Final Project

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Model Assumption

$$y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \gamma_k + \epsilon_{ijk}$$

where μ is the overall mean, τ_i is the mean of activity (walking and meditation)

```
wm <- read.csv("final_data.csv")
wm$User <- as.factor(wm$User)
wm$Time <- as.factor(wm$Time)
wm$Activity <- as.factor(wm$Activity)
```

Random effect of not studying the interaction of blocking factor

```
library(lmerTest)
```

```
## Loading required package: lme4
```

```
## Loading required package: Matrix
```

```
##
## Attaching package: 'lmerTest'
```

```
## The following object is masked from 'package:lme4':
##
##     lmer
```

```
## The following object is masked from 'package:stats':
##
##     step
```

```
wm_lmer <- lmer(Score ~ Time * Activity + (1|User),
                data = wm,
                contrasts = list(Time = "contr.helmert",
                Activity = "contr.helmert"))
```

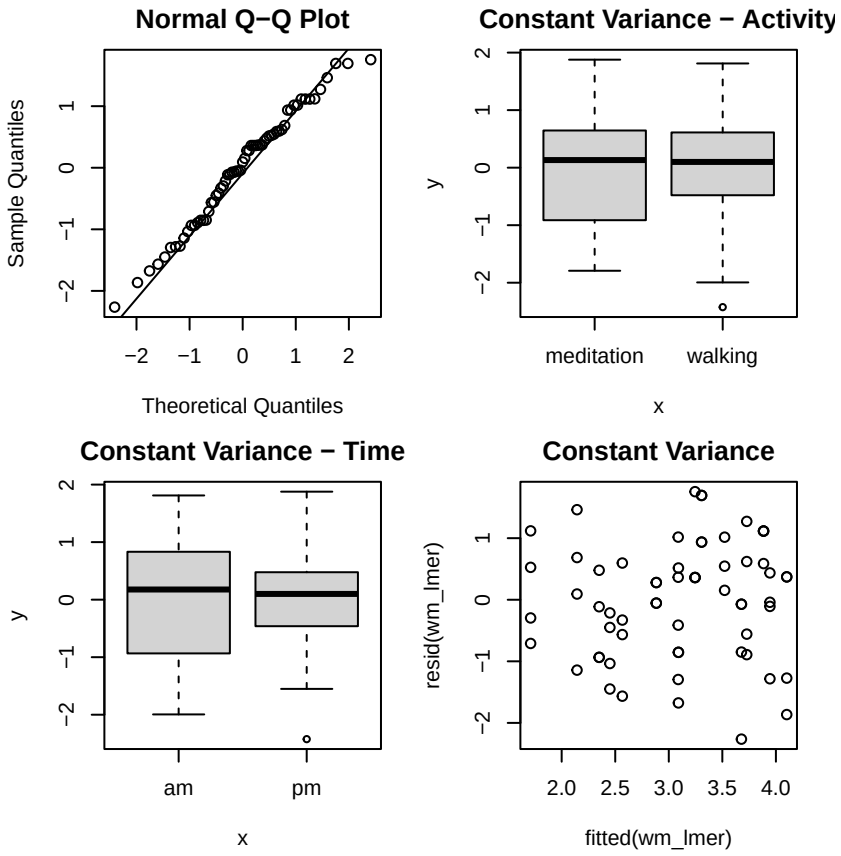
```
summary(wm_lmer)
```

```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: Score ~ Time * Activity + (1 | User)
##    Data: wm
##
## REML criterion at convergence: 189.4
##
## Scaled residuals:
##      Min       1Q   Median       3Q      Max
## -2.29089 -0.78917  0.09393  0.59871  1.77593
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  User     (Intercept) 0.5446   0.7379
##  Residual             0.9766   0.9882
## Number of obs: 63, groups:  User, 4
##
## Fixed effects:
##                 Estimate Std. Error      df t value Pr(>|t|)
## (Intercept)       3.1056     0.3894  3.0042   7.975  0.00409 **
## Time1            -0.2657     0.1246 56.0144  -2.133  0.03736 *
## Activity1         0.1624     0.1246 56.0144   1.303  0.19781
## Time1:Activity1   0.0542     0.1246 56.0144   0.435  0.66523
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) Time1 Actvt1
## Time1       0.005
## Activity1   0.005  0.017
## Tm1:Actvty1 0.005  0.017 0.017
```

