Mixed-Factorial ANOVA Demo

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2025-04-01

Mixed Factorial ANOVA | Research Context Prompt

The same stress researcher from our previous demonstration conducted another study to determine the impact of psychosocial stress on participants processing speed ability using a mixed-factorial research design.

The researcher randomly assigned 30 participants to one of two stress conditions: (1) Low Stress and (2) High Stress. Participants were assessed at three separate times across their academic career (Sophomore, Junior, and Senior) measuring a new processing speed performance measure. The dependent measure in this task was processing speed ability measured in milliseconds (500 ms = .5 seconds).

Again, this researcher believed that regulating feelings of stress would impair concurrent performance of processing speed and that these effects would materialize across time.

Mixed Factorial ANOVA | Data

```
library(psych)
library(tidyverse)
library(jmv)
library(ggpubr)
library(apaTables)
library(ez)
library(rstatix)
library(reshape)

dat_MF <- read.csv("Mixed_Factorial.csv")
dat_MF$Time <- 1000 - dat_MF$Time

# SUPER IMPORTANT FOR WITHIN SUBJECT DESIGNS
# Set Subject or ID variable to a factor
dat_MF$Subject <- factor(dat_MF$Subject)

# Set IVs to factors
dat_MF$Condition <- factor(dat_MF$Condition, labels = c("Low-Stress","High-Stress"))
dat_MF$Rank <- factor(dat_MF$Rank, labels = c("Sophomore", "Junior", "Senior"))

# Assess number of participants and variables in data set
dim(dat_MF)
```

```
## [1] 90  4
```

```
head(dat_MF)
```

```
##   Subject   Condition      Rank Time
## 1       1  Low-Stress Sophomore  488
## 2       1  Low-Stress    Junior  459
## 3       1  Low-Stress    Senior  397
## 4       2 High-Stress Sophomore  490
## 5       2 High-Stress    Junior  446
## 6       2 High-Stress    Senior  404
```

```
# To use anovaRM() we must reshape our data set from `long` to `wide`
dat_MFW <- cast(dat_MF,
                Subject + Condition ~ Rank, #Isolates each ID and Condition to form columns for
Rank
                value = "Time")             #Tells function to use Time variable to fill in Rank
s

dat_MFW$averageTime <- (dat_MFW$Sophomore + dat_MFW$Junior + dat_MFW$Senior) / 3 # This is used
later for assumption checking
```

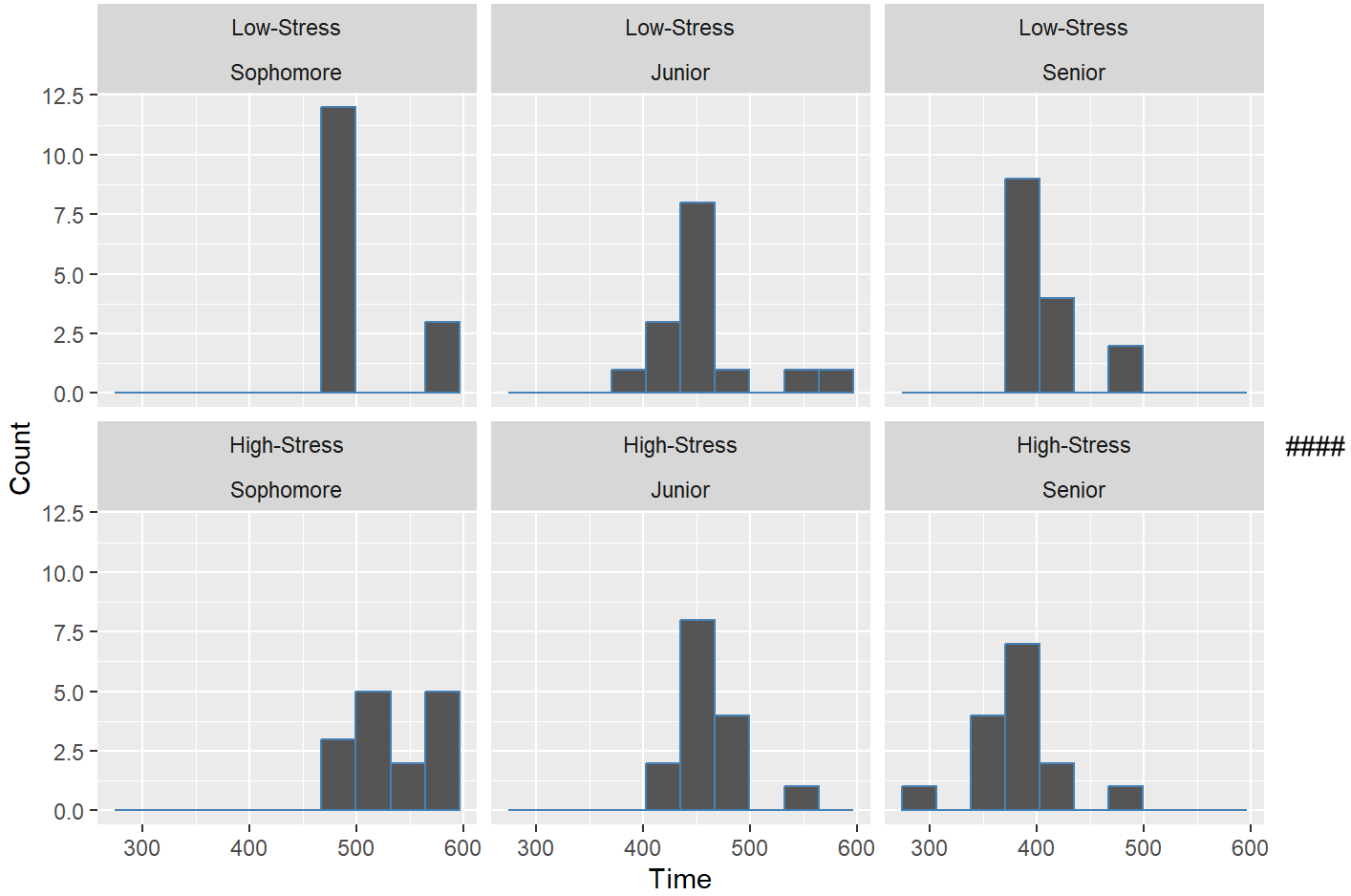
Mixed Factorial ANOVA | Descriptive Stats

```
# Descriptive Stats
describeBy(dat_MF$Time,
           list(dat_MF$Condition, dat_MF$Rank),
           mat=TRUE)
```

```
##     item      group1    group2 vars  n     mean       sd median  trimmed
## X11    1  Low-Stress Sophomore    1 15 503.2667 40.83672    488 499.4615
## X12    2 High-Stress Sophomore    1 15 534.4000 36.12834    520 533.6923
## X13    3  Low-Stress    Junior    1 15 456.4000 46.65650    441 452.1538
## X14    4 High-Stress    Junior    1 15 464.1333 26.90955    463 460.8462
## X15    5  Low-Stress    Senior    1 15 412.6667 33.77164    402 408.5385
## X16    6 High-Stress    Senior    1 15 381.5333 42.05416    384 379.4615
##          mad min max range      skew  kurtosis        se
## X11  8.8956 468 588   120 1.2901196 -0.135849 10.543997
## X12 44.4780 488 590   102 0.1840255 -1.659049  9.328298
## X13 28.1694 400 568   168 1.1918834  0.467006 12.046655
## X14 23.7216 431 540   109 1.2570249  1.603398  6.948016
## X15  8.8956 382 497   115 1.7747683  1.588227  8.719800
## X16 26.6868 300 490   190 0.5465190  1.044874 10.858337
```

