CIre within analysis

Load packages

```
pacman::p_load(readr, lme4, emmeans)
```

Load data

```
long = read_csv("long.csv")
```

```
## Rows: 288 Columns: 14

## -- Column specification --------------------------------------------------------
## Delimiter: ","
## chr (5): Time, Deviant, Listeninghabits, Channel, Group
## dbl (9): ID, DeviantLevel, AvCor, RoQ, M_knowledge, M_enjoyment, YearsWOHear...

##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```
long$Deviant=as.factor(long$Deviant)
long$DeviantLevel=as.factor(long$DeviantLevel)
long$Time = as.factor(long$Time)
long$ID=as.factor(long$ID)
long$M_knowledge = ordered(long$M_knowledge, levels = c("1","2","3","4","5"))
long$M_enjoyment=ordered(long$M_enjoyment, levels = c("1", "2", "3", "4", "5", "6","7"))
long$Listeninghabits=ordered(long$Listeninghabits, levels = c("Low", "High"))

change_all = read_csv("change_all.csv")
```

```
## Rows: 144 Columns: 30

## -- Column specification --------------------------------------------------------
## Delimiter: ","
## chr  (3): Deviant, Channel, Group
## dbl (25): ID, DeviantLevel, AvCor.T1, RoQ.T1, Listeninghabits.T1, M_knowledg...
## lgl  (2): M_knowledge.T2, YearsWOHearing.T2

##
## i Use `spec()` to retrieve the full column specification for this data.
## i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```
change_all$Deviant=as.factor(change_all$Deviant)
change_all$DeviantLevel=as.factor(change_all$DeviantLevel)
change_all$ID=as.factor(change_all$ID)
```

