Humpback Whales and Ship Noise

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05/07/2022

1 Data and Desciptive Statistics

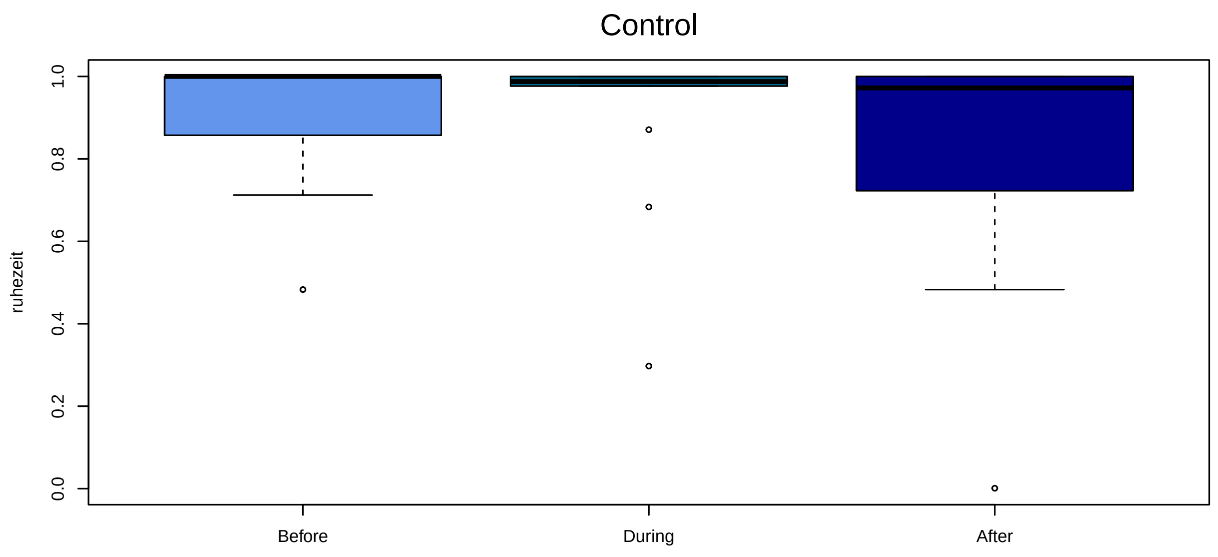
```
# import data (this dataset is unfortunatelly not public)
openxlsx::read.xlsx("./../Data/Humpback_Whales_Data.xlsx") -> dat_whale

# fist a quick look at the missing values in the data
sapply(dat_whale,  \(x) sum(is.na(x))) |> knitr::kable(col.names = "NAs")
```

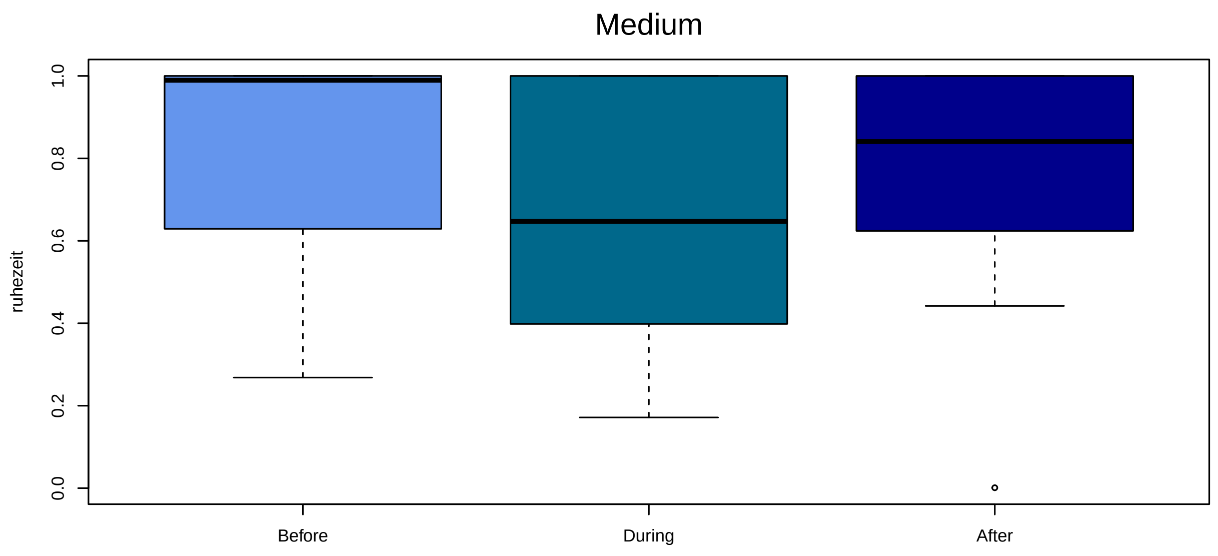
	NAs
Individuum	0
Treatment	0
Szenario	0
ruhezeit	0
speed	5
Atem	0