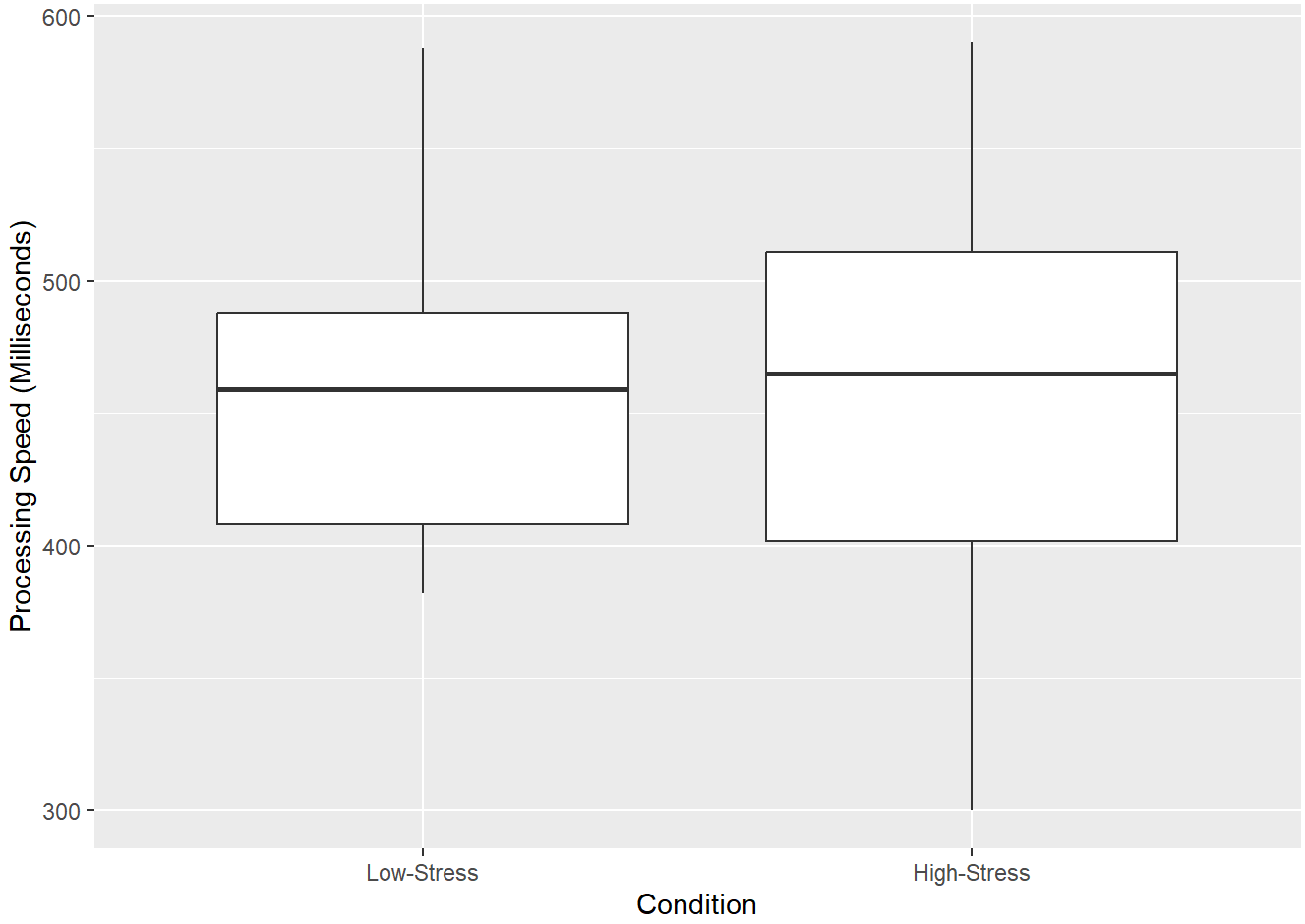
Mixed Factorial ANOVA | Histogram

```
ggplot(data = dat_MF,
       mapping = aes(x = Time)) +
  geom_histogram(bins = 10, color = "steelblue") +
  labs(y = "Count", x = "Time")+
  facet_wrap(~dat_MF$Condition + dat_MF$Rank)
```



