        1         F3                4
##    9           9           39          41        2         Pz                3
##    10         10           40          40        1        Fp1                1
##    11         11           40          44        1         T7                5
##    12         12           45          49        1         F4                5
##    13         13           46          48        1        Fp1                3
##    14         14           47          49        1         P4                3
##    15         15           48          49        1         C4                2
##    16         16           51          52        1         T7                2
##    17         17           61          68        3         P3                8
##    18         18           70          75        3        PO8                6
##    19         19           71          73        1        Fp2                3
##    20         20           83          86        1         C4                4
##    21         21           83          88        2         T7                6
##    22         22           96         105        4     F3 (2)                8
##    23         23          101         108        3     O2 (2)                6
##    24         24          110         117        6     C3 (2)                8
##    25         25          115         117        1         P8                3
##    26         26          125         126        1         F7                2
##    27         27          128         137        4         P8                9
##    28         28          133         135        2         C3                3
##    29         29          136         139        2        Fp1                4
##    30         30          137         139        2        PO7                3
##    31         31          142         144        1        Fp1                3
##    32         32          146         500       27         P7              343
##    33         33          148         157        8     C4 (3)                9
##    34         34          148         152        1         P7                5
##    35         35          153         154        1        Fp1                2
##    36         36          314         320        1        Fp1                7
##    37         37          336         341        1        Fp1                6
##    38         38          351         352        1        Fp1                2
##    39         39          363         367        1        Fp1                5
##    40         40          376         383        1        Fp1                8
##    41         41          408         421        1        Fp1               14
##    N. test  Clustermass P(>mass)
## 1        8 4.824842e+01   0.9958
## 2        8 5.655352e+01   0.9930
## 3        4 2.161425e+01   0.9996
## 4        1 4.595571e+00   1.0000
## 5        2 9.160799e+00   1.0000
## 6        3 1.727826e+01   1.0000
## 7        2 9.953708e+00   1.0000
## 8        4 2.247954e+01   0.9996
## 9        4 1.841798e+01   0.9998
## 10       1 5.834359e+00   1.0000
## 11       5 3.514078e+01   0.9976
## 12       5 3.062193e+01   0.9990
## 13       3 1.562175e+01   1.0000
## 14       3 1.855438e+01   0.9998
## 15       2 1.046127e+01   1.0000
## 16       2 1.091898e+01   1.0000
```