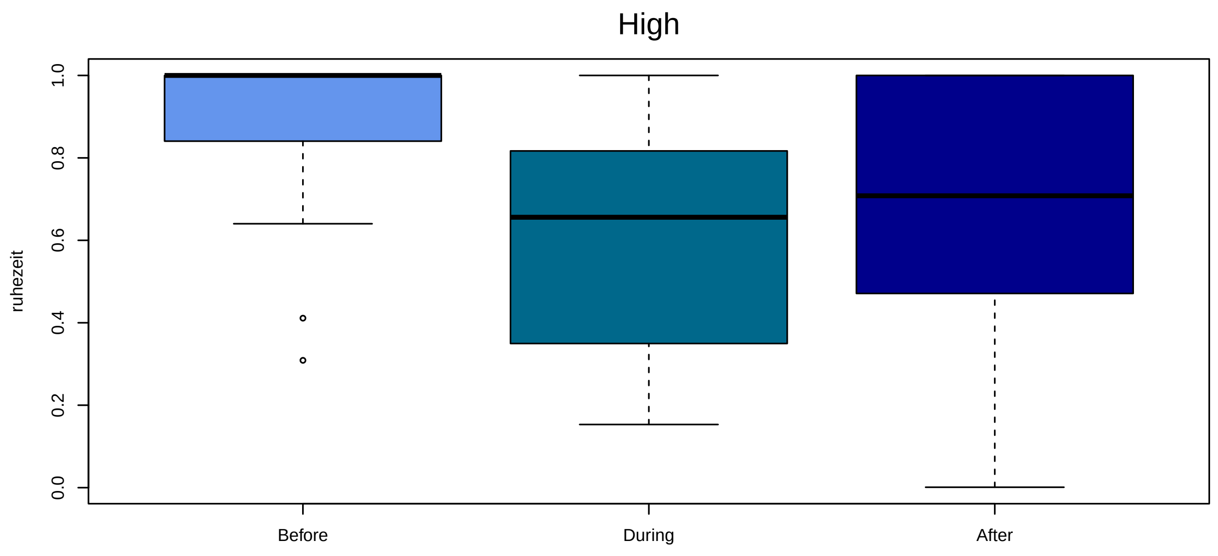
```
# harmonize names
colnames(dat_whale) <- tolower(colnames(dat_whale))

# to numeric
lapply(dat_whale[, c("ruhezeit", "speed", "atem")], as.numeric) -> dat_whale[, c("ruhezeit", "speed", "a

# to factor
lapply(dat_whale[ ,!(colnames(dat_whale) %in%  c("ruhezeit", "speed", "atem"))],
       as.factor) -> dat_whale[ ,!(colnames(dat_whale) %in%  c("ruhezeit", "speed", "atem"))]

# relevel
factor(dat_whale[, "szenario"],
       levels = c("Before", "During", "After")) -> dat_whale[, "szenario"]
factor(dat_whale[, "treatment"], c("Control", "Medium", "High")) -> dat_whale[, "treatment"]

# add log
within(dat_whale,{
   logspeed <- log(speed)
   atem[atem == 0] <- 0.001
   ruhezeit[ruhezeit == 0] <- 0.001
   logatem <- log(atem)
   logruhezeit <- log(ruhezeit)
   sqrtatem <- sqrt(atem)
   sqrtspeed <- sqrt(speed)
   sqrtruhezeit <- sqrt(ruhezeit * 100)
}) -> dat_whale


# frist split into different intensities
dat_whale_intens <- split(dat_whale, dat_whale[, "treatment"])
```

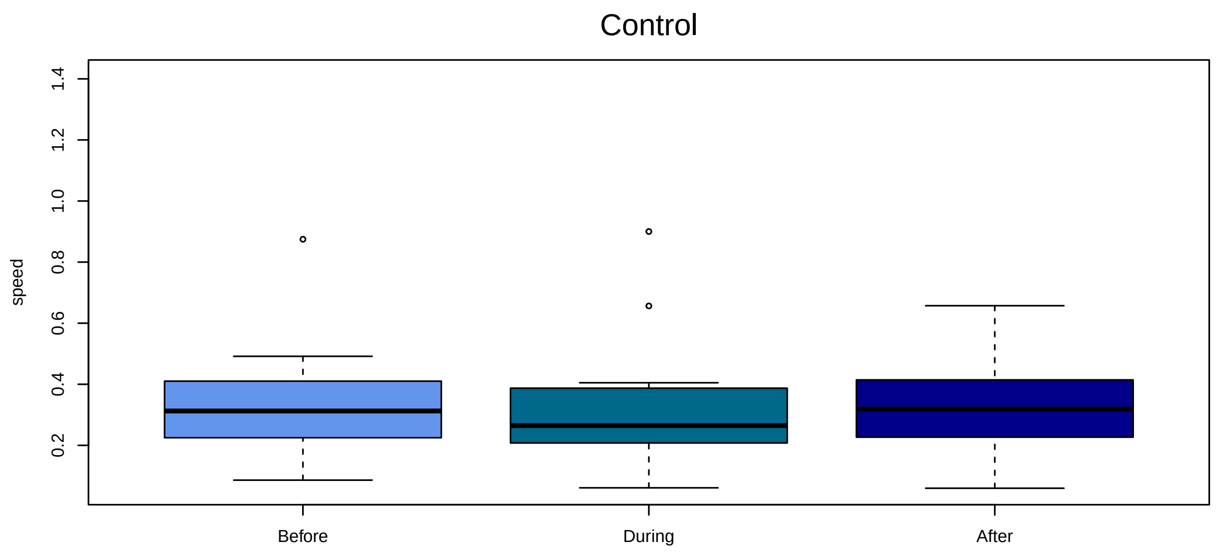
```
# build formulas
formulae <- paste(c("ruhezeit", "speed", "atem"), "~", "szenario")

# max and min for plot y-axis
sapply(c(min, max), \(x){
```

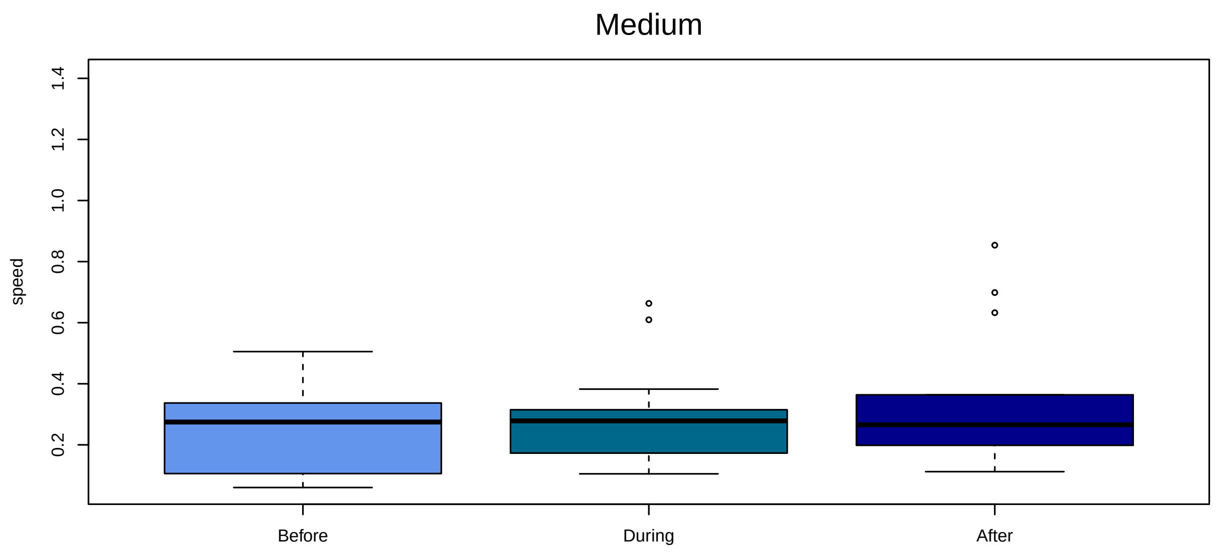
```r
   sapply(dat_whale[, c("ruhezeit", "speed", "atem")], \(y) x(y, na.rm = TRUE))


}) -> ylims

# over szenarios
invis.Map(\(y, nom, lims){

   # safe for presentation
   # pdf(paste0("./../Presentation/", nom, ".pdf"))

   # align
   par(mfrow = c(3, 1), mar = c(2, 4, 4, 2) + 0.1)

   # over treatment
   invis.Map(\(x, nom){

      # boxplots
      boxplot(as.formula(y), data = x,
              col = c("cornflowerblue", "deepskyblue4", "darkblue"),
              ylim = c(lims[1], lims[2]))

      # add label
      mtext(nom, side = 3, line = 1, cex = 1.2)

   }, dat_whale_intens, names(dat_whale_intens))

   # close graph. device
   # dev.off()

}, formulae, c("resting", "speed", "respatory"), ylims |> t() |> as.data.frame())
```