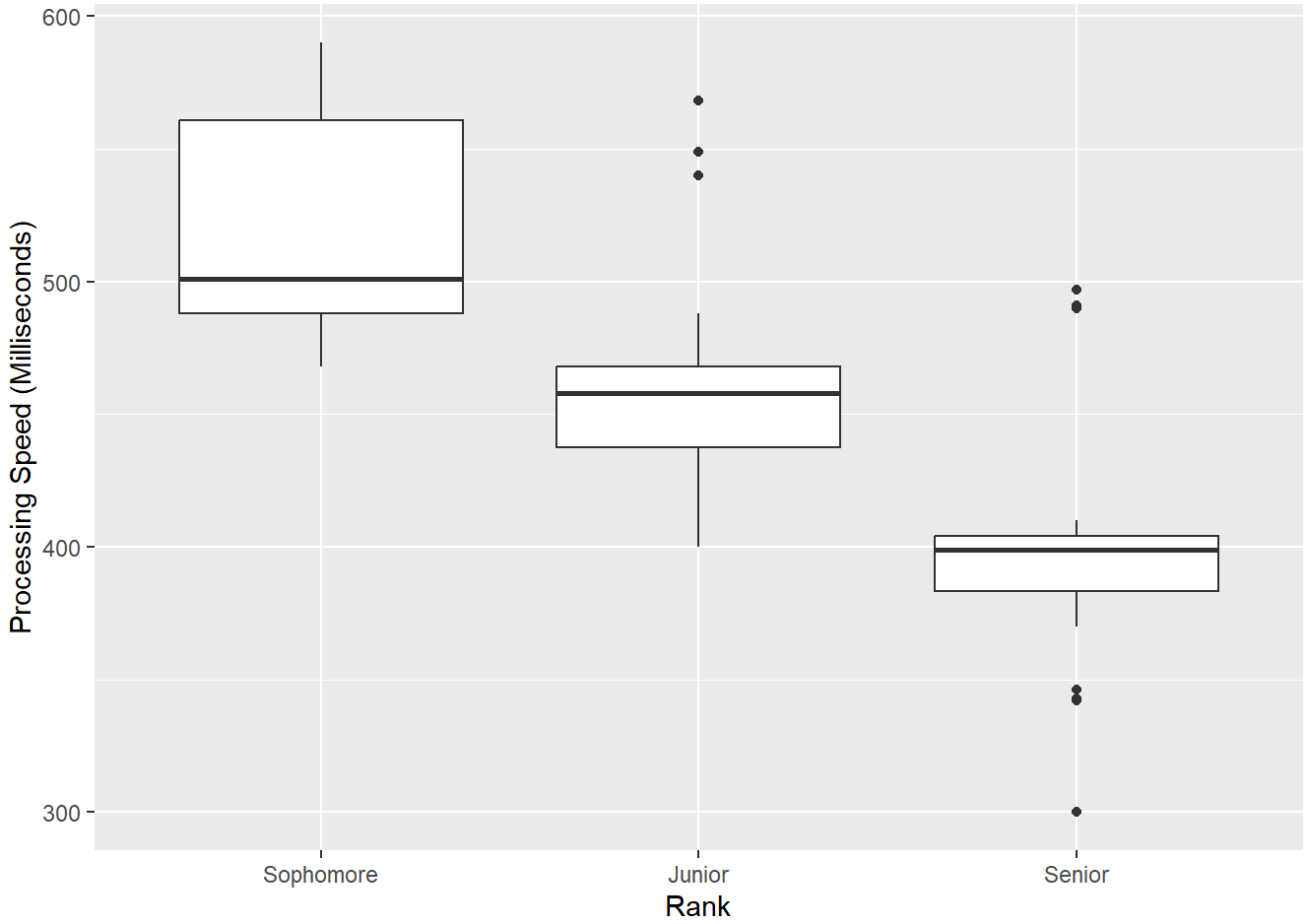
Mixed Factorial ANOVA | Boxplot

```
ggplot(data = dat_MF,
       mapping = aes(y = Time, x = Condition)) +
  geom_boxplot() +
    labs(y = "Processing Speed (Milliseconds)")
```



Mixed Factorial ANOVA | Boxplot

```
ggplot(data = dat_MF,
       mapping = aes(y = Time, x = Rank)) +
  geom_boxplot() +
    labs(y = "Processing Speed (Milliseconds)")
```