Hierarchical mixed effects modeling - MMN Amplitude

```
M0=lmer(Amplitude~1+(1|ID), data=long, REML = FALSE, control = lmerControl(optimizer = "nloptwrap", cal

M1=lmer(Amplitude~Deviant+(1|ID), data=long, REML = FALSE, control = lmerControl(optimizer = "nloptwrap

M2=lmer(Amplitude~Deviant+DeviantLevel+(1|ID), data=long, REML = FALSE, control = lmerControl(optimizer

M3=lmer(Amplitude~Deviant+DeviantLevel+Time+(1|ID), data=long, REML = FALSE, control = lmerControl(opti

M4=lmer(Amplitude~Deviant*DeviantLevel+Time+(1|ID), data=long, REML = FALSE, control = lmerControl(opti

M5=lmer(Amplitude~Deviant*DeviantLevel+Deviant*Time+(1|ID), data=long, REML = FALSE, control = lmerCont

M6=lmer(Amplitude~Deviant*DeviantLevel+Deviant*Time+DeviantLevel*Time+(1|ID), data=long, REML = FALSE, 

anova(M0,M1,M2,M3,M4,M5,M6)
```

```
## Data: long
## Models:
## M0: Amplitude ~ 1 + (1 | ID)
## M1: Amplitude ~ Deviant + (1 | ID)
## M2: Amplitude ~ Deviant + DeviantLevel + (1 | ID)
## M3: Amplitude ~ Deviant + DeviantLevel + Time + (1 | ID)
## M4: Amplitude ~ Deviant * DeviantLevel + Time + (1 | ID)
## M5: Amplitude ~ Deviant * DeviantLevel + Deviant * Time + (1 | ID)
## M6: Amplitude ~ Deviant * DeviantLevel + Deviant * Time + DeviantLevel * Time + (1 | ID)
##    npar    AIC    BIC  logLik deviance   Chisq Df Pr(>Chisq)
## M0    3 205.92 216.91 -99.959   199.92
## M1    6 201.62 223.59 -94.809   189.62 10.3009  3    0.01617 *
## M2    9 204.92 237.89 -93.462   186.92  2.6936  3    0.44131
## M3   10 202.99 239.62 -91.496   182.99  3.9316  1    0.04739 *
## M4   19 205.52 275.11 -83.759   167.52 15.4746  9    0.07870 .
## M5   22 201.39 281.98 -78.695   157.39 10.1274  3    0.01751 *
## M6   25 202.42 293.99 -76.210   152.42  4.9703  3    0.17398
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Best model

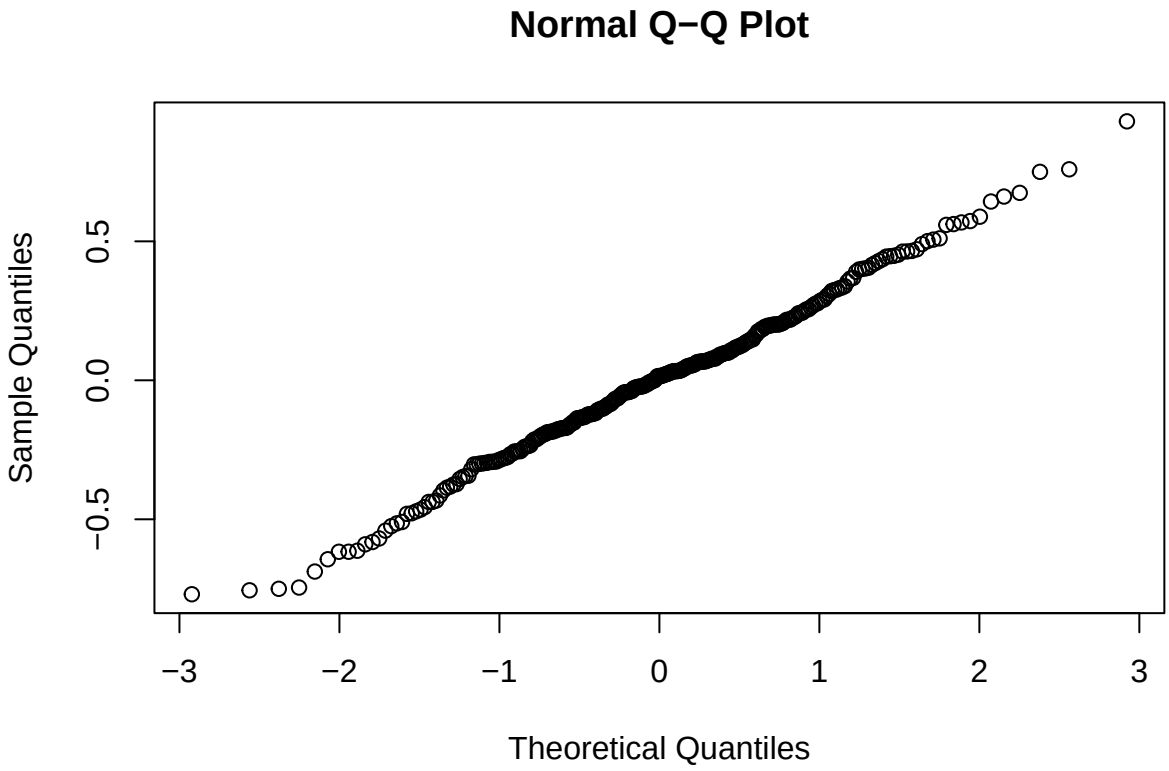
```
summary(M5)
```

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
## Formula: Amplitude ~ Deviant * DeviantLevel + Deviant * Time + (1 | ID)
```