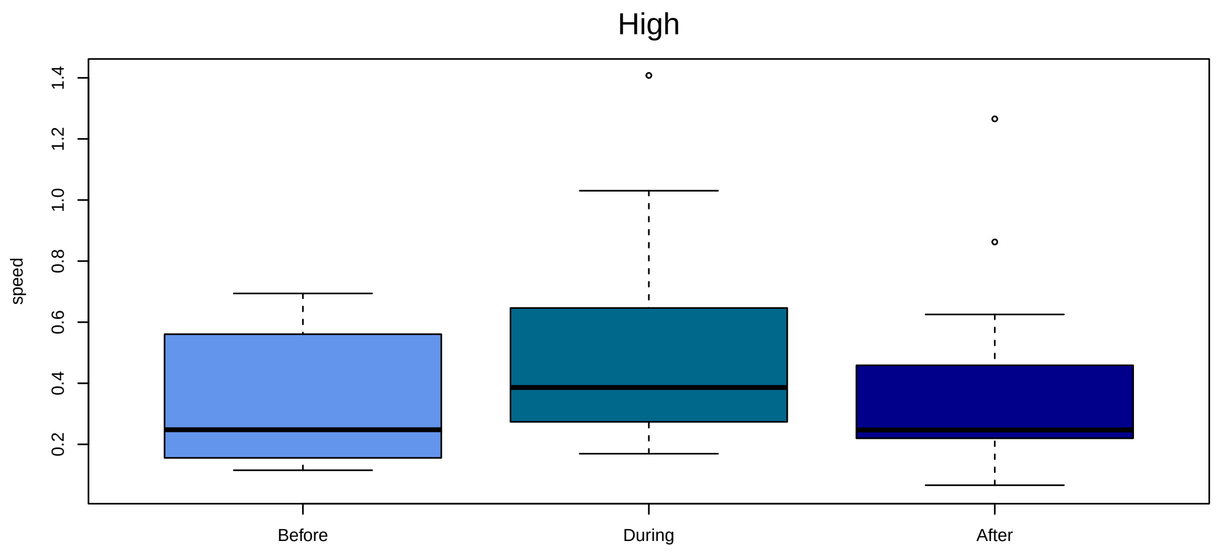

Control
ruhezeit
0.0
0.2
0.4
0.6
0.8
1.0
Before
During
After

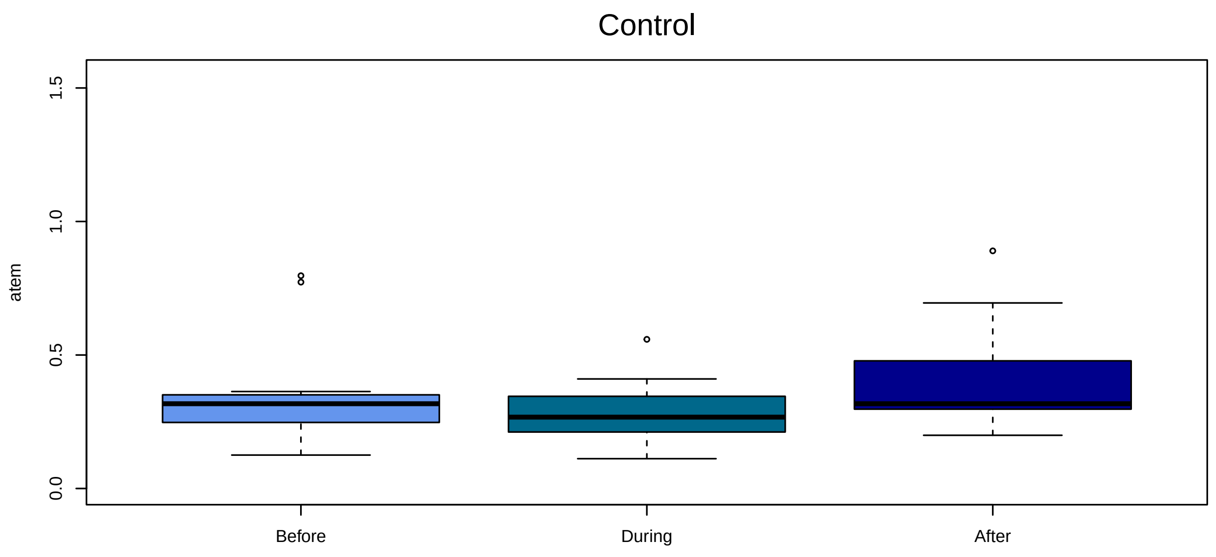

Medium
ruhezeit
0.0
0.2
0.4
0.6
0.8
1.0
Before
During
After

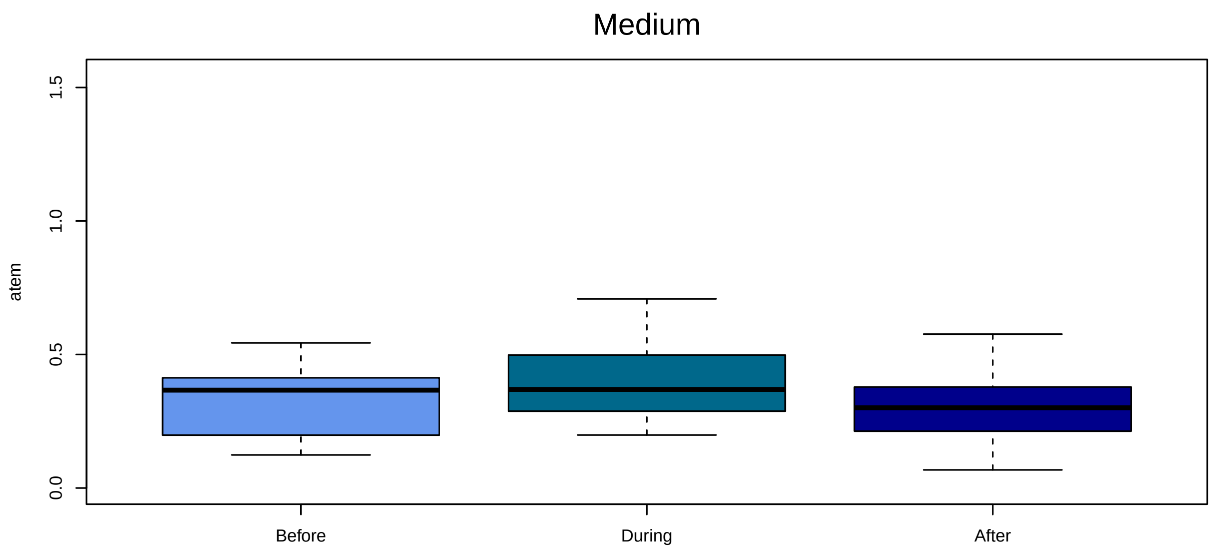

High
ruhezeit
0.0
0.2
0.4
0.6
0.8
1.0
Before
During
After

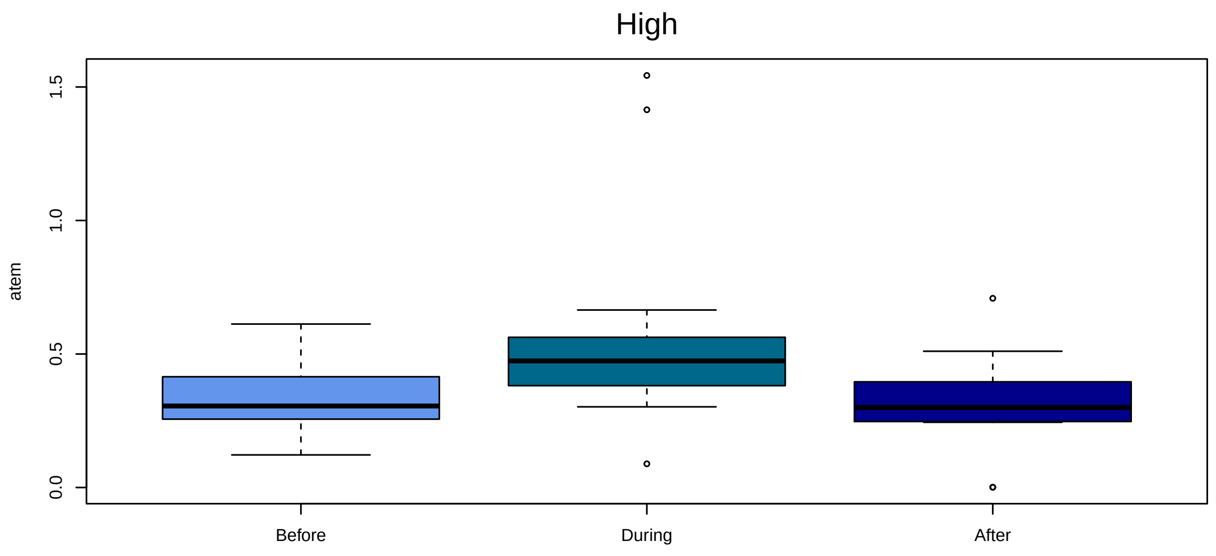

Control
speed
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Before
During
After


Medium
speed
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Before
During
After