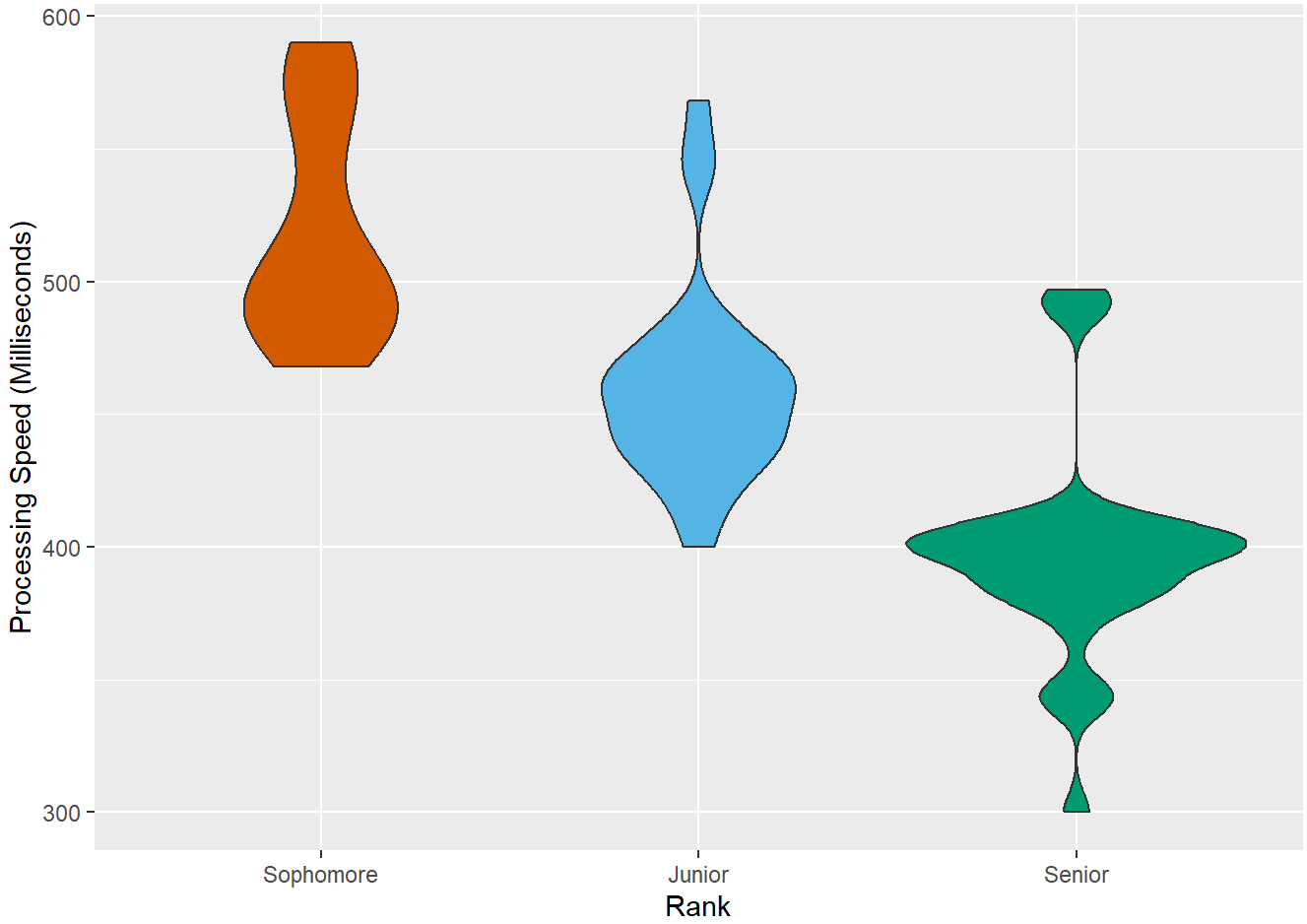


Mixed Factorial ANOVA | Violin Plot

```
ggplot(data = dat_MF,
       aes(x = Condition, y = Time,
           fill = Condition))+
  geom_violin(show.legend=FALSE)+
  ylab("Processing Speed (Milliseconds)")+
  xlab("Condition")+
  scale_fill_manual(values=c("#D55e00","#56B4E9","#009E73"))
```