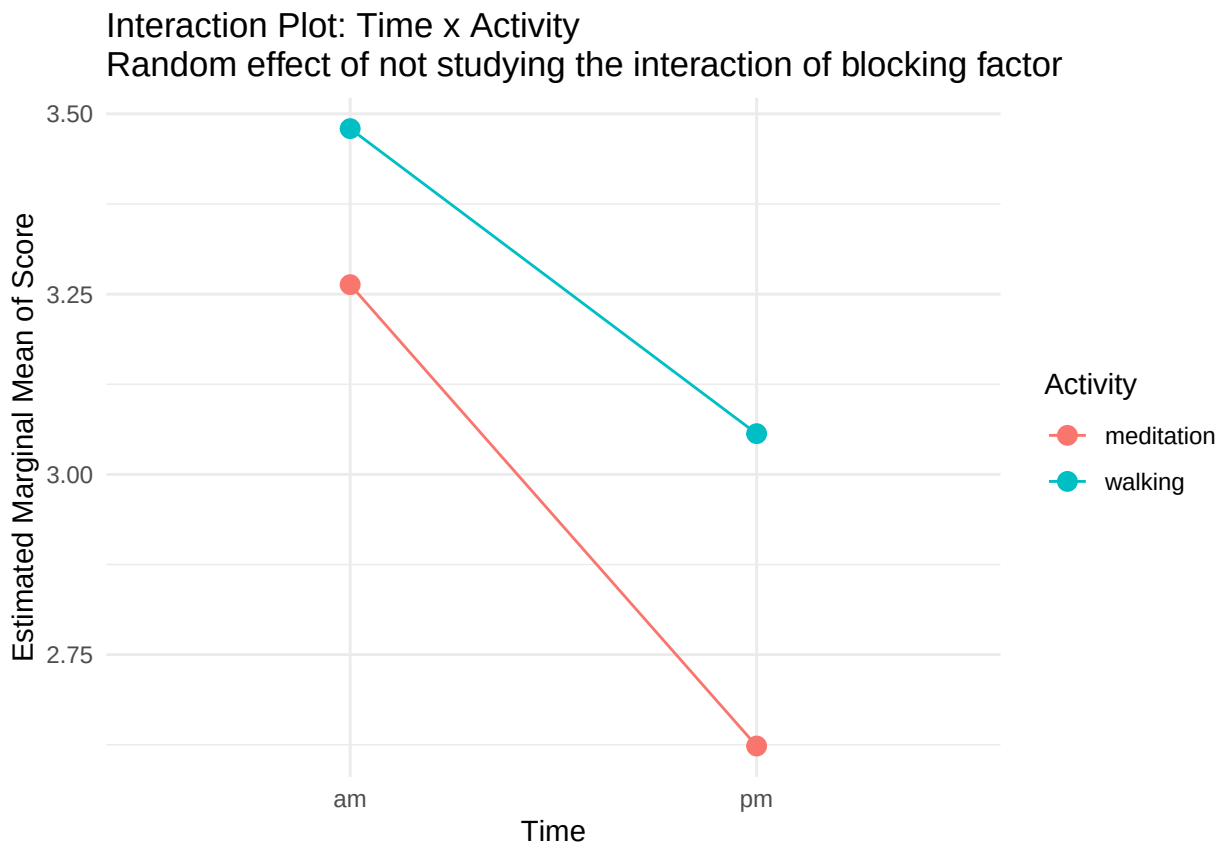
```
ranova(wm_lmer)
```

```
## ANOVA-like table for random-effects: Single term deletions
##
## Model:
## Score ~ Time + Activity + (1 | User) + Time:Activity
##            npar   logLik    AIC    LRT Df Pr(>Chisq)
## <none>        6  -94.724 201.45
## (1 | User)    5 -102.242 214.48 15.037  1  0.0001054 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
layout(matrix(1:6, 2, 3)); par(mar = c(4, 4, 2.5, 1.5))
# Check normality
qqnorm(residuals(wm_lmer))
qqline(residuals(wm_lmer))

#Residuals
plot(wm$Time, rstudent(wm_lmer), main = "Constant Variance - Time")
plot(wm$Activity, rstudent(wm_lmer), main = "Constant Variance - Activity")
plot(fitted(wm_lmer), resid(wm_lmer), main = "Constant Variance")
#plot(wm_lmer,which=4)
```




```
# Interaction Plot

# Estimate Marginal Means
library(emmeans)
emm_wm_lmer <- emmeans(wm_lmer, ~ Time * Activity)
emm_df_wm_lmer <- as.data.frame(emm_wm_lmer) #as DF

# Use ggplot2 for the interaction plot
library(ggplot2)
ggplot(emm_df_wm_lmer, aes(x = Time, y = emmean, group = Activity, color = Activity)) +
  geom_point(size = 3) +
  geom_line() +
  labs(title = "Interaction Plot: Time x Activity\nRandom effect of not studying the interaction of blo
       y = "Estimated Marginal Mean of Score") +
  theme_minimal()
```



