Linear Mixed-Effects Models for Temporal Properties

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# Load packages  
library(emmeans)  
library(nlme)  
library(effectsize)  
library(dabestr)

# Turn off scientific notation  
options(scipen = 999)

# Microstate 5/F GEV

# Read data  
data <- read.csv("lmem\_full\_temp\_prop\_data.csv")  
data <- data[data$microstate == 'F', ]  
  
data$simple\_id <- as.factor(data$simple\_id)  
  
data$time <- ifelse(data$time == 1, "1one",  
 ifelse(data$time == 2, "2two",  
 ifelse(data$time == 3, "3three",  
 ifelse(data$time == 4, "4four",  
 ifelse(data$time == 5, "5five", "other")))))  
  
data$time <- as.factor(data$time)  
contrasts(data$time) <- contr.sum  
contrasts(data$time)

## [,1] [,2] [,3] [,4]  
## 1one 1 0 0 0  
## 2two 0 1 0 0  
## 3three 0 0 1 0  
## 4four 0 0 0 1  
## 5five -1 -1 -1 -1

# Outliers (this is a simple univariate measure)  
# Outlier = above Q3 + 1.5xIQR or below Q1 - 1.5xIQR  
# Extreme outlier = above Q3 + 3xIQR or below Q1 - 3xIQR   
# Only exclude extreme outliers  
outliers <- data %>%  
 group\_by(time) %>%  
 identify\_outliers(gev)  
outliers

## # A tibble: 15 × 9  
## time simple\_id microstate gev duration coverage occurrence is.outlier is.extreme  
## <fct> <fct> <chr> <dbl> <dbl> <dbl> <dbl> <lgl> <lgl>   
## 1 1one 408 F 0.141 92.2 24.3 2.31 TRUE FALSE   
## 2 2two 408 F 0.160 91.8 25.9 2.42 TRUE FALSE   
## 3 3three 280 F 0.0442 81.2 12.8 1.38 TRUE FALSE   
## 4 3three 315 F 0.0383 73.8 10.5 1.28 TRUE FALSE   
## 5 3three 389 F 0.0368 79.2 10.1 1.13 TRUE FALSE   
## 6 3three 408 F 0.136 89.3 24.7 2.38 TRUE FALSE   
## 7 4four 280 F 0.0291 75.4 10.1 1.17 TRUE FALSE   
## 8 4four 315 F 0.0400 73.2 10.4 1.28 TRUE FALSE   
## 9 4four 389 F 0.0331 78.0 9.14 1.06 TRUE FALSE   
## 10 4four 390 F 0.0447 73.0 11.5 1.41 TRUE FALSE   
## 11 4four 408 F 0.134 89.7 24.0 2.29 TRUE TRUE   
## 12 5five 280 F 0.0357 79.0 11.1 1.24 TRUE FALSE   
## 13 5five 315 F 0.0458 76.6 11.5 1.35 TRUE FALSE   
## 14 5five 389 F 0.0417 78.1 10.7 1.22 TRUE FALSE   
## 15 5five 408 F 0.146 91.5 25.1 2.34 TRUE TRUE

# TWO EXTREME VALUES  
  
# Remove Extreme Observations  
data <- data %>%  
 filter(!(simple\_id == 408))

# Correlations  
data\_one <- data %>% filter(time == "1one")  
data\_two <- data %>% filter(time == "2two")  
data\_three <- data %>% filter(time == "3three")  
data\_four <- data %>% filter(time == "4four")  
data\_five <- data %>% filter(time == "5five")  
  
cor(data\_one$gev, data\_two$gev)

## [1] 0.8224504

cor(data\_one$gev, data\_three$gev)

## [1] 0.7389887

cor(data\_one$gev, data\_four$gev)

## [1] 0.6470245

cor(data\_one$gev, data\_five$gev)

## [1] 0.6039995

cor(data\_two$gev, data\_three$gev)

## [1] 0.9378903

cor(data\_two$gev, data\_four$gev)

## [1] 0.8308322

cor(data\_two$gev, data\_five$gev)

## [1] 0.7961884

cor(data\_three$gev, data\_four$gev)

## [1] 0.9266806

cor(data\_three$gev, data\_five$gev)

## [1] 0.9100787

cor(data\_four$gev, data\_five$gev)

## [1] 0.9790473

# Model  
m5\_gev\_model <- lme(gev ~ time, random = ~1|simple\_id,   
 correlation = corAR1(form = ~1|simple\_id), data = data)  
anova(m5\_gev\_model)