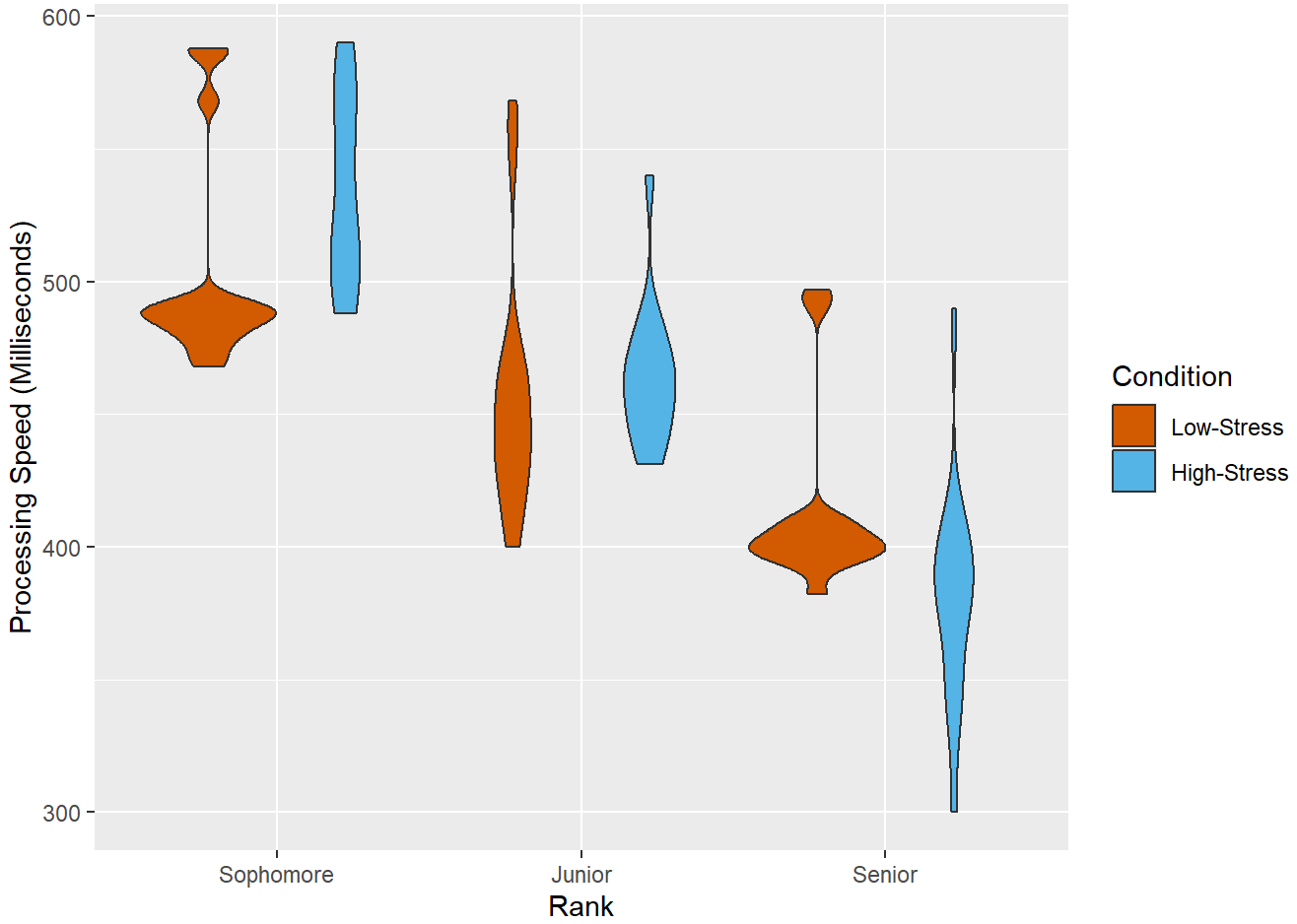
Mixed Factorial ANOVA | Violin Plot

```
ggplot(data = dat_MF,
       aes(x = Rank, y = Time,
           fill = Rank))+
  geom_violin(show.legend=FALSE)+
  ylab("Processing Speed (Milliseconds)")+
  xlab("Rank")+
  scale_fill_manual(values=c("#D55e00","#56B4E9","#009E73"))
```



Mixed Factorial ANOVA | Grouped Violin Plot

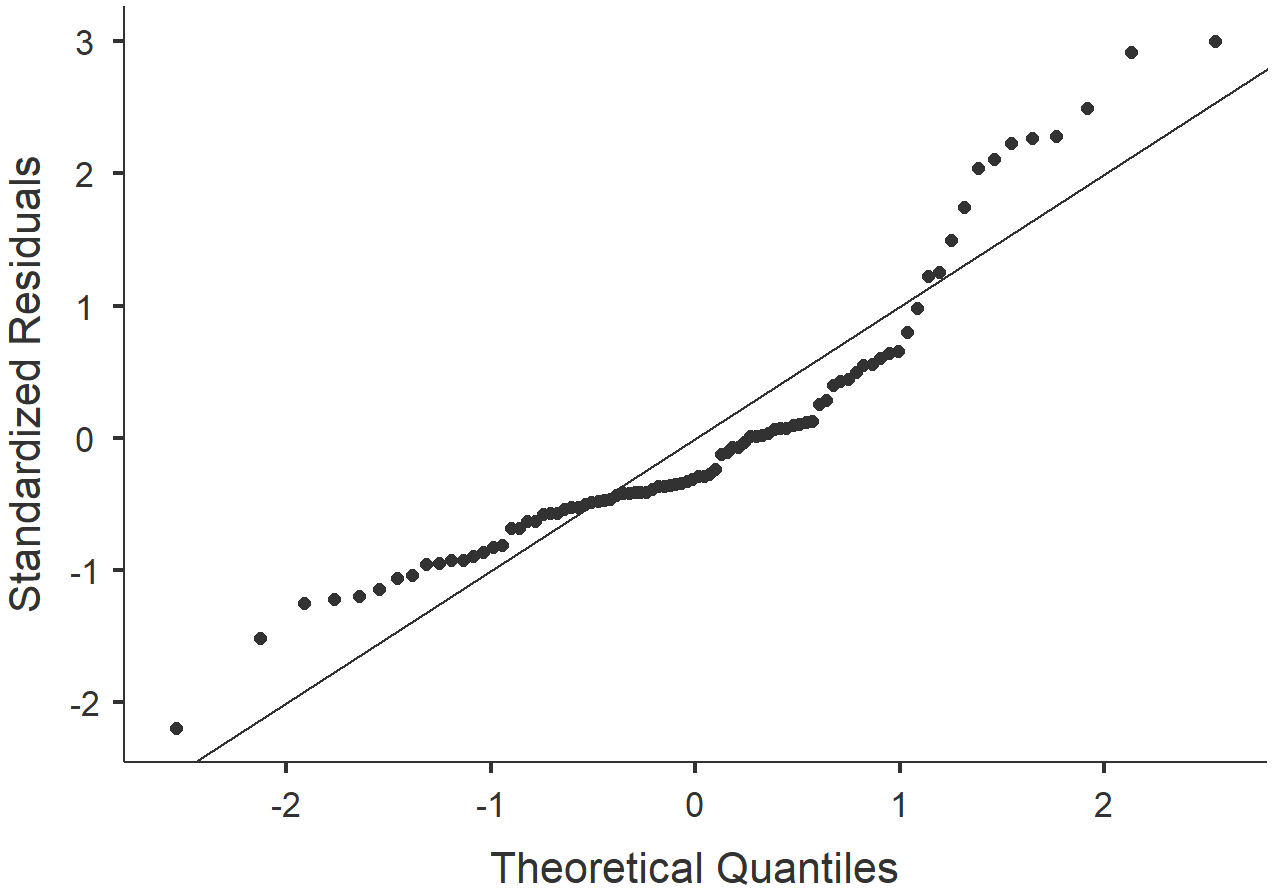
```
ggplot(data = dat_MF,
       aes(x = Rank, y = Time,
           fill = Condition))+
  geom_violin(show.legend=TRUE)+
  ylab("Processing Speed (Milliseconds)")+
  xlab("Rank")+
  scale_fill_manual(values=c("#D55e00","#56B4E9","#009E73"))
```