High
speed
1.4
1.2
1.0
0.8
0.6
0.4
0.2
Before
During
After

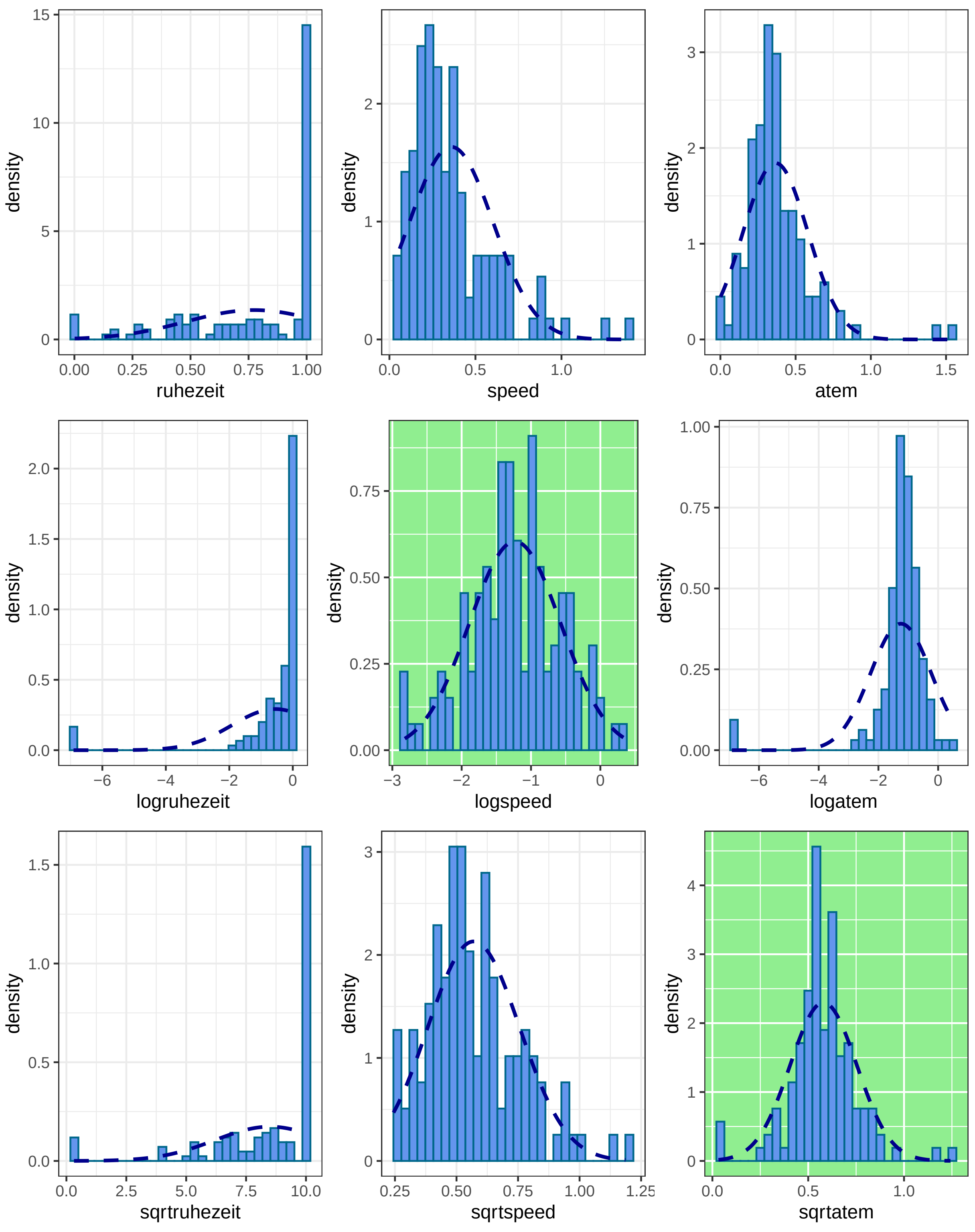

Control
atem
0.0
0.5
1.0
1.5
Before
During
After


Medium
atem
0.0
0.5
1.0
1.5
Before
During
After


High
atem
0.0
0.5
1.0
1.5
Before
During
After

2 Distribution of Covariates

```r
# vars
nom <- c("ruhezeit", "speed", "atem")
nom <- c(nom, paste0("log", nom), paste0("sqrt", nom))

# loop to generate plots
Map(\(x, bool) Dens_norm_plot(y = x, bg_alt = bool),
    nom, c(F, F, F, F, T, F, F ,F ,T)) -> plots

# display (remove useless bin width messages)
print((plots[[1]] + plots[[2]] + plots[[3]]) /
      (plots[[4]] + plots[[5]] + plots[[6]]) /
      (plots[[7]] + plots[[8]] + plots[[9]])) |>
      suppressWarnings() |>
      suppressMessages()
```



density
ruhezeit
speed
atem
logruhezeit
logspeed
logatem
sqrtruhezeit
sqrtspeed
sqrtatem

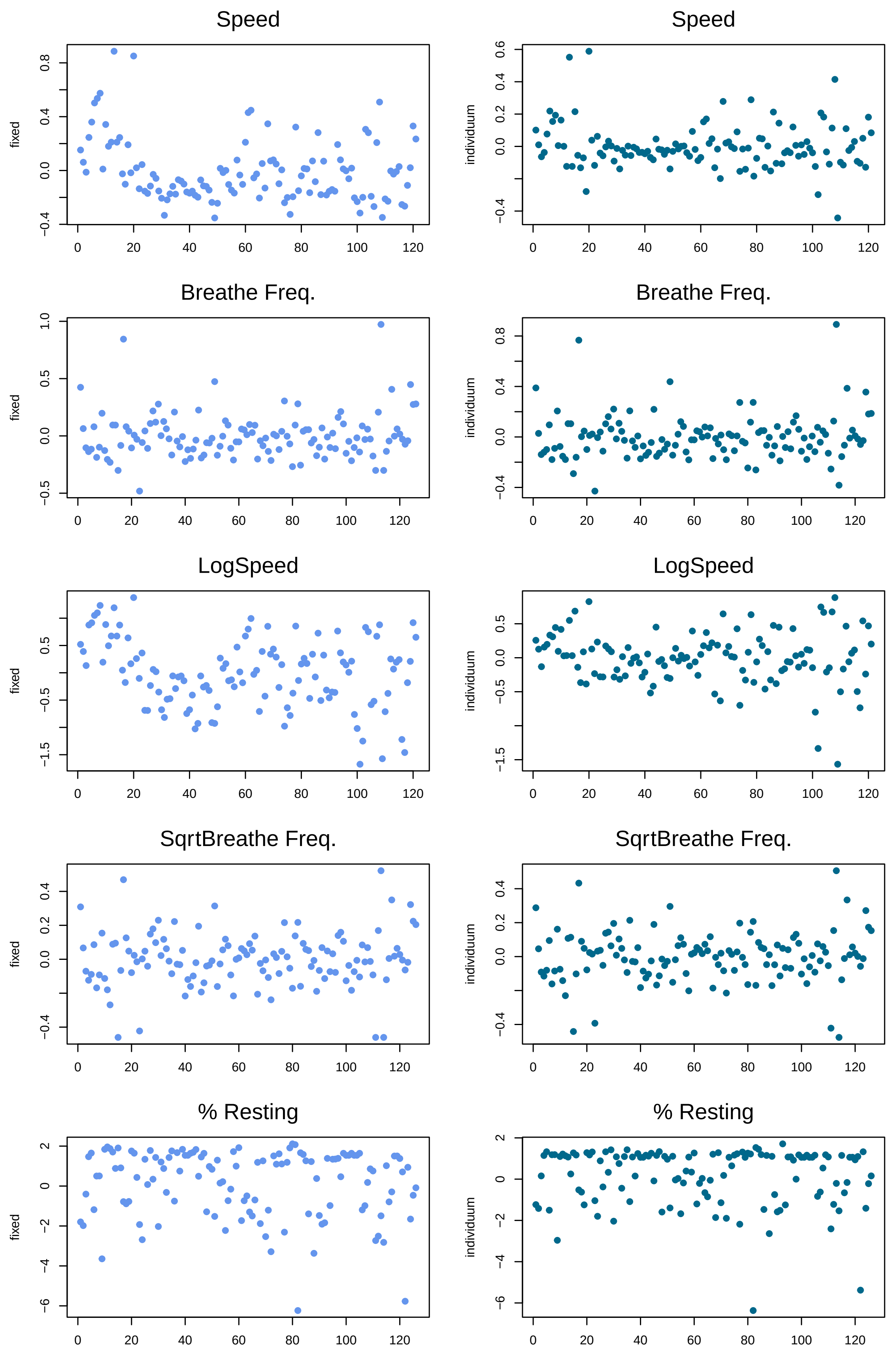
3 Model

```r
# formulas
formulae_lmm <- c("speed ~ I(treatment) * I(szenario)",
                  "atem ~ I(treatment) * I(szenario)",
                  "logspeed ~ I(treatment) * I(szenario)",
                  "sqrtatem ~ I(treatment) * I(szenario)")