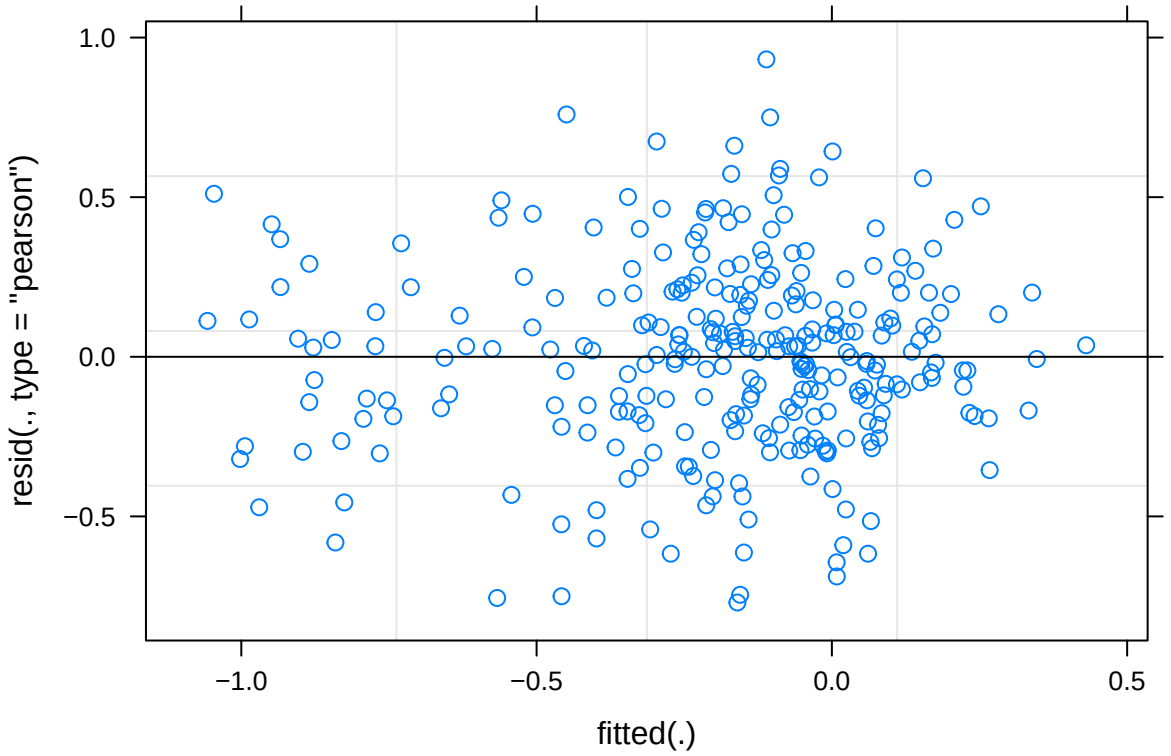
```
##    Data: long
## Control: lmerControl(optimizer = "nloptwrap", calc.derivs = FALSE)
##
##      AIC      BIC   logLik deviance df.resid
##    201.4    282.0    -78.7    157.4      266
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.54980 -0.61091  0.05113  0.64438  3.08648
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  ID       (Intercept) 0.07706  0.2776
##  Residual             0.09112  0.3019
## Number of obs: 288, groups:  ID, 9
##
## Fixed effects:
##                              Estimate Std. Error t value
## (Intercept)                  -0.11792    0.12203  -0.966
## DeviantPitch                 -0.06006    0.11250  -0.534
## DeviantRhythm                 0.20109    0.11250   1.788
## DeviantTimbre                -0.11935    0.11250  -1.061
## DeviantLevel2                -0.08132    0.10062  -0.808
## DeviantLevel3                -0.06494    0.10062  -0.645
## DeviantLevel4                -0.22831    0.10062  -2.269
## TimeT2                        0.11753    0.07115   1.652
## DeviantPitch:DeviantLevel2    0.16416    0.14230   1.154
## DeviantRhythm:DeviantLevel2 -0.14753    0.14230  -1.037
## DeviantTimbre:DeviantLevel2   0.19388    0.14230   1.362
## DeviantPitch:DeviantLevel3    0.10296    0.14230   0.724
## DeviantRhythm:DeviantLevel3 -0.24879    0.14230  -1.748
## DeviantTimbre:DeviantLevel3   0.10916    0.14230   0.767
## DeviantPitch:DeviantLevel4    0.28083    0.14230   1.974
## DeviantRhythm:DeviantLevel4   0.13090    0.14230   0.920
## DeviantTimbre:DeviantLevel4   0.21730    0.14230   1.527
## DeviantPitch:TimeT2          -0.27858    0.10062  -2.769
## DeviantRhythm:TimeT2         -0.20903    0.10062  -2.077
## DeviantTimbre:TimeT2         -0.27894    0.10062  -2.772

##
## Correlation matrix not shown by default, as p = 20 > 12.
## Use print(x, correlation=TRUE)  or
##     vcov(x)        if you need it
```

```
#Checking assumptions with diagnostic plots
qqnorm(resid(M5))
```


Normal Q−Q Plot
Sample Quantiles
−0.5
0.0
0.5
−3
−2
−1
0
1
2
3
Theoretical Quantiles

```
plot(M5)
```