## numDF denDF F-value p-value  
## (Intercept) 1 184 1159.0384 <.0001  
## time 4 184 22.0864 <.0001

effectsize::eta\_squared(m5\_gev\_model, partial = TRUE)

## # Effect Size for ANOVA  
##   
## Parameter | Eta2 (partial) | 95% CI  
## -----------------------------------------  
## time | 0.32 | [0.23, 1.00]  
##   
## - One-sided CIs: upper bound fixed at [1.00].

emmeans(m5\_gev\_model, list(pairwise ~ time), adjust = "scheffe")

## Warning: contrasts dropped from factor time

## $`emmeans of time`  
## time emmean SE df lower.CL upper.CL  
## 1one 0.0841 0.00257 46 0.0789 0.0893  
## 2two 0.0845 0.00257 46 0.0793 0.0897  
## 3three 0.0781 0.00257 46 0.0729 0.0833  
## 4four 0.0719 0.00257 46 0.0667 0.0770  
## 5five 0.0769 0.00257 46 0.0717 0.0820  
##   
## Degrees-of-freedom method: containment   
## Confidence level used: 0.95   
##   
## $`pairwise differences of time`  
## 1 estimate SE df t.ratio p.value  
## 1one - 2two -0.000407 0.00108 184 -0.377 0.9976  
## 1one - 3three 0.005989 0.00149 184 4.008 0.0038  
## 1one - 4four 0.012218 0.00179 184 6.827 <.0001  
## 1one - 5five 0.007218 0.00202 184 3.570 0.0147  
## 2two - 3three 0.006396 0.00108 184 5.918 <.0001  
## 2two - 4four 0.012625 0.00149 184 8.449 <.0001  
## 2two - 5five 0.007625 0.00179 184 4.261 0.0016  
## 3three - 4four 0.006229 0.00108 184 5.763 <.0001  
## 3three - 5five 0.001229 0.00149 184 0.823 0.9539  
## 4four - 5five -0.005000 0.00108 184 -4.626 0.0004  
##   
## Degrees-of-freedom method: containment   
## P value adjustment: scheffe method with rank 4

# Estimation statistics-based effect sizes and confidence intervals  
paired\_mean\_diff <- dabest(data, time, gev,  
 idx = list(c("2two", "1one"),  
 c("3three", "1one"),  
 c("4four", "1one"),  
 c("5five", "1one"),  
 c("3three", "2two"),  
 c("4four", "2two"),  
 c("5five", "2two"),  
 c("4four", "3three"),  
 c("5five", "3three"),  
 c("5five", "4four")),  
 paired = TRUE, id.col = simple\_id) %>%   
 mean\_diff()  
paired\_mean\_diff

## dabestr (Data Analysis with Bootstrap Estimation in R) v0.3.0  
## =============================================================  
##   
## Good evening!  
## The current time is 23:43 PM on Sunday January 21, 2024.  
##   
## Dataset : data  
## X Variable : time  
## Y Variable : gev  
##   
## Paired mean difference of 1one (n = 47) minus 2two (n = 47)  
## -0.000407 [95CI -0.00807; 0.00716]  
##   
## Paired mean difference of 1one (n = 47) minus 3three (n = 47)  
## 0.00599 [95CI -0.00112; 0.0133]  
##   
## Paired mean difference of 1one (n = 47) minus 4four (n = 47)  
## 0.0122 [95CI 0.00508; 0.0193]  
##   
## Paired mean difference of 1one (n = 47) minus 5five (n = 47)  
## 0.00722 [95CI 0.000113; 0.0144]  
##   
## Paired mean difference of 2two (n = 47) minus 3three (n = 47)  
## 0.0064 [95CI -0.000399; 0.0134]  
##   
## Paired mean difference of 2two (n = 47) minus 4four (n = 47)  
## 0.0126 [95CI 0.00582; 0.0196]  
##   
## Paired mean difference of 2two (n = 47) minus 5five (n = 47)  
## 0.00763 [95CI 0.000793; 0.0145]  
##   
## Paired mean difference of 3three (n = 47) minus 4four (n = 47)  
## 0.00623 [95CI -0.000126; 0.0127]  
##   
## Paired mean difference of 3three (n = 47) minus 5five (n = 47)  
## 0.00123 [95CI -0.00515; 0.00767]  
##   
## Paired mean difference of 4four (n = 47) minus 5five (n = 47)  
## -0.005 [95CI -0.0114; 0.00136]  
##   
##   
## 5000 bootstrap resamples.  
## All confidence intervals are bias-corrected and accelerated.