formulae_glmm <- "ruhezeit ~ I(treatment) * I(szenario)"

# comb
formulae_cmb <- list(formulae_lmm, formulae_glmm)

# fit models
Map(\(type, bool){

   lapply(type, \(x){

      if(bool){ # LMMs

         # fit LMM
         nlme::lme(as.formula(x), random = ~ 1 | individuum,
                   data = dat_whale, na.action = na.omit,
                   method = "REML") -> fit

         # summary
         list(fit,
              summary(fit))

      } else { # GLMMs

         # fit glmm PQL
         MASS::glmmPQL(as.formula(x), random = ~ 1 | individuum,
                       family = binomial(link = "logit"),
                       data = dat_whale) -> fit

         # summary
         list(fit,
              summary(fit))
      }

   }) |> setNames(type)

}, formulae_cmb, c(TRUE, FALSE)) |> setNames(c("LMM", "GLMM")) |>
   suppressMessages() |> suppressWarnings() -> models

# fits and summaries
LMM_fits <- lapply(models[[1]], "[[", 1)
LMM_summaries <- lapply(models[[1]], "[[", 2)
glmmPQL_fits <- lapply(models[[2]], "[[", 1)
glmmPQL_summaries <- lapply(models[[2]], "[[", 2)

# rebind fits for plotting
fits <- c(LMM_fits, glmmPQL_fits)
```