Post-hoc analysis

```
emm_r <- emmeans(M5, pairwise ~ Time)
```

```
## NOTE: Results may be misleading due to involvement in interactions
```

```
emm_rc <- emm_r[[2]]

emm_d <- emmeans(M5, pairwise ~ Deviant)
```

```
## NOTE: Results may be misleading due to involvement in interactions
```

```
emm_dc <- emm_d[[2]]

#Time by deviant interaction

emm_r.d <- emmeans(M5, pairwise ~ Time | Deviant)
IC_r.d <- contrast(emm_r.d[[1]], method = "pairwise")

emm_d.r <- emmeans(M5, pairwise ~ Deviant | Time)
IC_d.r <- contrast(emm_d.r[[1]], method = "pairwise")

rbind(emm_rc, emm_dc, IC_r.d[1:4], IC_d.r[1:12], adjust = "mvt")
```

```
##  contrast           Deviant   Time estimate     SE  df t.ratio p.value
```

```
##  T1 - T2            .         .      0.0741 0.0369 299   2.011  0.4420
##  Intensity - Pitch  .         .      0.0624 0.0521 299   1.197  0.9221
##  Intensity - Rhythm .         .     -0.0302 0.0521 299  -0.580  0.9989
##  Intensity - Timbre .         .      0.1287 0.0521 299   2.470  0.1871
##  Pitch - Rhythm     .         .     -0.0926 0.0521 299  -1.777  0.6043
##  Pitch - Timbre     .         .      0.0664 0.0521 299   1.274  0.8946
##  Rhythm - Timbre    .         .      0.1590 0.0521 299   3.050  0.0433
##  T1 - T2            Intensity .     -0.1175 0.0737 299  -1.595  0.7266
##  T1 - T2            Pitch     .      0.1611 0.0737 299   2.185  0.3321
##  T1 - T2            Rhythm    .      0.0915 0.0737 299   1.241  0.9069
##  T1 - T2            Timbre    .      0.1614 0.0737 299   2.190  0.3284
##  Intensity - Pitch  .         T1    -0.0769 0.0737 299  -1.044  0.9618
##  Intensity - Rhythm .         T1    -0.1347 0.0737 299  -1.828  0.5689
##  Intensity - Timbre .         T1    -0.0107 0.0737 299  -0.146  1.0000
##  Pitch - Rhythm     .         T1    -0.0578 0.0737 299  -0.784  0.9926
##  Pitch - Timbre     .         T1     0.0662 0.0737 299   0.898  0.9835
##  Rhythm - Timbre    .         T1     0.1240 0.0737 299   1.683  0.6695
##  Intensity - Pitch  .         T2     0.2017 0.0737 299   2.736  0.1006
##  Intensity - Rhythm .         T2     0.0743 0.0737 299   1.008  0.9684
##  Intensity - Timbre .         T2     0.2682 0.0737 299   3.639  0.0065
##  Pitch - Rhythm     .         T2    -0.1274 0.0737 299  -1.728  0.6385
##  Pitch - Timbre     .         T2     0.0666 0.0737 299   0.903  0.9830
##  Rhythm - Timbre    .         T2     0.1939 0.0737 299   2.631  0.1298
##
## Results are averaged over some or all of the levels of: Deviant, DeviantLevel, Time
## Degrees-of-freedom method: kenward-roger
## P value adjustment: mvt method for 23 tests
```

```
rbind(IC_r.d[1:4], adjust = "mvt")
```

```
##  contrast Deviant   estimate     SE  df t.ratio p.value
##  T1 - T2  Intensity  -0.1175 0.0737 299  -1.595  0.3768
##  T1 - T2  Pitch       0.1611 0.0737 299   2.185  0.1132
##  T1 - T2  Rhythm      0.0915 0.0737 299   1.241  0.6197
##  T1 - T2  Timbre      0.1614 0.0737 299   2.190  0.1119
##
## Results are averaged over some or all of the levels of: DeviantLevel
## Degrees-of-freedom method: kenward-roger
## P value adjustment: mvt method for 4 tests
```

```
rbind(IC_r.d[1:4], adjust = "none")
```

```
##  contrast Deviant   estimate     SE  df t.ratio p.value
##  T1 - T2  Intensity  -0.1175 0.0737 299  -1.595  0.1119
##  T1 - T2  Pitch       0.1611 0.0737 299   2.185  0.0297
##  T1 - T2  Rhythm      0.0915 0.0737 299   1.241  0.2154
##  T1 - T2  Timbre      0.1614 0.0737 299   2.190  0.0293
##
## Results are averaged over some or all of the levels of: DeviantLevel
## Degrees-of-freedom method: kenward-roger
```

```