Fixed effect of not studying the interaction of blocking factor

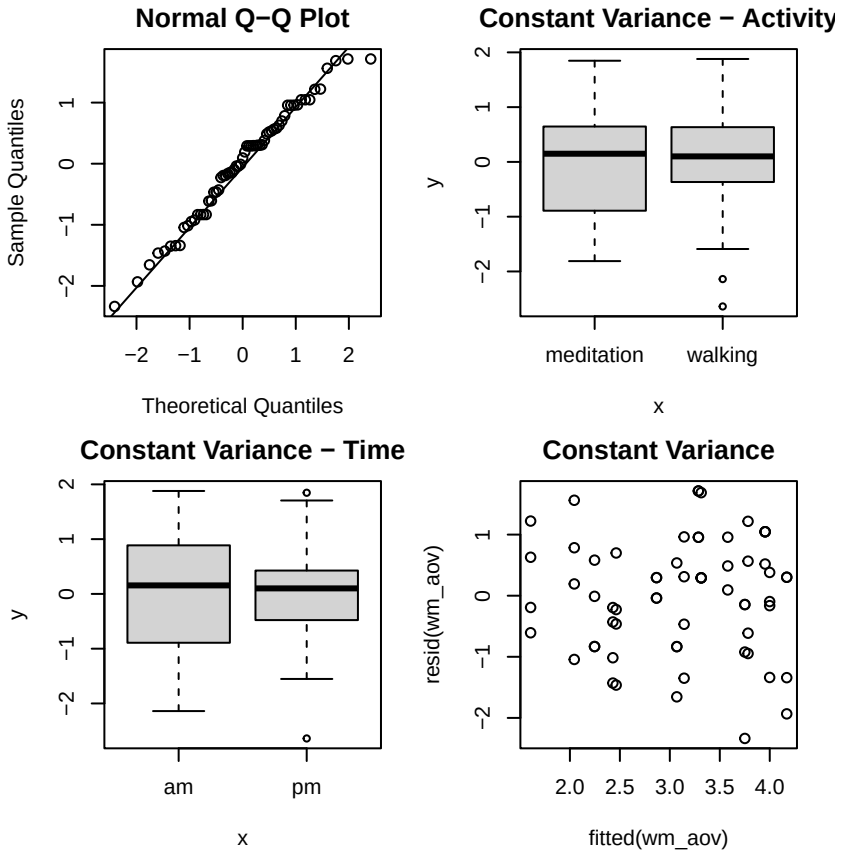
```
wm_aov <- aov(Score ~ Time * Activity + User,
              data = wm,
              contrasts = list(Time = "contr.helmert",
              Activity = "contr.helmert"))
```

```
summary(wm_aov)
```