```
## 17      13 9.673299e+01   0.9780
## 18      16 9.924648e+01   0.9772
## 19       3 1.701493e+01   1.0000
## 20       4 2.614448e+01   0.9994
## 21      10 7.604927e+01   0.9876
## 22      26 1.750308e+02   0.9316
## 23      17 1.039216e+02   0.9752
## 24      35 2.762222e+02   0.8660
## 25       3 1.367199e+01   1.0000
## 26       2 9.355923e+00   1.0000
## 27      27 1.703500e+02   0.9350
## 28       5 2.598810e+01   0.9994
## 29       6 3.007729e+01   0.9990
## 30       4 1.807287e+01   0.9998
## 31       3 1.823876e+01   0.9998
## 32    4788 1.041780e+05   0.0002
## 33      54 4.224551e+02   0.7770
## 34       5 3.646500e+01   0.9974
## 35       2 9.661613e+00   1.0000
## 36       7 5.632912e+01   0.9930
## 37       6 3.530033e+01   0.9974
## 38       2 9.153198e+00   1.0000
## 39       5 2.908355e+01   0.9994
## 40       8 6.388484e+01   0.9904
## 41      14 8.033085e+01   0.9846
```

We have only one significant cluster (32), with p-value equals to 0.0002. It is composed by 27 channels (the total set), with main channels P7. You can see in details the components of this cluster in

```
names(model$multiple_comparison$condition$clustermass$cluster$membership[which(as.vector(model$multi
```

```
##    [1] "O2_146"  "O2_147"  "O2_148"  "O2_149"  "O2_150"  "O2_151"  "Pz_151"
##    [8] "O2_152"  "Pz_152"  "O1_153"  "O2_153"  "Pz_153"  "O1_154"  "O2_154"
##   [15] "Pz_154"  "O1_155"  "O2_155"  "Pz_155"  "O1_156"  "O2_156"  "Pz_156"
##   [22] "O1_157"  "O2_157"  "Pz_157"  "P7_158"  "O1_158"  "Pz_158"  "P7_159"
##   [29] "O1_159"  "Pz_159"  "F4_160"  "P7_160"  "PO7_160" "Pz_160"  "Fp1_161"
##   [36] "Fp2_161" "F4_161"  "C4_161"  "T7_161"  "CP2_161" "P7_161"  "PO7_161"
##   [43] "Pz_161"  "Fp1_162" "Fp2_162" "F4_162"  "F7_162"  "F8_162"  "FC2_162"
##   [50] "C4_162"  "T7_162"  "CP2_162" "P7_162"  "P8_162"  "PO7_162" "Cz_162"
##   [57] "CPz_162" "Pz_162"  "Fp1_163" "Fp2_163" "F4_163"  "F8_163"  "FC2_163"
##   [64] "C4_163"  "T7_163"  "CP2_163" "P7_163"  "P8_163"  "PO7_163" "Fz_163"
##   [71] "FCz_163" "Cz_163"  "CPz_163" "Pz_163"  "Fp1_164" "Fp2_164" "F4_164"
##   [78] "F8_164"  "FC1_164" "FC2_164" "C4_164"  "T7_164"  "CP2_164" "P7_164"
##   [85] "P8_164"  "PO7_164" "PO8_164" "Fz_164"  "FCz_164" "Cz_164"  "CPz_164"
##   [92] "Pz_164"  "Fp1_165" "Fp2_165" "F3_165"  "F4_165"  "F8_165"  "FC1_165"
##   [99] "FC2_165" "C4_165"  "T7_165"  "CP1_165" "CP2_165" "P7_165"  "P8_165"
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## [1163] "CPz_212" "Fp1_213" "Fp2_213" "F3_213"  "F4_213"  "F7_213"  "F8_213"
## [1170] "FC1_213" "FC2_213" "C4_213"  "T7_213"  "CP2_213" "P7_213"  "P8_213"
## [1177] "P3_213"  "PO7_213" "PO8_213" "O1_213"  "O2_213"  "Fz_213"  "FCz_213"
## [1184] "Cz_213"  "CPz_213" "Fp1_214" "Fp2_214" "F3_214"  "F4_214"  "F7_214"
## [1191] "F8_214"  "FC1_214" "FC2_214" "C4_214"  "T7_214"  "CP2_214" "P7_214"
## [1198] "P8_214"  "P3_214"  "PO7_214" "PO8_214" "O1_214"  "O2_214"  "Fz_214"
## [1205] "FCz_214" "Cz_214"  "CPz_214" "Fp1_215" "Fp2_215" "F3_215"  "F4_215"
## [1212] "F7_215"  "F8_215"  "FC1_215" "FC2_215" "C4_215"  "T7_215"  "CP2_215"
## [1219] "P7_215"  "P8_215"  "P3_215"  "PO7_215" "PO8_215" "O1_215"  "O2_215"
## [1226] "Fz_215"  "FCz_215" "Cz_215"  "CPz_215" "Fp1_216" "Fp2_216" "F3_216"
## [1233] "F4_216"  "F7_216"  "F8_216"  "FC1_216" "FC2_216" "C4_216"  "T7_216"
## [1240] "CP2_216" "P7_216"  "P8_216"  "P3_216"  "PO7_216" "PO8_216" "O1_216"
## [1247] "O2_216"  "Fz_216"  "FCz_216" "Cz_216"  "CPz_216" "Fp1_217" "Fp2_217"
## [1254] "F3_217"  "F4_217"  "F7_217"  "F8_217"  "FC1_217" "FC2_217" "C4_217"
## [1261] "T7_217"  "CP2_217" "P7_217"  "P8_217"  "P3_217"  "PO7_217" "PO8_217"
## [1268] "O1_217"  "O2_217"  "Fz_217"  "FCz_217" "Cz_217"  "CPz_217" "Fp1_218"
## [1275] "Fp2_218" "F3_218"  "F4_218"  "F7_218"  "F8_218"  "FC1_218" "FC2_218"
## [1282] "C4_218"  "CP2_218" "P7_218"  "P8_218"  "P3_218"  "PO7_218" "PO8_218"
## [1289] "O1_218"  "O2_218"  "Fz_218"  "FCz_218" "Cz_218"  "CPz_218" "Fp1_219"
## [1296] "Fp2_219" "F3_219"  "F4_219"  "F7_219"  "F8_219"  "FC1_219" "FC2_219"
## [1303] "C4_219"  "CP2_219" "P7_219"  "P8_219"  "P3_219"  "PO7_219" "PO8_219"
## [1310] "O1_219"  "O2_219"  "Fz_219"  "FCz_219" "Cz_219"  "CPz_219" "Fp1_220"
## [1317] "Fp2_220" "F3_220"  "F4_220"  "F7_220"  "F8_220"  "FC1_220" "FC2_220"
## [1324] "C4_220"  "CP1_220" "CP2_220" "P7_220"  "P8_220"  "P3_220"  "PO7_220"
## [1331] "PO8_220" "O1_220"  "O2_220"  "Fz_220"  "FCz_220" "Cz_220"  "CPz_220"
## [1338] "Fp1_221" "Fp2_221" "F3_221"  "F4_221"  "F7_221"  "F8_221"  "FC1_221"
## [1345] "FC2_221" "C3_221"  "C4_221"  "CP1_221" "CP2_221" "P7_221"  "P8_221"
## [1352] "P3_221"  "PO7_221" "PO8_221" "O1_221"  "O2_221"  "Fz_221"  "FCz_221"
## [1359] "Cz_221"  "CPz_221" "Fp1_222" "Fp2_222" "F3_222"  "F4_222"  "F7_222"
## [1366] "F8_222"  "FC1_222" "FC2_222" "C3_222"  "C4_222"  "CP1_222" "CP2_222"
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## [1380] "Fz_222"  "FCz_222" "Cz_222"  "CPz_222" "Fp1_223" "Fp2_223" "F3_223"
## [1387] "F4_223"  "F7_223"  "F8_223"  "FC1_223" "FC2_223" "C3_223"  "C4_223"
## [1394] "CP1_223" "CP2_223" "P7_223"  "P8_223"  "P3_223"  "PO7_223" "PO8_223"
## [1401] "O1_223"  "O2_223"  "Fz_223"  "FCz_223" "Cz_223"  "CPz_223" "Fp1_224"
## [1408] "Fp2_224" "F3_224"  "F4_224"  "F7_224"  "F8_224"  "FC1_224" "FC2_224"
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## [1415] "C3_224"  "C4_224"  "CP1_224" "CP2_224" "P7_224"  "P8_224"  "P3_224"
## [1422] "PO7_224" "PO8_224" "O1_224"  "O2_224"  "Fz_224"  "FCz_224" "Cz_224"
## [1429] "CPz_224" "Pz_224"  "Fp1_225" "Fp2_225" "F3_225"  "F4_225"  "F7_225"
## [1436] "F8_225"  "FC1_225" "FC2_225" "C3_225"  "C4_225"  "CP1_225" "CP2_225"
## [1443] "P7_225"  "P8_225"  "P3_225"  "PO7_225" "PO8_225" "O1_225"  "O2_225"
## [1450] "Fz_225"  "FCz_225" "Cz_225"  "CPz_225" "Pz_225"  "Fp1_226" "Fp2_226"
## [1457] "F3_226"  "F4_226"  "F7_226"  "F8_226"  "FC1_226" "FC2_226" "C3_226"
## [1464] "C4_226"  "CP1_226" "CP2_226" "P7_226"  "P8_226"  "P3_226"  "PO7_226"
## [1471] "PO8_226" "O1_226"  "O2_226"  "Fz_226"  "FCz_226" "Cz_226"  "CPz_226"
## [1478] "Pz_226"  "Fp1_227" "Fp2_227" "F3_227"  "F4_227"  "F7_227"  "F8_227"
## [1485] "FC1_227" "FC2_227" "C3_227"  "C4_227"  "CP1_227" "CP2_227" "P7_227"
## [1492] "P8_227"  "P3_227"  "PO7_227" "PO8_227" "O1_227"  "O2_227"  "Fz_227"
## [1499] "FCz_227" "Cz_227"  "CPz_227" "Pz_227"  "Fp1_228" "F3_228"  "F4_228"
## [1506] "F7_228"  "F8_228"  "FC1_228" "FC2_228" "C3_228"  "C4_228"  "CP1_228"
## [1513] "CP2_228" "P7_228"  "P8_228"  "P3_228"  "PO7_228" "PO8_228" "O1_228"
## [1520] "O2_228"  "Fz_228"  "FCz_228" "Cz_228"  "CPz_228" "Pz_228"  "Fp1_229"
## [1527] "F3_229"  "F4_229"  "F7_229"  "F8_229"  "FC1_229" "FC2_229" "C3_229"
## [1534] "C4_229"  "CP1_229" "CP2_229" "P7_229"  "P8_229"  "PO7_229" "PO8_229"
## [1541] "O1_229"  "O2_229"  "Fz_229"  "FCz_229" "Cz_229"  "CPz_229" "Pz_229"
## [1548] "Fp1_230" "F3_230"  "F4_230"  "F7_230"  "F8_230"  "FC1_230" "FC2_230"
## [1555] "C3_230"  "C4_230"  "CP1_230" "CP2_230" "P7_230"  "P8_230"  "PO7_230"
## [1562] "PO8_230" "O1_230"  "O2_230"  "Fz_230"  "FCz_230" "Cz_230"  "CPz_230"
## [1569] "Pz_230"  "Fp1_231" "F3_231"  "F4_231"  "F7_231"  "F8_231"  "FC1_231"
## [1576] "FC2_231" "C3_231"  "C4_231"  "CP1_231" "CP2_231" "P7_231"  "P8_231"
## [1583] "PO7_231" "PO8_231" "O1_231"  "O2_231"  "Fz_231"  "FCz_231" "Cz_231"
## [1590] "CPz_231" "Pz_231"  "Fp1_232" "F3_232"  "F4_232"  "F7_232"  "F8_232"
## [1597] "FC1_232" "FC2_232" "C3_232"  "C4_232"  "CP1_232" "CP2_232" "P7_232"
## [1604] "P8_232"  "PO7_232" "PO8_232" "O1_232"  "O2_232"  "Fz_232"  "FCz_232"
## [1611] "Cz_232"  "CPz_232" "Pz_232"  "Fp1_233" "F3_233"  "F4_233"  "F7_233"
## [1618] "F8_233"  "FC1_233" "FC2_233" "C3_233"  "C4_233"  "CP1_233" "CP2_233"
## [1625] "P7_233"  "P8_233"  "PO7_233" "PO8_233" "O1_233"  "O2_233"  "Fz_233"
## [1632] "FCz_233" "Cz_233"  "CPz_233" "Pz_233"  "Fp1_234" "F3_234"  "F4_234"
## [1639] "F7_234"  "F8_234"  "FC1_234" "FC2_234" "C3_234"  "C4_234"  "CP1_234"
## [1646] "CP2_234" "P7_234"  "P8_234"  "PO7_234" "PO8_234" "O1_234"  "O2_234"
## [1653] "Fz_234"  "FCz_234" "Cz_234"  "CPz_234" "Pz_234"  "Fp1_235" "F3_235"
## [1660] "F4_235"  "F7_235"  "F8_235"  "FC1_235" "FC2_235" "C3_235"  "C4_235"
## [1667] "CP1_235" "CP2_235" "P7_235"  "P8_235"  "PO7_235" "PO8_235" "O1_235"
## [1674] "O2_235"  "Fz_235"  "FCz_235" "Cz_235"  "CPz_235" "Pz_235"  "Fp1_236"
## [1681] "F3_236"  "F4_236"  "F7_236"  "F8_236"  "FC1_236" "FC2_236" "C3_236"
## [1688] "C4_236"  "CP1_236" "CP2_236" "P7_236"  "P8_236"  "PO7_236" "PO8_236"
## [1695] "O1_236"  "O2_236"  "Fz_236"  "FCz_236" "Cz_236"  "CPz_236" "Pz_236"
## [1702] "Fp1_237" "F3_237"  "F4_237"  "F7_237"  "F8_237"  "FC1_237" "FC2_237"
## [1709] "C3_237"  "C4_237"  "CP1_237" "CP2_237" "P7_237"  "P8_237"  "PO7_237"
## [1716] "PO8_237" "O1_237"  "O2_237"  "Fz_237"  "FCz_237" "Cz_237"  "CPz_237"
## [1723] "Pz_237"  "Fp1_238" "F3_238"  "F4_238"  "F7_238"  "F8_238"  "FC1_238"
## [1730] "FC2_238" "C3_238"  "C4_238"  "CP1_238" "CP2_238" "P7_238"  "P8_238"
## [1737] "PO7_238" "PO8_238" "O1_238"  "O2_238"  "Fz_238"  "FCz_238" "Cz_238"
## [1744] "CPz_238" "Pz_238"  "Fp1_239" "F3_239"  "F4_239"  "F7_239"  "F8_239"
## [1751] "FC1_239" "FC2_239" "C3_239"  "C4_239"  "CP1_239" "CP2_239" "P7_239"
## [1758] "P8_239"  "PO7_239" "PO8_239" "O1_239"  "O2_239"  "Fz_239"  "FCz_239"
## [1765] "Cz_239"  "CPz_239" "Pz_239"  "Fp1_240" "F3_240"  "F4_240"  "F7_240"
## [1772] "F8_240"  "FC1_240" "FC2_240" "C3_240"  "C4_240"  "CP1_240" "CP2_240"
## [1779] "P7_240"  "P8_240"  "PO7_240" "PO8_240" "O1_240"  "O2_240"  "Fz_240"
## [1786] "FCz_240" "Cz_240"  "CPz_240" "Pz_240"  "Fp1_241" "F3_241"  "F4_241"
## [1793] "F7_241"  "F8_241"  "FC1_241" "FC2_241" "C3_241"  "C4_241"  "CP1_241"
## [1800] "CP2_241" "P7_241"  "P8_241"  "PO7_241" "PO8_241" "O1_241"  "O2_241"
## [1807] "Fz_241"  "FCz_241" "Cz_241"  "CPz_241" "Pz_241"  "Fp1_242" "F3_242"
## [1814] "F4_242"  "F7_242"  "F8_242"  "FC1_242" "FC2_242" "C3_242"  "C4_242"
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## [1821] "CP1_242" "CP2_242" "P7_242"  "P8_242"  "PO7_242" "PO8_242" "O1_242"