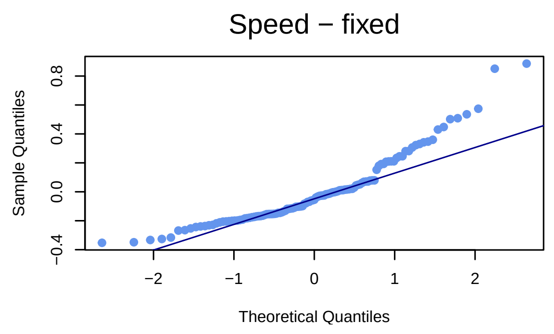
```r
summaries <- c(LMM_summaries, glmmPQL_summaries)
```

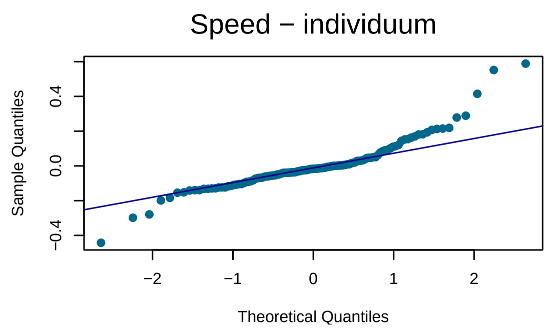
4 Residual Diagnostics

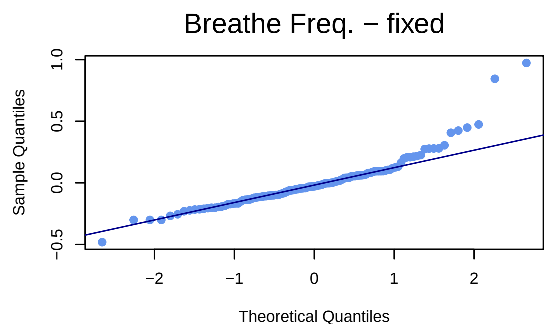
```r
# align
par(mfrow = c(5, 2), mar = c(2, 4, 4, 2) + 0.1)

# residual plots
invis.Map(\(x, nom){

   invis.Map(\(y, col){

      # plots
      plot(x[["residuals"]][, y], type = "p", ylab = y, xlab = "", pch = 19,
           col = col)

      # label
      mtext(nom, side = 3, line = 1, cex = 1.2)

   }, c("fixed", "individuum"), c("cornflowerblue", "deepskyblue4"))

}, fits, c("Speed", "Breathe Freq.", "LogSpeed", "SqrtBreathe Freq.", "% Resting"))
```

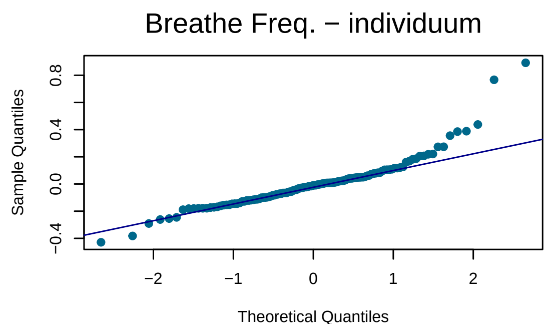

Speed
fixed
Speed
individuum
Breathe Freq.
fixed
Breathe Freq.
individuum
LogSpeed
fixed
LogSpeed
individuum
SqrtBreathe Freq.
fixed
SqrtBreathe Freq.
individuum
% Resting
fixed
% Resting
individuum