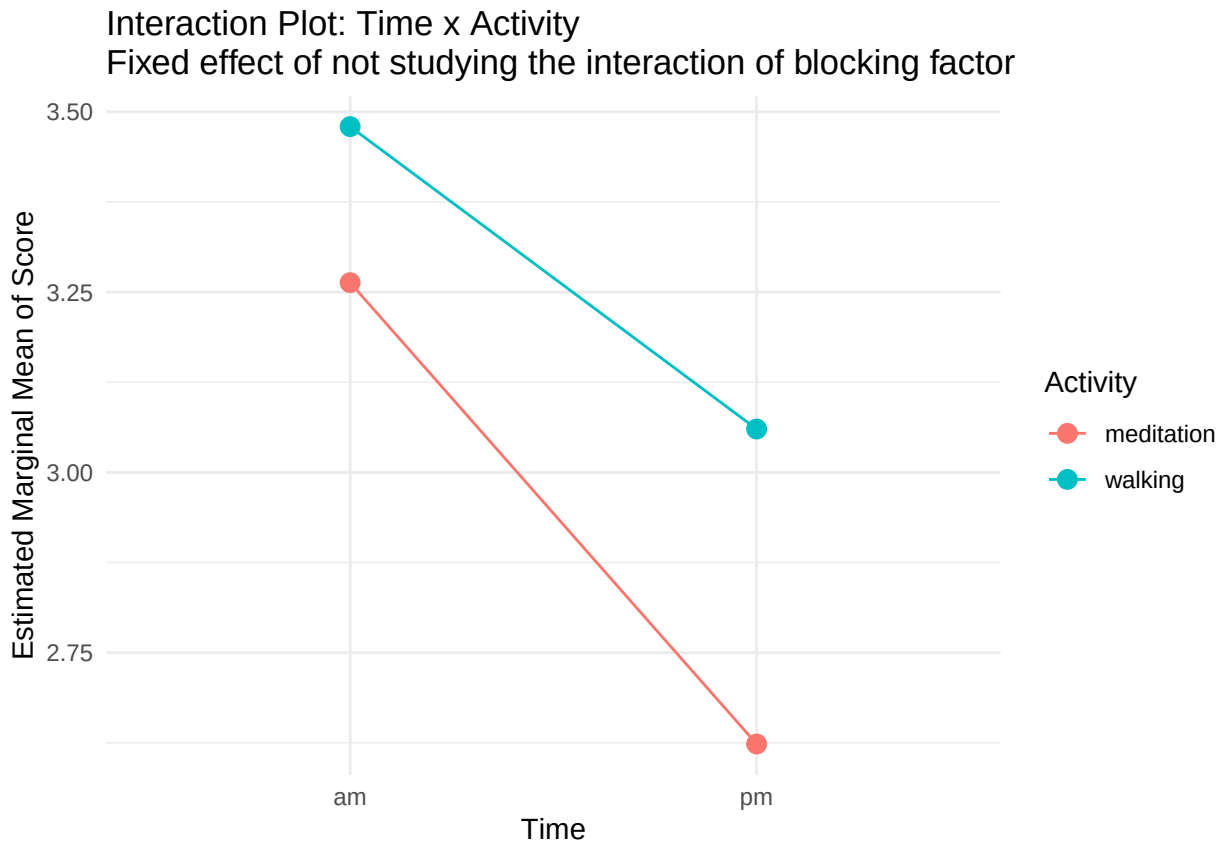
```
##               Df Sum Sq Mean Sq F value   Pr(>F)
## Time           1   4.82   4.822   4.938   0.0303 *
## Activity       1   1.49   1.491   1.527   0.2218
## User           3  28.73   9.578   9.807 2.69e-05 ***
## Time:Activity  1   0.19   0.191   0.196   0.6600
## Residuals     56  54.69   0.977
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
layout(matrix(1:6, 2, 3)); par(mar = c(4, 4, 2.5, 1.5))
# Check normality
qqnorm(residuals(wm_aov))
qqline(residuals(wm_aov))
```

```r
# Check constant variance
plot(wm$Time, rstudent(wm_aov), main = "Constant Variance - Time")
plot(wm$Activity, rstudent(wm_aov), main = "Constant Variance - Activity")
plot(fitted(wm_aov), resid(wm_aov), main = "Constant Variance")
```




```r
# Interaction Plot

# Estimate Marginal Means
emm_wm_aov <- emmeans(wm_aov, ~ Time * Activity)
emm_df_wm_aov <- as.data.frame(emm_wm_aov) #as DF

# Interaction plot
ggplot(emm_df_wm_aov, aes(x = Time, y = emmean, group = Activity, color = Activity)) +
  geom_point(size = 3) +
  geom_line() +
  labs(title = "Interaction Plot: Time x Activity\nFixed effect of not studying the interaction of block
       y = "Estimated Marginal Mean of Score") +
  theme_minimal()
```