Mixed Factorial ANOVA | anovaRM() Omnibus Assumption Checks

```
anovaRM(data=dat_MFW,
        bs = list('Condition'),
        bsTerms = list('Condition'),
        rm = list(
             list(label = 'Rank',
                  levels = list('Sophomore',
                                'Junior',
                                'Senior'))),
        rmCells = list(
           list(measure = 'Sophomore',
                cell = 'Sophomore'),
           list(measure = 'Junior',
                cell = 'Junior'),
           list(measure = 'Senior',
                cell = 'Senior')),
        rmTerms= list('Rank'),
        leveneTest = TRUE,
        qq = TRUE,
        spherTests = TRUE)
```

```
##
##  REPEATED MEASURES ANOVA
##
##  Within Subjects Effects
##  ──────────────────────────────────────────────────────────────────────────────
##                      Sum of Squares    df    Mean Square    F            p
##  ──────────────────────────────────────────────────────────────────────────────
##    Rank                   222390.87     2    111195.4333    158.38122    < .0000001
##    Rank:Condition          14838.29     2      7419.1444     10.56746     0.0001277
##    Residual                39316.18    56       702.0746
##  ──────────────────────────────────────────────────────────────────────────────
##    Note. Type 3 Sums of Squares
##
##
##  Between Subjects Effects
##  ──────────────────────────────────────────────────────────────────────────
##                 Sum of Squares    df    Mean Square    F             p
##  ──────────────────────────────────────────────────────────────────────────
##    Condition           149.5111     1       149.5111    0.05004870    0.8246028
##    Residual          83644.7556    28      2987.3127
##  ──────────────────────────────────────────────────────────────────────────
##    Note. Type 3 Sums of Squares
##
##
##  ASSUMPTIONS
##
##  Tests of Sphericity
##  ──────────────────────────────────────────────────────────────────────────────
##            Mauchly's W    p            Greenhouse-Geisser ε    Huynh-Feldt ε
##  ──────────────────────────────────────────────────────────────────────────────
##    Rank      0.6845379    0.0059961               0.7601891        0.7947804
##  ──────────────────────────────────────────────────────────────────────────────
##
##
##  Homogeneity of Variances Test (Levene's)
##  ──────────────────────────────────────────────────────
##                 F             df1    df2    p
##  ──────────────────────────────────────────────────────
##    Sophomore    0.02578285      1     28    0.8735846
##    Junior       2.03565460      1     28    0.1647047
##    Senior       0.32438535      1     28    0.5735255
##  ──────────────────────────────────────────────────────
```



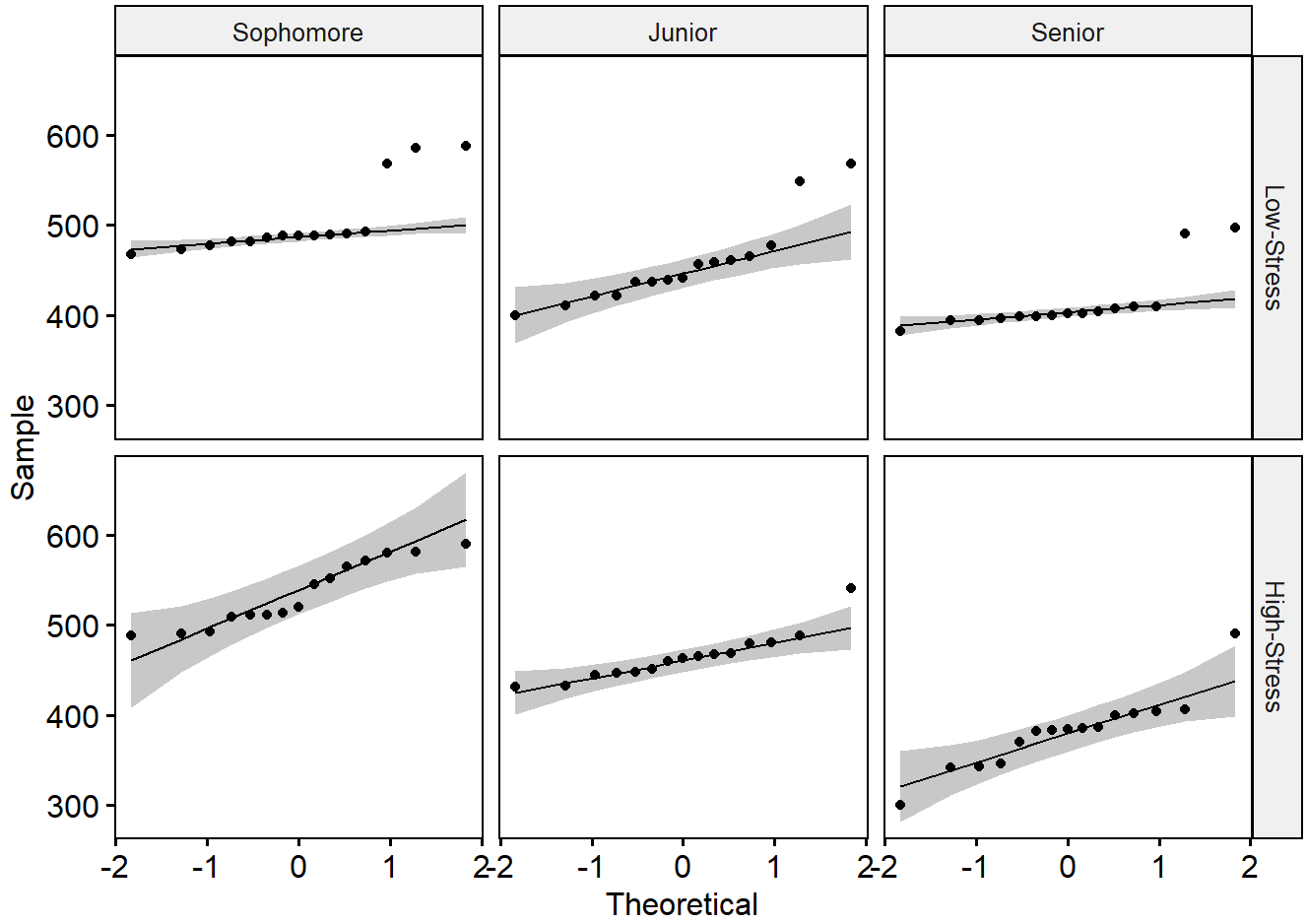
Mixed Factorial ANOVA | Group Level Assumption Checks

```
dat_MF %>%
  group_by(Condition, Rank) %>%
  shapiro_test(Time)
```

```
## # A tibble: 6 × 5
##   Condition   Rank      variable statistic         p
##   <fct>       <fct>     <chr>        <dbl>     <dbl>
## 1 Low-Stress  Sophomore Time         0.672 0.000126
## 2 Low-Stress  Junior    Time         0.841 0.0131
## 3 Low-Stress  Senior    Time         0.617 0.0000365
## 4 High-Stress Sophomore Time         0.901 0.0977
## 5 High-Stress Junior    Time         0.875 0.0395
## 6 High-Stress Senior    Time         0.899 0.0935
```