rbind(IC_r.d[c(1,2,4)], adjust = "none")
```

```
##  contrast Deviant   estimate     SE  df t.ratio p.value
##  T1 - T2  Intensity   -0.118 0.0737 299  -1.595  0.1119
##  T1 - T2  Pitch        0.161 0.0737 299   2.185  0.0297
##  T1 - T2  Timbre       0.161 0.0737 299   2.190  0.0293
##
## Results are averaged over some or all of the levels of: DeviantLevel
## Degrees-of-freedom method: kenward-roger
```

```
IC_r.d[1:4]
```

```
## Note: adjust = "tukey" was changed to "sidak"
## because "tukey" is only appropriate for one set of pairwise comparisons
```

```
##  contrast Deviant   estimate     SE  df t.ratio p.value
##  T1 - T2  Intensity  -0.1175 0.0737 299  -1.595  0.3778
##  T1 - T2  Pitch       0.1611 0.0737 299   2.185  0.1134
##  T1 - T2  Rhythm      0.0915 0.0737 299   1.241  0.6210
##  T1 - T2  Timbre      0.1614 0.0737 299   2.190  0.1121
##
## Results are averaged over the levels of: DeviantLevel
## Degrees-of-freedom method: kenward-roger
## P value adjustment: sidak method for 4 tests
```

```
IC_d.r[1:12]
```

```
## Note: adjust = "tukey" was changed to "sidak"
## because "tukey" is only appropriate for one set of pairwise comparisons
```

```
##  contrast           Time estimate     SE  df t.ratio p.value
##  Intensity - Pitch  T1    -0.0769 0.0737 299  -1.044  0.9855
##  Intensity - Rhythm T1    -0.1347 0.0737 299  -1.828  0.5734
##  Intensity - Timbre T1    -0.0107 0.0737 299  -0.146  1.0000
##  Pitch - Rhythm     T1    -0.0578 0.0737 299  -0.784  0.9989
##  Pitch - Timbre     T1     0.0662 0.0737 299   0.898  0.9961
##  Rhythm - Timbre    T1     0.1240 0.0737 299   1.683  0.6921
##  Intensity - Pitch  T2     0.2017 0.0737 299   2.736  0.0763
##  Intensity - Rhythm T2     0.0743 0.0737 299   1.008  0.9892
##  Intensity - Timbre T2     0.2682 0.0737 299   3.639  0.0039
##  Pitch - Rhythm     T2    -0.1274 0.0737 299  -1.728  0.6556
##  Pitch - Timbre     T2     0.0666 0.0737 299   0.903  0.9959
##  Rhythm - Timbre    T2     0.1939 0.0737 299   2.631  0.1023
##
## Results are averaged over the levels of: DeviantLevel
## Degrees-of-freedom method: kenward-roger
## P value adjustment: sidak method for 12 tests
```

```
IC_d.r[c(1,3,7,9)]
```

```
## Note: adjust = "tukey" was changed to "sidak"
## because "tukey" is only appropriate for one set of pairwise comparisons
```

```
##  contrast           Time estimate     SE  df t.ratio p.value
##  Intensity - Pitch  T1    -0.0769 0.0737 299  -1.044  0.7564
##  Intensity - Timbre T1    -0.0107 0.0737 299  -0.146  0.9998
##  Intensity - Pitch  T2     0.2017 0.0737 299   2.736  0.0261
##  Intensity - Timbre T2     0.2682 0.0737 299   3.639  0.0013
##
## Results are averaged over the levels of: DeviantLevel
## Degrees-of-freedom method: kenward-roger
## P value adjustment: sidak method for 4 tests
```

```
IC_IC_d.r <- contrast(emm_d.r[[1]], interaction = c("pairwise", "consec"), by = NULL)
rbind(IC_IC_d.r[1:6], adjust = "bonferroni")
```

```
##  Deviant_pairwise   Time_consec  estimate    SE  df t.ratio p.value
##  Intensity - Pitch  T2 - T1      0.278580 0.104 299   2.673  0.0476
##  Intensity - Rhythm T2 - T1      0.209026 0.104 299   2.005  0.2749
##  Intensity - Timbre T2 - T1      0.278942 0.104 299   2.676  0.0471
##  Pitch - Rhythm     T2 - T1     -0.069553 0.104 299  -0.667  1.0000
##  Pitch - Timbre     T2 - T1      0.000362 0.104 299   0.003  1.0000
##  Rhythm - Timbre    T2 - T1      0.069916 0.104 299   0.671  1.0000
##
## Results are averaged over some or all of the levels of: DeviantLevel
## Degrees-of-freedom method: kenward-roger
## P value adjustment: bonferroni method for 6 tests
```