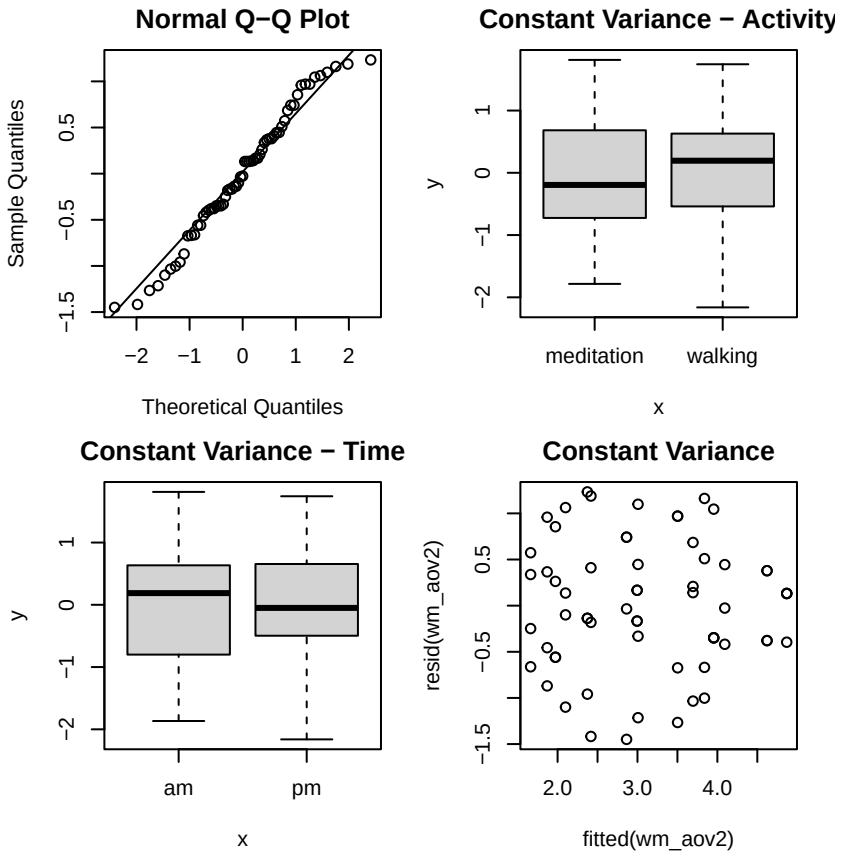
Fixed effect of study the interaction of blocking factor

```
wm_aov2 <- aov(Score ~ Time * Activity * User,
               data = wm,
               contrasts = list(Time = "contr.helmert",
               Activity = "contr.helmert"))
```