# Microstate 2/B Duration

# Read data  
data <- read.csv("lmem\_full\_temp\_prop\_data.csv")  
data <- data[data$microstate == 'B', ]  
  
data$simple\_id <- as.factor(data$simple\_id)  
  
data$time <- ifelse(data$time == 1, "1one",  
 ifelse(data$time == 2, "2two",  
 ifelse(data$time == 3, "3three",  
 ifelse(data$time == 4, "4four",  
 ifelse(data$time == 5, "5five", "other")))))  
  
data$time <- as.factor(data$time)  
contrasts(data$time) <- contr.sum  
contrasts(data$time)

## [,1] [,2] [,3] [,4]  
## 1one 1 0 0 0  
## 2two 0 1 0 0  
## 3three 0 0 1 0  
## 4four 0 0 0 1  
## 5five -1 -1 -1 -1

# Outliers (this is a simple univariate measure)  
# Outlier = above Q3 + 1.5xIQR or below Q1 - 1.5xIQR  
# Extreme outlier = above Q3 + 3xIQR or below Q1 - 3xIQR   
# Only exclude extreme outliers  
outliers <- data %>%  
 group\_by(time) %>%  
 identify\_outliers(duration)  
outliers

## # A tibble: 9 × 9  
## time simple\_id microstate gev duration coverage occurrence is.outlier is.extreme  
## <fct> <fct> <chr> <dbl> <dbl> <dbl> <dbl> <lgl> <lgl>   
## 1 1one 207 B 0.147 101. 25.1 2.05 TRUE FALSE   
## 2 2two 207 B 0.150 100. 23.7 1.99 TRUE TRUE   
## 3 2two 280 B 0.167 92.7 26.4 2.40 TRUE FALSE   
## 4 3three 207 B 0.126 93.7 20.9 1.88 TRUE FALSE   
## 5 3three 280 B 0.145 92.1 24.9 2.29 TRUE FALSE   
## 6 4four 207 B 0.121 92.8 21.2 1.92 TRUE FALSE   
## 7 4four 280 B 0.155 92.3 26.8 2.43 TRUE FALSE   
## 8 5five 207 B 0.120 95.7 21.1 1.86 TRUE FALSE   
## 9 5five 280 B 0.152 91.2 26.3 2.41 TRUE FALSE

# ONE EXTREME VALUE  
  
# Remove Extreme Observations  
data <- data %>%  
 filter(!(simple\_id == 207))

# Correlations  
data\_one <- data %>% filter(time == "1one")  
data\_two <- data %>% filter(time == "2two")  
data\_three <- data %>% filter(time == "3three")  
data\_four <- data %>% filter(time == "4four")  
data\_five <- data %>% filter(time == "5five")  
  
cor(data\_one$duration, data\_two$duration)

## [1] 0.8123154

cor(data\_one$duration, data\_three$duration)

## [1] 0.7349442

cor(data\_one$duration, data\_four$duration)

## [1] 0.7002862

cor(data\_one$duration, data\_five$duration)

## [1] 0.6828089

cor(data\_two$duration, data\_three$duration)

## [1] 0.879673

cor(data\_two$duration, data\_four$duration)

## [1] 0.859978

cor(data\_two$duration, data\_five$duration)

## [1] 0.835005

cor(data\_three$duration, data\_four$duration)

## [1] 0.8718062

cor(data\_three$duration, data\_five$duration)

## [1] 0.8910937

cor(data\_four$duration, data\_five$duration)

## [1] 0.9344183

# Model  
m2\_duration\_model <- lme(duration ~ time, random = ~1|simple\_id,  
 correlation = corAR1(form = ~1|simple\_id), data = data)  
anova(m2\_duration\_model)

## numDF denDF F-value p-value  
## (Intercept) 1 184 21461.958 <.0001  
## time 4 184 2.328 0.0579

effectsize::eta\_squared(m2\_duration\_model, partial = TRUE)

## # Effect Size for ANOVA  
##   
## Parameter | Eta2 (partial) | 95% CI  
## -----------------------------------------  
## time | 0.05 | [0.00, 1.00]  
##   
## - One-sided CIs: upper bound fixed at [1.00].

emmeans(m2\_duration\_model, list(pairwise ~ time), adjust = "scheffe")