Mixed Factorial ANOVA | Group Level Assumption Checks

```
ggqqplot(dat_MF,
         'Time',
         facet.by = c("Condition","Rank"))
```



Mixed Factorial ANOVA | Group Level Assumption Checks

```
dat_MFW %>%
  levene_test(averageTime ~ Condition,
              center = mean)
```

```
## # A tibble: 1 × 4
##     df1   df2 statistic     p
##   <int> <int>     <dbl> <dbl>
## 1     1    28      1.90 0.179
```

Mixed Factorial ANOVA | Group Level Assumption Checks

```
# Must be conducted ON A MATRIX!! Also, note that it is using the long version of the data!

box_m(as.data.frame(dat_MF$Time),
      dat_MF$Condition)
```

```
## # A tibble: 1 × 4
##   statistic p.value parameter method
##       <dbl>   <dbl>     <dbl> <chr>
## 1      3.31  0.0690         1 Box's M-test for Homogeneity of Covariance Matric…
```

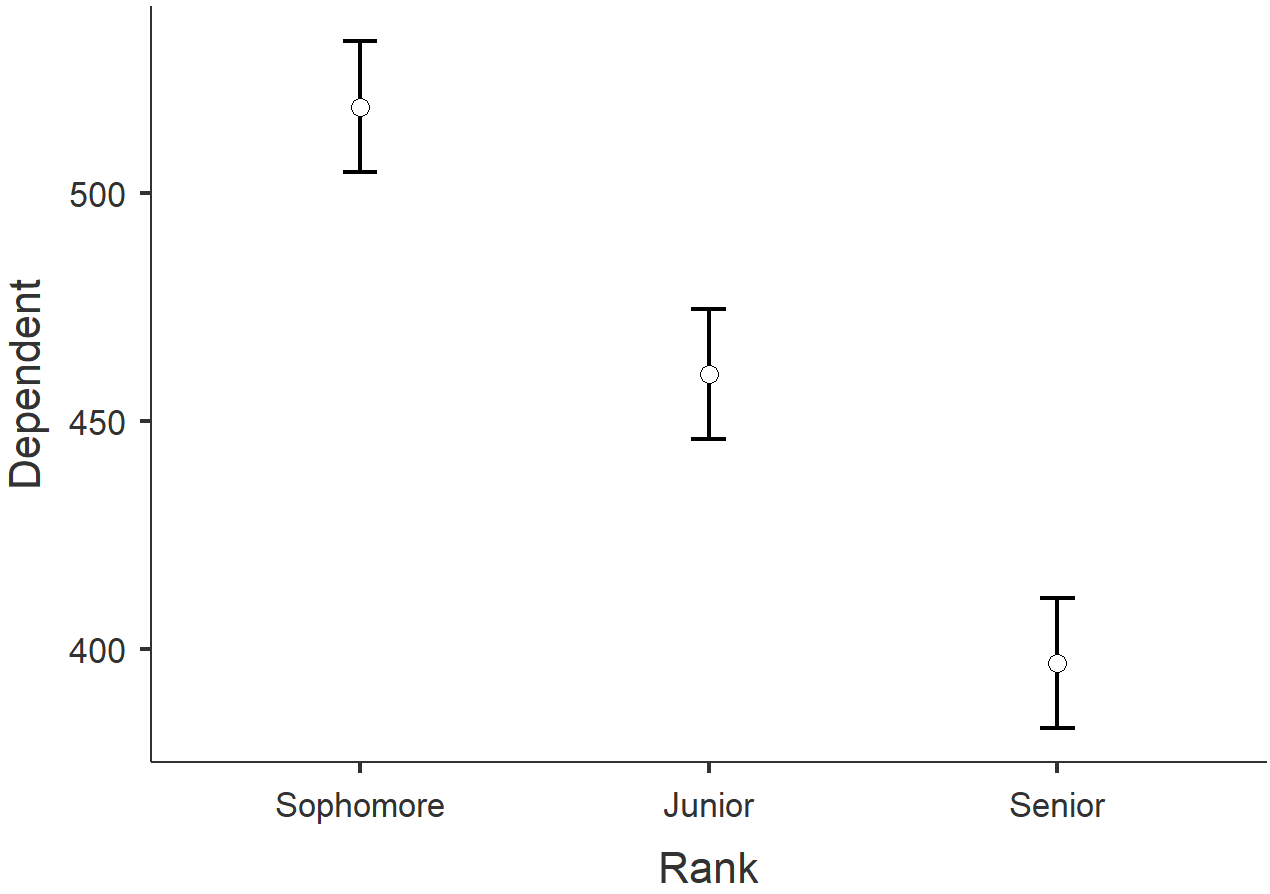
Mixed Factorial ANOVA | Conducting the ANOVA