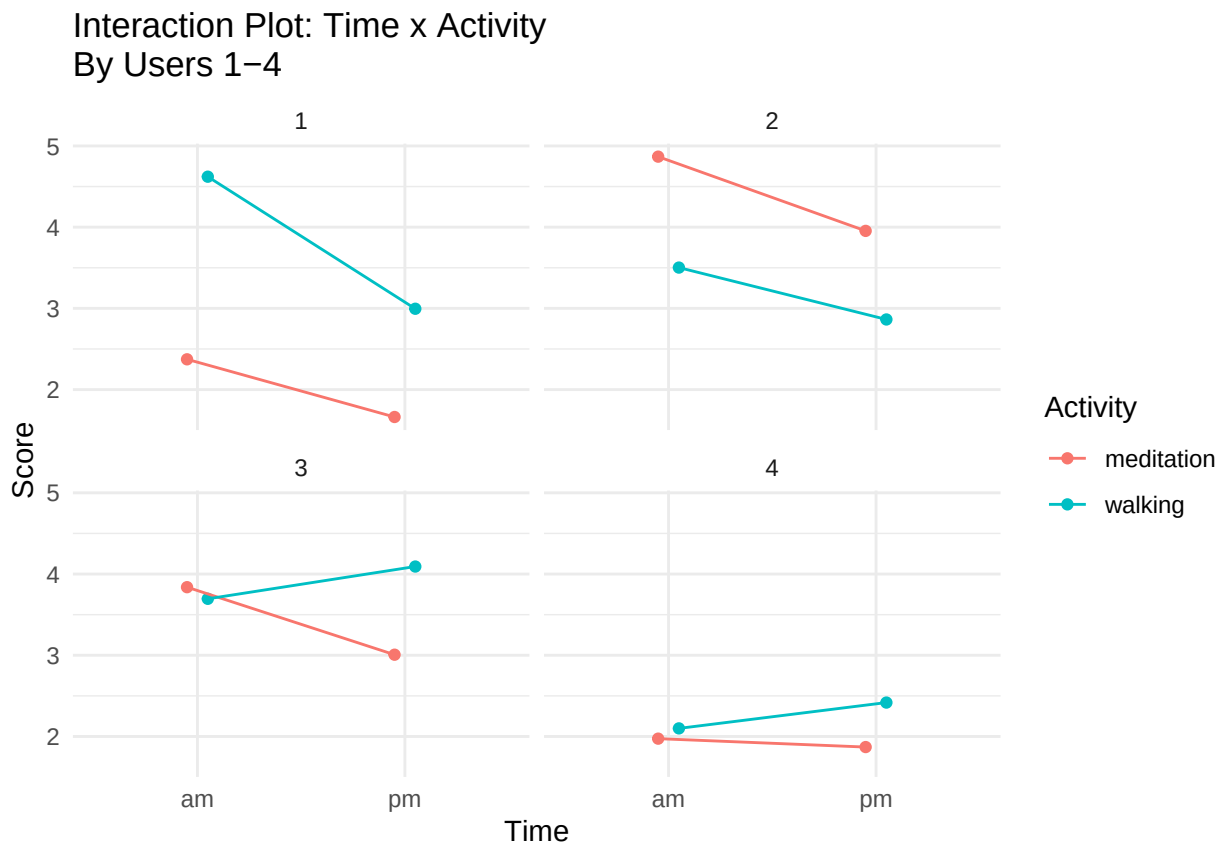
```
anova(wm_aov2)
```

```
## Analysis of Variance Table
##
## Response: Score
##                     Df  Sum Sq Mean Sq F value    Pr(>F)
## Time                 1  4.8225  4.8225  7.4626  0.008845 **
## Activity             1  1.4911  1.4911  2.3074  0.135454
## User                 3 28.7346  9.5782 14.8218 6.340e-07 ***
## Time:Activity        1  0.1911  0.1911  0.2957  0.589179
## Time:User            3  3.7619  1.2540  1.9404  0.135950
## Activity:User        3 18.2854  6.0951  9.4319 5.452e-05 ***
## Time:Activity:User   3  2.2722  0.7574  1.1721  0.330432
## Residuals           47 30.3726  0.6462
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
layout(matrix(1:6, 2, 3)); par(mar = c(4, 4, 2.5, 1.5))
# Check normality
qqnorm(residuals(wm_aov2))
qqline(residuals(wm_aov2))

# Check constant variance
plot(wm$Time, rstudent(wm_aov2), main = "Constant Variance - Time")
plot(wm$Activity, rstudent(wm_aov2), main = "Constant Variance - Activity")
plot(fitted(wm_aov2), resid(wm_aov2), main = "Constant Variance")
```




```r
ggplot(wm, aes(x = Time, y = Score, color = Activity, group = Activity)) +
  stat_summary(fun = mean, geom = "point", position = position_dodge(0.2)) +
  stat_summary(fun = mean, geom = "line", position = position_dodge(0.2)) +
  facet_wrap(~ User) +
  labs(title = "Interaction Plot: Time x Activity\nBy Users 1-4") +
  theme_minimal()
```



Random effect of studying the interaction of blocking factor

```
wm_lmer2 <- lmer(Score ~ Time * Activity
                 + (Time + Activity|User),
                data = wm,
                contrasts = list(Time = "contr.helmert",
                Activity = "contr.helmert"))
```

```
## boundary (singular) fit: see help('isSingular')
```

```
summary(wm_lmer2)
```