Hierarchical mixed effects modeling - 3-AFC (Behavioral)

```
M0=glmer(cbind(AvCor*6,6)~1+(1|ID), data=long, family="binomial", control = glmerControl(optimizer = "nl

M1=glmer(cbind(AvCor*6,6)~Deviant+(1|ID), data=long, family="binomial", control = glmerControl(optimize

M2=glmer(cbind(AvCor*6,6)~Deviant+DeviantLevel+(1|ID), data=long, family="binomial", control = glmerCon

M3=glmer(cbind(AvCor*6,6)~Deviant+DeviantLevel+Time+(1|ID), data=long,family="binomial", control = glme

M4=glmer(cbind(AvCor*6,6)~Deviant*DeviantLevel+Time+(1|ID), data=long, family="binomial", control = glm

M5=glmer(cbind(AvCor*6,6)~Deviant*DeviantLevel+Deviant*Time+(1|ID), data=long, family="binomial", contr

M6=glmer(cbind(AvCor*6,6)~Deviant*DeviantLevel+Deviant*Time+DeviantLevel*Time+(1|ID), data=long, family

anova(M0,M1,M2,M3,M4,M5,M6)
```

```
## Data: long
## Models:
## M0: cbind(AvCor * 6, 6) ~ 1 + (1 | ID)
## M1: cbind(AvCor * 6, 6) ~ Deviant + (1 | ID)
```

```
## M2: cbind(AvCor * 6, 6) ~ Deviant + DeviantLevel + (1 | ID)
## M3: cbind(AvCor * 6, 6) ~ Deviant + DeviantLevel + Time + (1 | ID)
## M4: cbind(AvCor * 6, 6) ~ Deviant * DeviantLevel + Time + (1 | ID)
## M5: cbind(AvCor * 6, 6) ~ Deviant * DeviantLevel + Deviant * Time + (1 | ID)
## M6: cbind(AvCor * 6, 6) ~ Deviant * DeviantLevel + Deviant * Time + DeviantLevel * Time + (1 | ID)
##    npar    AIC    BIC  logLik deviance    Chisq Df Pr(>Chisq)
## M0    2 1640.0 1647.3 -818.00   1636.0
## M1    5 1485.8 1504.1 -737.90   1475.8 160.2033  3  < 2.2e-16 ***
## M2    8 1424.8 1454.1 -704.41   1408.8  66.9716  3  1.899e-14 ***
## M3    9 1426.5 1459.4 -704.22   1408.5   0.3766  1     0.5394
## M4   18 1430.2 1496.1 -697.07   1394.2  14.3042  9     0.1119
## M5   21 1434.7 1511.6 -696.34   1392.7   1.4569  3     0.6923
## M6   24 1437.9 1525.8 -694.94   1389.9   2.8127  3     0.4214
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Best model