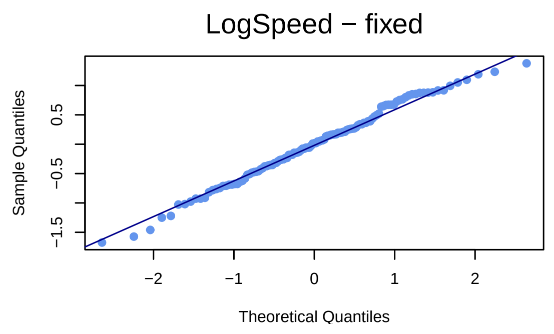
```r
# qqplots
par(mfrow = c(5, 2), mar = c(3.8, 4, 4, 2) + 0.1)

# residual plots
invis.Map(\(x, nom){

   invis.Map(\(y, col){

      # plots
      qqnorm(x[["residuals"]][, y], pch = 19, col = col, main = "")

      # line
      qqline(x[["residuals"]][, y], col = "darkblue")

      # label
      mtext(paste(nom, "-", y), side = 3, line = 1, cex = 1.2)

   }, c("fixed", "individuum"), c("cornflowerblue", "deepskyblue4"))

}, fits, c("Speed", "Breathe Freq.", "LogSpeed", "SqrtBreathe Freq.", "% Resting"))
```

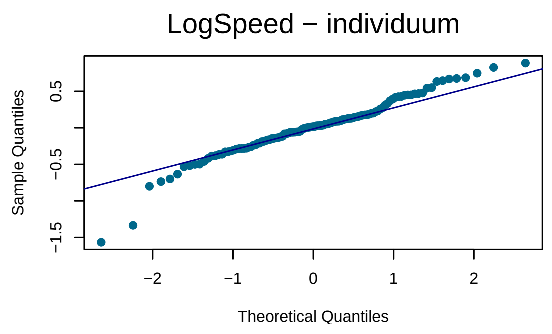

Speed − fixed
Sample Quantiles
−0.4
0.0
0.4
0.8
−2
−1
0
1
2
Theoretical Quantiles

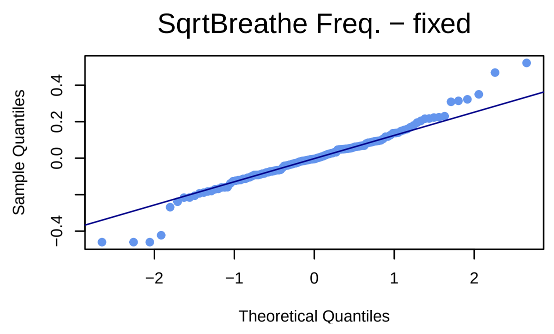

Speed − individuum
Sample Quantiles
−0.4
0.0
0.4
−2
−1
0
1
2
Theoretical Quantiles

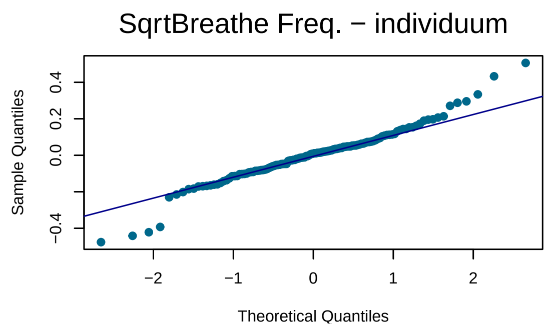

Breathe Freq. − fixed
Sample Quantiles
−0.5
0.0
0.5
1.0
−2
−1
0
1
2
Theoretical Quantiles

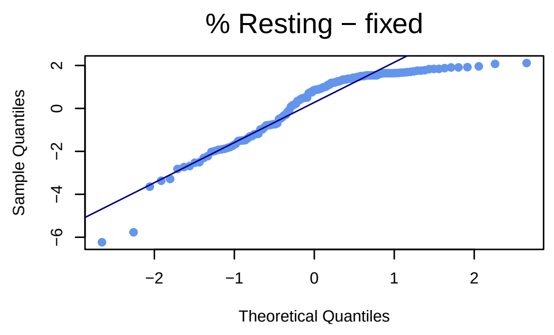

Breathe Freq. − individuum
Sample Quantiles
−0.4
0.0
0.4
0.8
−2
−1
0
1
2
Theoretical Quantiles

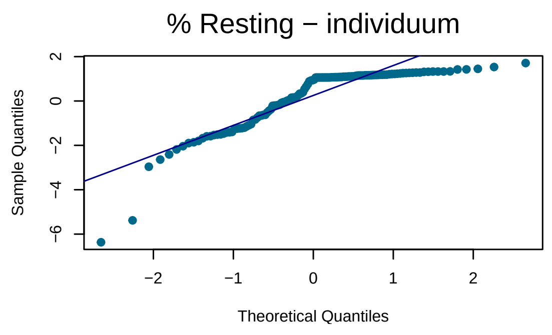

LogSpeed − fixed
Sample Quantiles
−1.5
−0.5
0.5
−2
−1
0
1
2
Theoretical Quantiles


LogSpeed − individuum
Sample Quantiles
−1.5
−0.5
0.5
−2
−1
0
1
2
Theoretical Quantiles


SqrtBreathe Freq. − fixed
Sample Quantiles
−0.4
0.0
0.2
0.4
−2
−1
0
1
2
Theoretical Quantiles


SqrtBreathe Freq. − individuum
Sample Quantiles
−0.4
0.0
0.2
0.4
−2
−1
0
1
2
Theoretical Quantiles


% Resting − fixed
Sample Quantiles
−6
−4
−2
0
2
−2
−1
0
1
2
Theoretical Quantiles


% Resting − individuum
Sample Quantiles
−6
−4
−2
0
2
−2
−1
0
1
2
Theoretical Quantiles