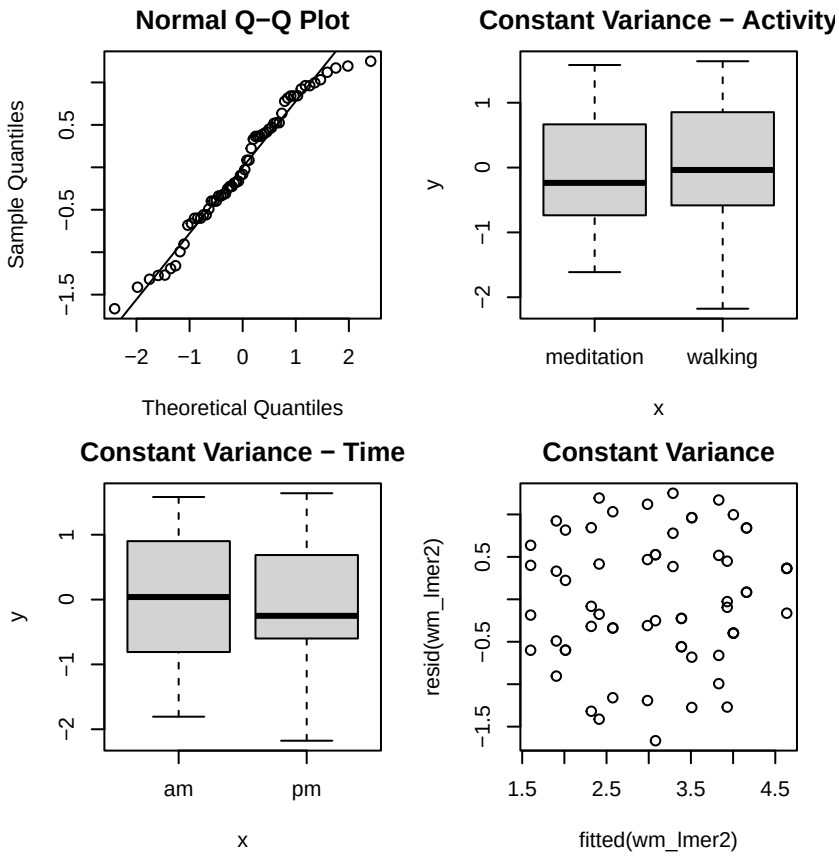
```
## Linear mixed model fit by REML. t-tests use Satterthwaite's method [
## lmerModLmerTest]
## Formula: Score ~ Time * Activity + (Time + Activity | User)
##    Data: wm
##
## REML criterion at convergence: 173
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.0675 -0.6511 -0.1025  0.6521  1.5508
##
```

```
## Random effects:
##  Groups   Name            Variance Std.Dev. Corr
##  User     (Intercept)     1.4960   1.2231
##           Timepm          0.1679   0.4098   -0.38
##           Activitywalking 1.3634   1.1677   -0.73 -0.35
##  Residual                 0.6493   0.8058
## Number of obs: 63, groups:  User, 4
##
## Fixed effects:
##                 Estimate Std. Error       df t value Pr(>|t|)
## (Intercept)      3.10195    0.38775  3.00386   8.000  0.00406 **
## Time1           -0.26937    0.14427  3.64002  -1.867  0.14233
## Activity1        0.15874    0.30909  3.01231   0.514  0.64284
## Time1:Activity1  0.05055    0.10159 53.01758   0.498  0.62080
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Correlation of Fixed Effects:
##             (Intr) Time1  Actvt1
## Time1       -0.425
## Activity1   -0.464 -0.233
## Tm1:Actvty1  0.004  0.012  0.006
## optimizer (nloptwrap) convergence code: 0 (OK)
## boundary (singular) fit: see help('isSingular')
```