```
summary(M2)
```

```
## Generalized linear mixed model fit by maximum likelihood (Laplace
##   Approximation) [glmerMod]
##  Family: binomial  ( logit )
## Formula: cbind(AvCor * 6, 6) ~ Deviant + DeviantLevel + (1 | ID)
##    Data: long
## Control: glmerControl(optimizer = "nloptwrap", calc.derivs = FALSE)
##
##      AIC      BIC   logLik deviance df.resid
##   1424.8   1454.1   -704.4   1408.8      280
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -17.3877  -0.6257   0.0096   0.4718   2.6604
##
## Random effects:
##  Groups Name        Variance Std.Dev.
##  ID     (Intercept) 0.02301  0.1517
## Number of obs: 288, groups:  ID, 9
##
## Fixed effects:
##               Estimate Std. Error z value Pr(>|z|)
## (Intercept)    3.20487    0.08169  39.231  < 2e-16 ***
## DeviantPitch   0.72414    0.06930  10.449  < 2e-16 ***
## DeviantRhythm  0.83091    0.06907  12.030  < 2e-16 ***
## DeviantTimbre  0.61835    0.06904   8.957  < 2e-16 ***
## DeviantLevel2  0.26418    0.06912   3.822 0.000132 ***
## DeviantLevel3  0.49143    0.06898   7.124 1.05e-12 ***
## DeviantLevel4  0.49728    0.06901   7.206 5.78e-13 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
```

```
##             (Intr) DvntPt DvntRh DvntTm DvntL2 DvntL3
## DeviantPtch -0.431
## DevntRhythm -0.399  0.505
## DeviantTmbr -0.419  0.504  0.504
## DeviantLvl2 -0.409 -0.008 -0.058 -0.008
## DeviantLvl3 -0.408 -0.004 -0.047 -0.031  0.504
## DeviantLvl4 -0.427  0.031 -0.028  0.006  0.504  0.505
```

Hierarchical mixed effects modeling - Latency

```
M0=lmer(Latency_peak~1+(1|ID), data=long, REML = FALSE, control = lmerControl(optimizer = "nloptwrap", c

M1=lmer(Latency_peak~Deviant+(1|ID), data=long, REML = FALSE, control = lmerControl(optimizer = "nloptwr

M2=lmer(Latency_peak~Deviant+DeviantLevel+(1|ID), data=long, REML = FALSE, control = lmerControl(optimiz

M3=lmer(Latency_peak~Deviant+DeviantLevel+Time+(1|ID), data=long, REML = FALSE, control = lmerControl(op

M4=lmer(Latency_peak~Deviant*DeviantLevel+Time+(1|ID), data=long, REML = FALSE, control = lmerControl(op

M5=lmer(Latency_peak~Deviant*DeviantLevel+Deviant*Time+(1|ID), data=long, REML = FALSE, control = lmerCo

M6=lmer(Latency_peak~Deviant*DeviantLevel+Deviant*Time+DeviantLevel*Time+(1|ID), data=long, REML = FALSE


anova(M0,M1,M2,M3,M4,M5,M6)
```

```
## Data: long
## Models:
## M0: Latency_peak ~ 1 + (1 | ID)
## M1: Latency_peak ~ Deviant + (1 | ID)
## M2: Latency_peak ~ Deviant + DeviantLevel + (1 | ID)
## M3: Latency_peak ~ Deviant + DeviantLevel + Time + (1 | ID)
## M4: Latency_peak ~ Deviant * DeviantLevel + Time + (1 | ID)
## M5: Latency_peak ~ Deviant * DeviantLevel + Deviant * Time + (1 | ID)
## M6: Latency_peak ~ Deviant * DeviantLevel + Deviant * Time + DeviantLevel * Time + (1 | ID)
##    npar    AIC    BIC  logLik deviance   Chisq Df Pr(>Chisq)
## M0    3 2899.4 2910.4 -1446.7   2893.4
## M1    6 2905.3 2927.3 -1446.7   2893.3  0.0828  3     0.9938
## M2    9 2909.0 2942.0 -1445.5   2891.0  2.3231  3     0.5081
## M3   10 2910.1 2946.7 -1445.0   2890.1  0.9634  1     0.3263
## M4   19 2915.2 2984.8 -1438.6   2877.2 12.8390  9     0.1700
## M5   22 2920.0 3000.6 -1438.0   2876.0  1.2282  3     0.7463
## M6   25 2921.8 3013.4 -1435.9   2871.8  4.1460  3     0.2461
```