## [1828] "O2_242"  "Fz_242"  "FCz_242" "Cz_242"  "CPz_242" "Pz_242"  "Fp1_243"
## [1835] "F3_243"  "F4_243"  "F7_243"  "F8_243"  "FC1_243" "FC2_243" "C3_243"
## [1842] "C4_243"  "CP1_243" "CP2_243" "P7_243"  "P8_243"  "PO7_243" "PO8_243"
## [1849] "O1_243"  "O2_243"  "Fz_243"  "FCz_243" "Cz_243"  "CPz_243" "Pz_243"
## [1856] "Fp1_244" "F3_244"  "F4_244"  "F7_244"  "F8_244"  "FC1_244" "FC2_244"
## [1863] "C3_244"  "C4_244"  "CP1_244" "CP2_244" "P7_244"  "P8_244"  "PO7_244"
## [1870] "PO8_244" "O1_244"  "O2_244"  "Fz_244"  "FCz_244" "Cz_244"  "CPz_244"
## [1877] "Pz_244"  "Fp1_245" "F3_245"  "F4_245"  "F7_245"  "F8_245"  "FC1_245"
## [1884] "FC2_245" "C3_245"  "C4_245"  "CP1_245" "CP2_245" "P7_245"  "P8_245"
## [1891] "PO7_245" "PO8_245" "O1_245"  "O2_245"  "Fz_245"  "FCz_245" "Cz_245"
## [1898] "CPz_245" "Pz_245"  "Fp1_246" "F3_246"  "F4_246"  "F7_246"  "F8_246"
## [1905] "FC1_246" "FC2_246" "C3_246"  "C4_246"  "CP1_246" "CP2_246" "P7_246"
## [1912] "P8_246"  "PO7_246" "PO8_246" "O1_246"  "O2_246"  "Fz_246"  "FCz_246"
## [1919] "Cz_246"  "CPz_246" "Pz_246"  "F3_247"  "F4_247"  "F7_247"  "FC1_247"
## [1926] "FC2_247" "C4_247"  "CP1_247" "CP2_247" "P7_247"  "P8_247"  "PO7_247"
## [1933] "PO8_247" "O1_247"  "O2_247"  "Fz_247"  "FCz_247" "Cz_247"  "CPz_247"
## [1940] "Pz_247"  "F3_248"  "F4_248"  "F7_248"  "FC1_248" "FC2_248" "C4_248"
## [1947] "CP1_248" "CP2_248" "P7_248"  "P8_248"  "PO7_248" "PO8_248" "O1_248"
## [1954] "O2_248"  "Fz_248"  "FCz_248" "Cz_248"  "CPz_248" "Pz_248"  "F3_249"
## [1961] "F4_249"  "F7_249"  "FC1_249" "FC2_249" "C4_249"  "CP1_249" "CP2_249"
## [1968] "P7_249"  "P8_249"  "PO7_249" "PO8_249" "O1_249"  "O2_249"  "Fz_249"
## [1975] "FCz_249" "Cz_249"  "CPz_249" "Pz_249"  "F3_250"  "F4_250"  "F7_250"
## [1982] "FC1_250" "FC2_250" "CP1_250" "CP2_250" "P7_250"  "P8_250"  "PO7_250"
## [1989] "PO8_250" "O1_250"  "O2_250"  "Fz_250"  "FCz_250" "Cz_250"  "CPz_250"
## [1996] "Pz_250"  "F3_251"  "F4_251"  "F7_251"  "FC1_251" "FC2_251" "CP1_251"
## [2003] "CP2_251" "P7_251"  "P8_251"  "PO7_251" "PO8_251" "O1_251"  "O2_251"
## [2010] "Fz_251"  "FCz_251" "Cz_251"  "CPz_251" "Pz_251"  "F3_252"  "F4_252"
## [2017] "F7_252"  "FC1_252" "FC2_252" "CP1_252" "CP2_252" "P7_252"  "P8_252"
## [2024] "PO7_252" "PO8_252" "O1_252"  "O2_252"  "Fz_252"  "FCz_252" "Cz_252"
## [2031] "CPz_252" "Pz_252"  "F3_253"  "FC1_253" "FC2_253" "CP1_253" "CP2_253"
## [2038] "P7_253"  "P8_253"  "PO7_253" "PO8_253" "O2_253"  "Fz_253"  "FCz_253"
## [2045] "Cz_253"  "CPz_253" "Pz_253"  "F3_254"  "FC1_254" "FC2_254" "CP1_254"
## [2052] "CP2_254" "P7_254"  "P8_254"  "PO7_254" "PO8_254" "O2_254"  "Fz_254"
## [2059] "FCz_254" "Cz_254"  "CPz_254" "Pz_254"  "F3_255"  "FC1_255" "FC2_255"
## [2066] "CP1_255" "CP2_255" "P7_255"  "P8_255"  "PO7_255" "PO8_255" "O2_255"
## [2073] "Fz_255"  "FCz_255" "Cz_255"  "CPz_255" "Pz_255"  "FC1_256" "FC2_256"
## [2080] "CP1_256" "CP2_256" "P7_256"  "P8_256"  "PO7_256" "PO8_256" "O2_256"
## [2087] "Fz_256"  "FCz_256" "Cz_256"  "CPz_256" "Pz_256"  "FC1_257" "FC2_257"
## [2094] "CP1_257" "CP2_257" "P7_257"  "P8_257"  "PO7_257" "PO8_257" "O2_257"
## [2101] "Fz_257"  "FCz_257" "Cz_257"  "CPz_257" "Pz_257"  "FC1_258" "FC2_258"
## [2108] "CP1_258" "CP2_258" "P7_258"  "P8_258"  "PO7_258" "PO8_258" "O1_258"
## [2115] "O2_258"  "Fz_258"  "FCz_258" "Cz_258"  "CPz_258" "Pz_258"  "FC1_259"
## [2122] "FC2_259" "CP1_259" "CP2_259" "P7_259"  "P8_259"  "PO7_259" "PO8_259"
## [2129] "O1_259"  "O2_259"  "Fz_259"  "FCz_259" "Cz_259"  "CPz_259" "Pz_259"
## [2136] "FC1_260" "FC2_260" "CP1_260" "CP2_260" "P7_260"  "P8_260"  "PO7_260"
## [2143] "PO8_260" "O1_260"  "O2_260"  "Fz_260"  "FCz_260" "Cz_260"  "CPz_260"
## [2150] "Pz_260"  "FC1_261" "FC2_261" "CP1_261" "CP2_261" "P7_261"  "P8_261"
## [2157] "PO7_261" "PO8_261" "O1_261"  "Fz_261"  "FCz_261" "Cz_261"  "CPz_261"
## [2164] "Pz_261"  "FC1_262" "FC2_262" "CP1_262" "CP2_262" "P7_262"  "P8_262"
## [2171] "PO7_262" "PO8_262" "O1_262"  "Fz_262"  "FCz_262" "Cz_262"  "CPz_262"
## [2178] "Pz_262"  "FC1_263" "FC2_263" "CP1_263" "CP2_263" "P7_263"  "P8_263"
## [2185] "PO7_263" "PO8_263" "Fz_263"  "FCz_263" "Cz_263"  "CPz_263" "Pz_263"
## [2192] "FC1_264" "FC2_264" "CP1_264" "CP2_264" "P7_264"  "P8_264"  "PO7_264"
## [2199] "PO8_264" "Fz_264"  "FCz_264" "Cz_264"  "CPz_264" "Pz_264"  "FC1_265"
## [2206] "FC2_265" "CP1_265" "CP2_265" "P7_265"  "P8_265"  "PO7_265" "PO8_265"
## [2213] "Fz_265"  "FCz_265" "Cz_265"  "CPz_265" "Pz_265"  "FC2_266" "CP1_266"
## [2220] "CP2_266" "P7_266"  "P8_266"  "PO7_266" "PO8_266" "Fz_266"  "FCz_266"
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## [4390] "Pz_457"  "T8_458"  "CP1_458" "CP2_458" "P7_458"  "P8_458"  "P3_458"
## [4397] "P4_458"  "CPz_458" "Pz_458"  "T8_459"  "CP1_459" "CP2_459" "P7_459"
## [4404] "P8_459"  "P3_459"  "P4_459"  "CPz_459" "Pz_459"  "T8_460"  "CP1_460"
## [4411] "CP2_460" "P7_460"  "P8_460"  "P3_460"  "P4_460"  "CPz_460" "Pz_460"
## [4418] "CP1_461" "CP2_461" "P7_461"  "P8_461"  "P3_461"  "P4_461"  "CPz_461"
## [4425] "Pz_461"  "CP1_462" "CP2_462" "P7_462"  "P8_462"  "P3_462"  "P4_462"
## [4432] "CPz_462" "Pz_462"  "CP1_463" "CP2_463" "P7_463"  "P8_463"  "P3_463"
## [4439] "P4_463"  "Cz_463"  "CPz_463" "Pz_463"  "T7_464"  "CP1_464" "CP2_464"
## [4446] "P7_464"  "P8_464"  "P3_464"  "P4_464"  "Cz_464"  "CPz_464" "Pz_464"
## [4453] "T7_465"  "CP1_465" "CP2_465" "P7_465"  "P8_465"  "P3_465"  "P4_465"
## [4460] "Cz_465"  "CPz_465" "Pz_465"  "T7_466"  "CP1_466" "CP2_466" "P7_466"
## [4467] "P8_466"  "P3_466"  "P4_466"  "Cz_466"  "CPz_466" "Pz_466"  "T7_467"
## [4474] "T8_467"  "CP1_467" "CP2_467" "P7_467"  "P8_467"  "P3_467"  "P4_467"
## [4481] "Cz_467"  "CPz_467" "Pz_467"  "T7_468"  "T8_468"  "CP1_468" "CP2_468"
## [4488] "P7_468"  "P8_468"  "P3_468"  "P4_468"  "Cz_468"  "CPz_468" "Pz_468"
## [4495] "T8_469"  "CP1_469" "CP2_469" "P7_469"  "P8_469"  "P3_469"  "P4_469"
## [4502] "Cz_469"  "CPz_469" "Pz_469"  "T8_470"  "CP1_470" "CP2_470" "P7_470"
## [4509] "P8_470"  "P3_470"  "P4_470"  "Cz_470"  "CPz_470" "Pz_470"  "CP1_471"
## [4516] "CP2_471" "P7_471"  "P8_471"  "P3_471"  "P4_471"  "Cz_471"  "CPz_471"
## [4523] "Pz_471"  "CP1_472" "CP2_472" "P7_472"  "P8_472"  "P3_472"  "P4_472"
## [4530] "Cz_472"  "CPz_472" "Pz_472"  "CP1_473" "CP2_473" "P7_473"  "P8_473"
## [4537] "P3_473"  "P4_473"  "Cz_473"  "CPz_473" "Pz_473"  "CP1_474" "CP2_474"
## [4544] "P7_474"  "P8_474"  "P3_474"  "P4_474"  "Cz_474"  "CPz_474" "Pz_474"
## [4551] "CP1_475" "CP2_475" "P7_475"  "P8_475"  "P3_475"  "P4_475"  "Cz_475"
## [4558] "CPz_475" "Pz_475"  "CP1_476" "CP2_476" "P7_476"  "P8_476"  "P3_476"
## [4565] "P4_476"  "Cz_476"  "CPz_476" "Pz_476"  "T8_477"  "CP1_477" "CP2_477"
## [4572] "P7_477"  "P8_477"  "P3_477"  "P4_477"  "Cz_477"  "CPz_477" "Pz_477"
## [4579] "T8_478"  "CP1_478" "CP2_478" "P7_478"  "P8_478"  "P3_478"  "P4_478"
## [4586] "Cz_478"  "CPz_478" "Pz_478"  "T7_479"  "T8_479"  "CP1_479" "CP2_479"
## [4593] "P7_479"  "P8_479"  "P3_479"  "P4_479"  "Cz_479"  "CPz_479" "Pz_479"
## [4600] "T7_480"  "T8_480"  "CP1_480" "CP2_480" "P7_480"  "P8_480"  "P3_480"
## [4607] "P4_480"  "Cz_480"  "CPz_480" "Pz_480"  "T7_481"  "T8_481"  "CP1_481"
## [4614] "CP2_481" "P7_481"  "P8_481"  "P3_481"  "P4_481"  "Cz_481"  "CPz_481"
## [4621] "Pz_481"  "T7_482"  "T8_482"  "CP1_482" "CP2_482" "P7_482"  "P8_482"
## [4628] "P3_482"  "P4_482"  "Cz_482"  "CPz_482" "Pz_482"  "T7_483"  "T8_483"
## [4635] "CP1_483" "CP2_483" "P7_483"  "P8_483"  "P3_483"  "P4_483"  "CPz_483"
## [4642] "Pz_483"  "T7_484"  "T8_484"  "CP1_484" "CP2_484" "P7_484"  "P8_484"
## [4649] "P3_484"  "P4_484"  "CPz_484" "Pz_484"  "T7_485"  "CP1_485" "CP2_485"
## [4656] "P7_485"  "P8_485"  "P3_485"  "P4_485"  "CPz_485" "Pz_485"  "T7_486"
```
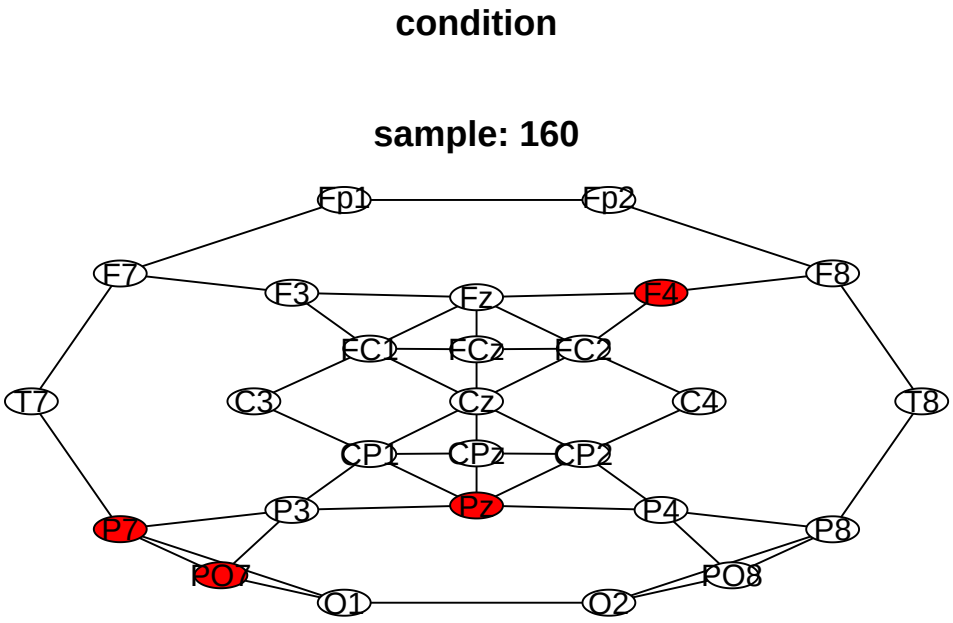

```
## [4663] "CP1_486" "CP2_486" "P7_486"  "P8_486"  "P3_486"  "P4_486"  "CPz_486"
## [4670] "Pz_486"  "T7_487"  "CP1_487" "CP2_487" "P7_487"  "P8_487"  "P3_487"
## [4677] "P4_487"  "CPz_487" "Pz_487"  "T7_488"  "CP1_488" "CP2_488" "P7_488"
## [4684] "P8_488"  "P3_488"  "P4_488"  "CPz_488" "Pz_488"  "T7_489"  "CP1_489"
## [4691] "CP2_489" "P7_489"  "P8_489"  "P3_489"  "P4_489"  "CPz_489" "Pz_489"
## [4698] "T7_490"  "CP1_490" "CP2_490" "P7_490"  "P8_490"  "P3_490"  "P4_490"
## [4705] "CPz_490" "Pz_490"  "T7_491"  "CP1_491" "CP2_491" "P7_491"  "P8_491"
## [4712] "P3_491"  "P4_491"  "CPz_491" "Pz_491"  "CP1_492" "CP2_492" "P7_492"
## [4719] "P8_492"  "P3_492"  "P4_492"  "CPz_492" "Pz_492"  "CP1_493" "CP2_493"
## [4726] "P7_493"  "P8_493"  "P3_493"  "P4_493"  "CPz_493" "Pz_493"  "CP1_494"
## [4733] "CP2_494" "P7_494"  "P8_494"  "P3_494"  "P4_494"  "CPz_494" "Pz_494"
## [4740] "CP1_495" "CP2_495" "P7_495"  "P8_495"  "P3_495"  "P4_495"  "CPz_495"
## [4747] "Pz_495"  "CP1_496" "CP2_496" "P7_496"  "P8_496"  "P3_496"  "P4_496"
## [4754] "CPz_496" "Pz_496"  "CP1_497" "CP2_497" "P7_497"  "P8_497"  "P3_497"
## [4761] "P4_497"  "CPz_497" "Pz_497"  "CP1_498" "CP2_498" "P7_498"  "P8_498"
## [4768] "P3_498"  "P4_498"  "CPz_498" "Pz_498"  "CP1_499" "CP2_499" "P7_499"
## [4775] "P8_499"  "P3_499"  "P4_499"  "CPz_499" "Pz_499"  "T7_500"  "CP1_500"
## [4782] "CP2_500" "P7_500"  "P8_500"  "P3_500"  "P4_500"  "CPz_500" "Pz_500"
```

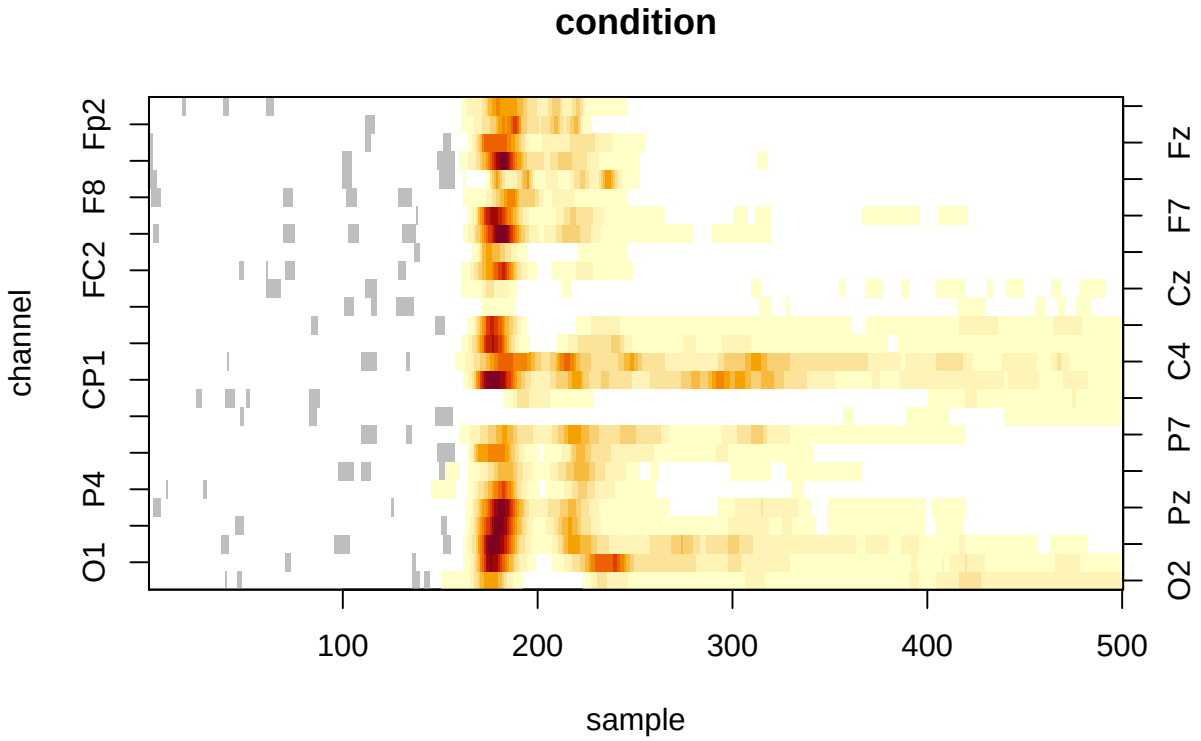
You can see the significant cluster (in red) at fixed time points (e.g. 160) using plot:

```
plot(model, samples = 160)
```



and the significant cluster over time and over channels using:

```
image(model)
```



where the significant clusters are represented in a colour-scale and the non-significant one in grey. The white pixels are tests which statistic are below the threshold.