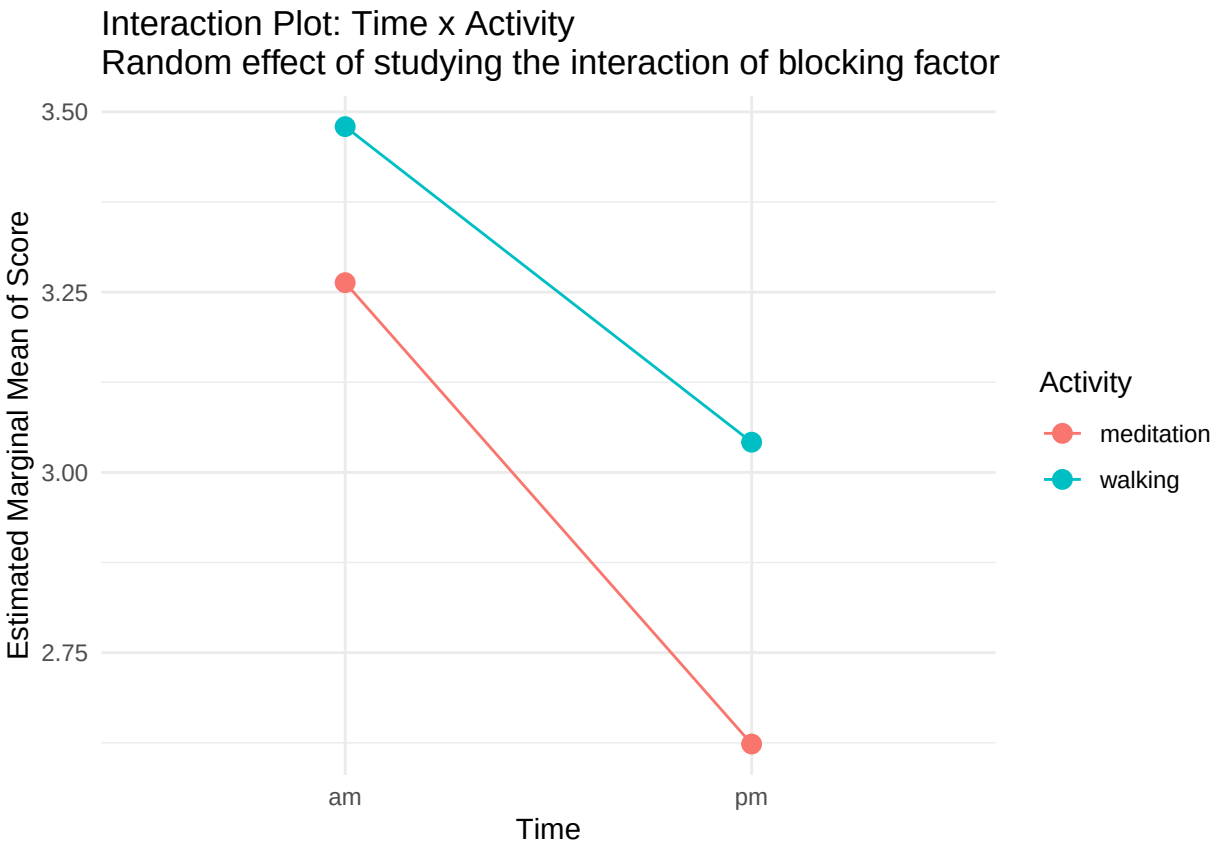
```
ranova(wm_lmer2)
```

```
## ANOVA-like table for random-effects: Single term deletions
##
## Model:
## Score ~ Time + Activity + (Time + Activity | User) + Time:Activity
##                                       npar  logLik    AIC     LRT Df Pr(>Chisq)
## <none>                                  11 -86.501 195.00
## Time in (Time + Activity | User)         8 -87.778 191.56  2.5531  3   0.465778
## Activity in (Time + Activity | User)     8 -94.355 204.71 15.7068  3   0.001302
##
## <none>
## Time in (Time + Activity | User)
## Activity in (Time + Activity | User) **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
layout(matrix(1:6, 2, 3)); par(mar = c(4, 4, 2.5, 1.5))
# Check normality
qqnorm(residuals(wm_lmer2))
qqline(residuals(wm_lmer2))

# Check constant variance
plot(wm$Time, rstudent(wm_lmer2), main = "Constant Variance - Time")
plot(wm$Activity, rstudent(wm_lmer2), main = "Constant Variance - Activity")
plot(fitted(wm_lmer2), resid(wm_lmer2), main = "Constant Variance")
```




```r
# Interaction Plot

# Estimate Marginal Means
emm_wm_lmer2 <- emmeans(wm_lmer2, ~ Time * Activity)
emm_df_wm_lmer2 <- as.data.frame(emm_wm_lmer2) # as DF

# Interaction plot
ggplot(emm_df_wm_lmer2, aes(x = Time, y = emmean, group = Activity, color = Activity)) +
  geom_point(size = 3) +
  geom_line() +
  labs(title = "Interaction Plot: Time x Activity\nRandom effect of studying the interaction of blockin
       y = "Estimated Marginal Mean of Score") +
  theme_minimal()
```


Interaction Plot: Time x Activity
Random effect of studying the interaction of blocking factor
Estimated Marginal Mean of Score
3.50
3.25
3.00
2.75
am
pm
Time
Activity
meditation
walking