5 Coefficients and t-Tests

```r
invis.lapply(names(summaries), \(x){

  # mods
  mod <- summaries[[x]][["tTable"]]

  # print table
  knitr::kable(mod)

}) |> setNames(names(summaries))
```

```
## $`speed ~ I(treatment) * I(szenario)`
##
##
## |                                     |      Value| Std.Error| DF|    t-value|   p-value|
## |:------------------------------------|----------:|---------:|--:|----------:|---------:|
## |(Intercept)                          |  0.3392015| 0.0675357| 73|  5.0225532| 0.0000035|
## |I(treatment)Medium                   | -0.0796659| 0.0950416| 39| -0.8382218| 0.4070142|
## |I(treatment)High                     |  0.0128286| 0.0922713| 39|  0.1390310| 0.8901411|
## |I(szenario)During                    | -0.0132775| 0.0659405| 73| -0.2013561| 0.8409802|
## |I(szenario)After                     |  0.0365231| 0.0677611| 73|  0.5389981| 0.5915282|
## |I(treatment)Medium:I(szenario)During |  0.0571340| 0.0932540| 73|  0.6126709| 0.5419979|
## |I(treatment)High:I(szenario)During   |  0.1831087| 0.0900919| 73|  2.0324658| 0.0457448|
## |I(treatment)Medium:I(szenario)After  |  0.0556807| 0.0941578| 73|  0.5913548| 0.5561095|
## |I(treatment)High:I(szenario)After    |  0.0262800| 0.0935384| 73|  0.2809546| 0.7795400|
##
## $`atem ~ I(treatment) * I(szenario)`
##
##
## |                                     |      Value| Std.Error| DF|    t-value|   p-value|
## |:------------------------------------|----------:|---------:|--:|----------:|---------:|
## |(Intercept)                          |  0.3487213| 0.0568680| 78|  6.1321165| 0.0000000|
## |I(treatment)Medium                   | -0.0228728| 0.0789743| 39| -0.2896229| 0.7736389|
## |I(treatment)High                     | -0.0161951| 0.0776965| 39| -0.2084406| 0.8359698|
## |I(szenario)During                    | -0.0644547| 0.0757239| 78| -0.8511814| 0.3972742|
## |I(szenario)After                     |  0.0673726| 0.0757239| 78|  0.8897145| 0.3763551|
## |I(treatment)Medium:I(szenario)During |  0.1421530| 0.1051600| 78|  1.3517785| 0.1803532|
## |I(treatment)High:I(szenario)During   |  0.3022035| 0.1034585| 78|  2.9210116| 0.0045609|
## |I(treatment)Medium:I(szenario)After  | -0.0945670| 0.1051600| 78| -0.8992675| 0.3712780|
## |I(treatment)High:I(szenario)After    | -0.0978333| 0.1034585| 78| -0.9456288| 0.3472582|
##
## $`logspeed ~ I(treatment) * I(szenario)`
##
##
## |                                     |      Value| Std.Error| DF|    t-value|   p-value|
## |:------------------------------------|----------:|---------:|--:|----------:|---------:|
## |(Intercept)                          | -1.2308608| 0.1828628| 73| -6.7310605| 0.0000000|
## |I(treatment)Medium                   | -0.3267841| 0.2573970| 39| -1.2695723| 0.2117607|
## |I(treatment)High                     | -0.0179156| 0.2498382| 39| -0.0717087| 0.9432002|
## |I(szenario)During                    | -0.1078457| 0.1807837| 73| -0.5965456| 0.5526563|
## |I(szenario)After                     |  0.0853729| 0.1857559| 73|  0.4595971| 0.6471713|
## |I(treatment)Medium:I(szenario)During |  0.3393236| 0.2556667| 73|  1.3272106| 0.1885751|
## |I(treatment)High:I(szenario)During   |  0.5076296| 0.2469975| 73|  2.0552010| 0.0434380|
## |I(treatment)Medium:I(szenario)After  |  0.2628398| 0.2581038| 73|  1.0183495| 0.3118751|
## |I(treatment)High:I(szenario)After    |  0.0214941| 0.2564104| 73|  0.0838269| 0.9334235|
##
## $`sqrtatem ~ I(treatment) * I(szenario)`
##
##
## |                                      |      Value| Std.Error| DF|    t-value|   p-value|
## |:-------------------------------------|----------:|---------:|--:|----------:|---------:|
## |(Intercept)                           |  0.5703680| 0.0458895| 78| 12.4291561| 0.0000000|
## |I(treatment)Medium                    | -0.0123334| 0.0637282| 39| -0.1935318| 0.8475469|
## |I(treatment)High                      | -0.0050724| 0.0626970| 39| -0.0809038| 0.9359322|
## |I(szenario)During                     | -0.0472330| 0.0622771| 78| -0.7584316| 0.4504783|
## |I(szenario)After                      |  0.0589025| 0.0622771| 78|  0.9458125| 0.3471650|
## |I(treatment)Medium:I(szenario)During |  0.1147202| 0.0864861| 78|  1.3264577| 0.1885589|
## |I(treatment)High:I(szenario)During   |  0.2023393| 0.0850868| 78|  2.3780343| 0.0198531|
## |I(treatment)Medium:I(szenario)After  | -0.0878070| 0.0864861| 78| -1.0152724| 0.3131150|
## |I(treatment)High:I(szenario)After    | -0.1322060| 0.0850868| 78| -1.5537787| 0.1242856|
##
## $`ruhezeit ~ I(treatment) * I(szenario)`
##
##
## |                                      |      Value| Std.Error| DF|    t-value|   p-value|
## |:-------------------------------------|----------:|---------:|--:|----------:|---------:|
## |(Intercept)                           |  2.3808540| 0.6231463| 78|  3.8206985| 0.0002658|
## |I(treatment)Medium                    | -0.7865013| 0.7862894| 39| -1.0002696| 0.3233462|
## |I(treatment)High                      | -0.3502397| 0.8093376| 39| -0.4327486| 0.6675812|
## |I(szenario)During                     | -0.0267061| 0.8095529| 78| -0.0329887| 0.9737679|
## |I(szenario)After                      | -1.0226216| 0.7058604| 78| -1.4487589| 0.1514133|
## |I(treatment)Medium:I(szenario)During | -0.7751521| 0.9789670| 78| -0.7918062| 0.4308751|
## |I(treatment)High:I(szenario)During   | -1.5056474| 0.9912816| 78| -1.5188896| 0.1328334|
## |I(treatment)Medium:I(szenario)After  |  0.7143004| 0.9101265| 78|  0.7848364| 0.4349268|
## |I(treatment)High:I(szenario)After    | -0.3409966| 0.9105983| 78| -0.3744753| 0.7090669|
```