ARI in EEG cluster mass

However, our significant cluster (11) says only that at least one combination channels/time-points is different from 0, we don't know how many combinations are significant (**spatial specificity paradox**). So, we can apply ARI to understand the lower bound of the number of true discovery proportion:

```
ARIeeg(model = model)
```

```
##        ID Total  clustermass pvalue False Null True Null Active Proportion
##  [1,]  1     8 4.824842e+01 0.9958          0         8         0.0000000
##  [2,]  2     8 5.655352e+01 0.9930          0         8         0.0000000
##  [3,]  3     4 2.161425e+01 0.9996          0         4         0.0000000
##  [4,]  4     1 4.595571e+00 1.0000          0         1         0.0000000
##  [5,]  5     2 9.160799e+00 1.0000          0         2         0.0000000
##  [6,]  6     3 1.727826e+01 1.0000          0         3         0.0000000
##  [7,]  7     2 9.953708e+00 1.0000          0         2         0.0000000
##  [8,]  8     4 2.247954e+01 0.9996          0         4         0.0000000
##  [9,]  9     4 1.841798e+01 0.9998          0         4         0.0000000
## [10,] 10     1 5.834359e+00 1.0000          0         1         0.0000000
## [11,] 11     5 3.514078e+01 0.9976          0         5         0.0000000
## [12,] 12     5 3.062193e+01 0.9990          0         5         0.0000000
## [13,] 13     3 1.562175e+01 1.0000          0         3         0.0000000
## [14,] 14     3 1.855438e+01 0.9998          0         3         0.0000000
## [15,] 15     2 1.046127e+01 1.0000          0         2         0.0000000
## [16,] 16     2 1.091898e+01 1.0000          0         2         0.0000000
## [17,] 17    13 9.673299e+01 0.9780          0        13         0.0000000
## [18,] 18    16 9.924648e+01 0.9772          0        16         0.0000000
## [19,] 19     3 1.701493e+01 1.0000          0         3         0.0000000
```

```
## [20,] 20     4 2.614448e+01 0.9994          0         4         0.0000000
## [21,] 21    10 7.604927e+01 0.9876          0        10         0.0000000
## [22,] 22    26 1.750308e+02 0.9316          0        26         0.0000000
## [23,] 23    17 1.039216e+02 0.9752          0        17         0.0000000
## [24,] 24    35 2.762222e+02 0.8660          0        35         0.0000000
## [25,] 25     3 1.367199e+01 1.0000          0         3         0.0000000
## [26,] 26     2 9.355923e+00 1.0000          0         2         0.0000000
## [27,] 27    27 1.703500e+02 0.9350          0        27         0.0000000
## [28,] 28     5 2.598810e+01 0.9994          0         5         0.0000000
## [29,] 29     6 3.007729e+01 0.9990          0         6         0.0000000
## [30,] 30     4 1.807287e+01 0.9998          0         4         0.0000000
## [31,] 31     3 1.823876e+01 0.9998          0         3         0.0000000
## [32,] 32  4788 1.041780e+05 0.0002        778      4010         0.1624896
## [33,] 33    54 4.224551e+02 0.7770          0        54         0.0000000
## [34,] 34     5 3.646500e+01 0.9974          0         5         0.0000000
## [35,] 35     2 9.661613e+00 1.0000          0         2         0.0000000
## [36,] 36     7 5.632912e+01 0.9930          0         7         0.0000000
## [37,] 37     6 3.530033e+01 0.9974          0         6         0.0000000
## [38,] 38     2 9.153198e+00 1.0000          0         2         0.0000000
## [39,] 39     5 2.908355e+01 0.9994          0         5         0.0000000
## [40,] 40     8 6.388484e+01 0.9904          0         8         0.0000000
## [41,] 41    14 8.033085e+01 0.9846          0        14         0.0000000
```

So, we have at least 15% truly active component in the cluster 32.

References

- Maris, E., & Oostenveld, R. (2007). Nonparametric statistical testing of EEG-and MEG-data. Journal of neuroscience methods, 164(1), 177-190.
- Kherad-Pajouh, S., & Renaud, O. (2015). A general permutation approach for analyzing repeated measures ANOVA and mixed-model designs. Statistical Papers, 56(4), 947-967.
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