## Warning: contrasts dropped from factor time

## $`emmeans of time`  
## time emmean SE df lower.CL upper.CL  
## 1one 80.2 0.599 46 79.0 81.4  
## 2two 79.5 0.599 46 78.3 80.7  
## 3three 79.5 0.599 46 78.3 80.7  
## 4four 80.0 0.599 46 78.8 81.2  
## 5five 79.5 0.599 46 78.3 80.7  
##   
## Degrees-of-freedom method: containment   
## Confidence level used: 0.95   
##   
## $`pairwise differences of time`  
## 1 estimate SE df t.ratio p.value  
## 1one - 2two 0.66051 0.314 184 2.101 0.3565  
## 1one - 3three 0.71685 0.397 184 1.804 0.5181  
## 1one - 4four 0.15744 0.440 184 0.358 0.9980  
## 1one - 5five 0.66787 0.463 184 1.442 0.7210  
## 2two - 3three 0.05635 0.314 184 0.179 0.9999  
## 2two - 4four -0.50306 0.397 184 -1.266 0.8081  
## 2two - 5five 0.00736 0.440 184 0.017 1.0000  
## 3three - 4four -0.55941 0.314 184 -1.779 0.5322  
## 3three - 5five -0.04899 0.397 184 -0.123 1.0000  
## 4four - 5five 0.51042 0.314 184 1.623 0.6214  
##   
## Degrees-of-freedom method: containment   
## P value adjustment: scheffe method with rank 4

# Estimation statistics-based effect sizes and confidence intervals  
paired\_mean\_diff <- dabest(data, time, duration,  
 idx = list(c("2two", "1one"),  
 c("3three", "1one"),  
 c("4four", "1one"),  
 c("5five", "1one"),  
 c("3three", "2two"),  
 c("4four", "2two"),  
 c("5five", "2two"),  
 c("4four", "3three"),  
 c("5five", "3three"),  
 c("5five", "4four")),  
 paired = TRUE, id.col = simple\_id) %>%   
 mean\_diff()  
paired\_mean\_diff

## dabestr (Data Analysis with Bootstrap Estimation in R) v0.3.0  
## =============================================================  
##   
## Good evening!  
## The current time is 23:43 PM on Sunday January 21, 2024.  
##   
## Dataset : data  
## X Variable : time  
## Y Variable : duration  
##   
## Paired mean difference of 1one (n = 47) minus 2two (n = 47)  
## 0.661 [95CI -1.25; 2.48]  
##   
## Paired mean difference of 1one (n = 47) minus 3three (n = 47)  
## 0.717 [95CI -1.04; 2.42]  
##   
## Paired mean difference of 1one (n = 47) minus 4four (n = 47)  
## 0.157 [95CI -1.48; 1.84]  
##   
## Paired mean difference of 1one (n = 47) minus 5five (n = 47)  
## 0.668 [95CI -0.985; 2.33]  
##   
## Paired mean difference of 2two (n = 47) minus 3three (n = 47)  
## 0.0563 [95CI -1.68; 1.75]  
##   
## Paired mean difference of 2two (n = 47) minus 4four (n = 47)  
## -0.503 [95CI -2.15; 1.14]  
##   
## Paired mean difference of 2two (n = 47) minus 5five (n = 47)  
## 0.00736 [95CI -1.59; 1.68]  
##   
## Paired mean difference of 3three (n = 47) minus 4four (n = 47)  
## -0.559 [95CI -2.04; 0.957]  
##   
## Paired mean difference of 3three (n = 47) minus 5five (n = 47)  
## -0.049 [95CI -1.5; 1.43]  
##   
## Paired mean difference of 4four (n = 47) minus 5five (n = 47)  
## 0.51 [95CI -0.899; 1.94]  
##   
##   
## 5000 bootstrap resamples.  
## All confidence intervals are bias-corrected and accelerated.

# Correction for Multiple Comparisons

# Without Outliers Removed  
p = c(  
 0.0002,  
 0.000000001080395,  
 0.1346235,  
 0.00000000000002176037,  
 0.000000000000002442491, # Change 1  
   
 0.1744792,  
 0.06670067, # Change 2  
 0.04116499,  
 0.005043416,  
 0.00311029,  
   
 0.00000002799927,  
 0.0000000000004719558,  
 0.002970316,  
 0.00000000005082268,  
 0.000000000000004662937,  
   
 0.000001775535,  
 0.0000000001170206,  
 0.2150346,  
 0.000000008653745,  
 0.000000000000144551  
)  
p.adjust(p, method = "bonferroni")

## [1] 0.00400000000000000008 0.00000002160790000000 1.00000000000000000000 0.00000000000043520740 0.00000000000004884982  
## [6] 1.00000000000000000000 1.00000000000000000000 0.82329980000000002605 0.10086832000000001131 0.06220579999999999860  
## [11] 0.00000055998540000000 0.00000000000943911600 0.05940632000000000551 0.00000000101645360000 0.00000000000009325874  
## [16] 0.00003551070000000000 0.00000000234041200000 1.00000000000000000000 0.00000017307490000000 0.00000000000289102000