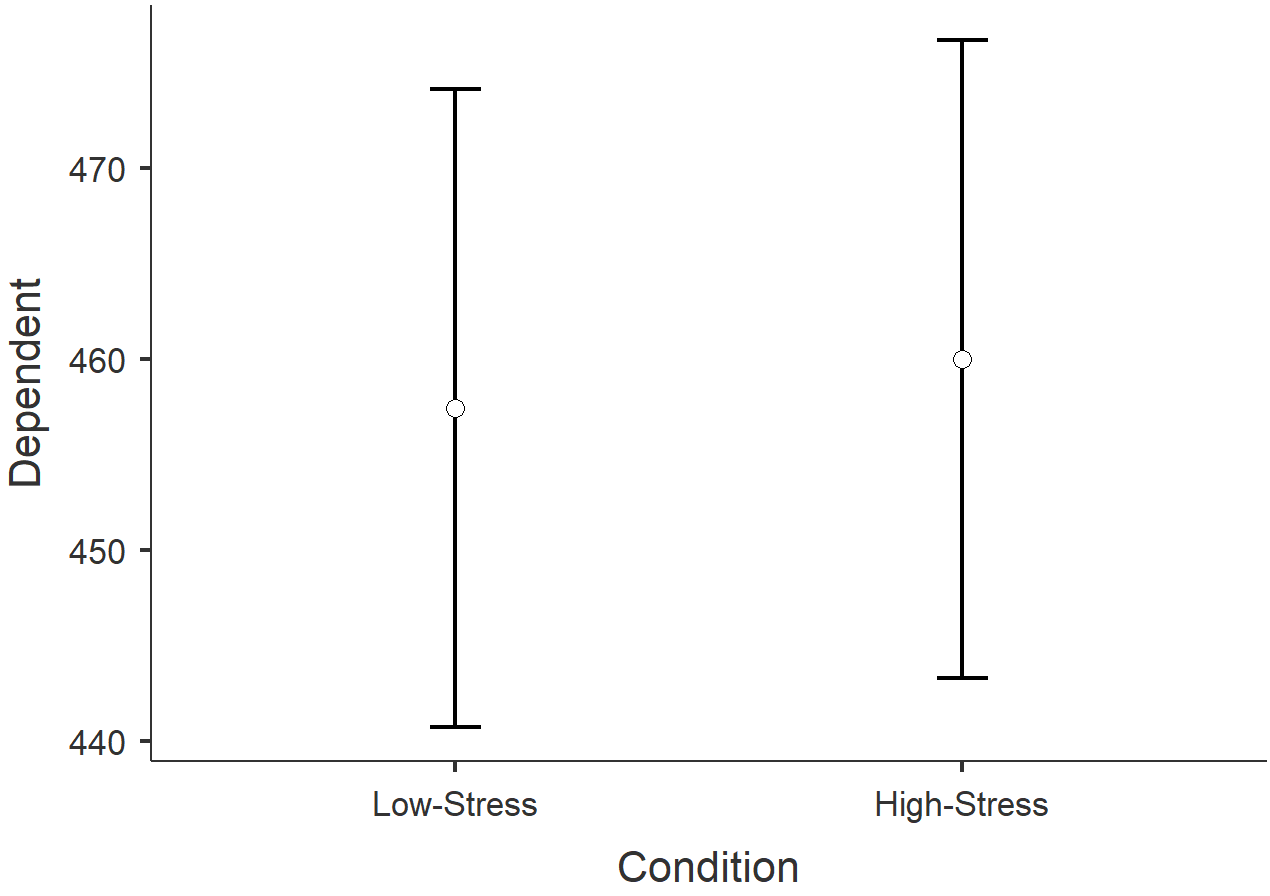
```
options(digits = 3)
anovaRM(data = dat_MFW,
        bs = list('Condition'),
        bsTerms = list('Condition'),
        rm = list(
             list(label = 'Rank',
                  levels = list('Sophomore',
                                'Junior',
                                'Senior'))),
        rmCells = list(
           list(measure = 'Sophomore',
                cell = 'Sophomore'),
           list(measure = 'Junior',
                cell = 'Junior'),
           list(measure = 'Senior',
                cell = 'Senior')),
        rmTerms = list('Rank'),
        postHoc = list('Rank', c('Rank','Condition')),
        postHocCorr = 'bonf',
        emMeans = list('Rank','Condition', c('Rank','Condition')),
        emmPlots = TRUE,
        emmTables = TRUE,
        effectSize = 'partEta')
```

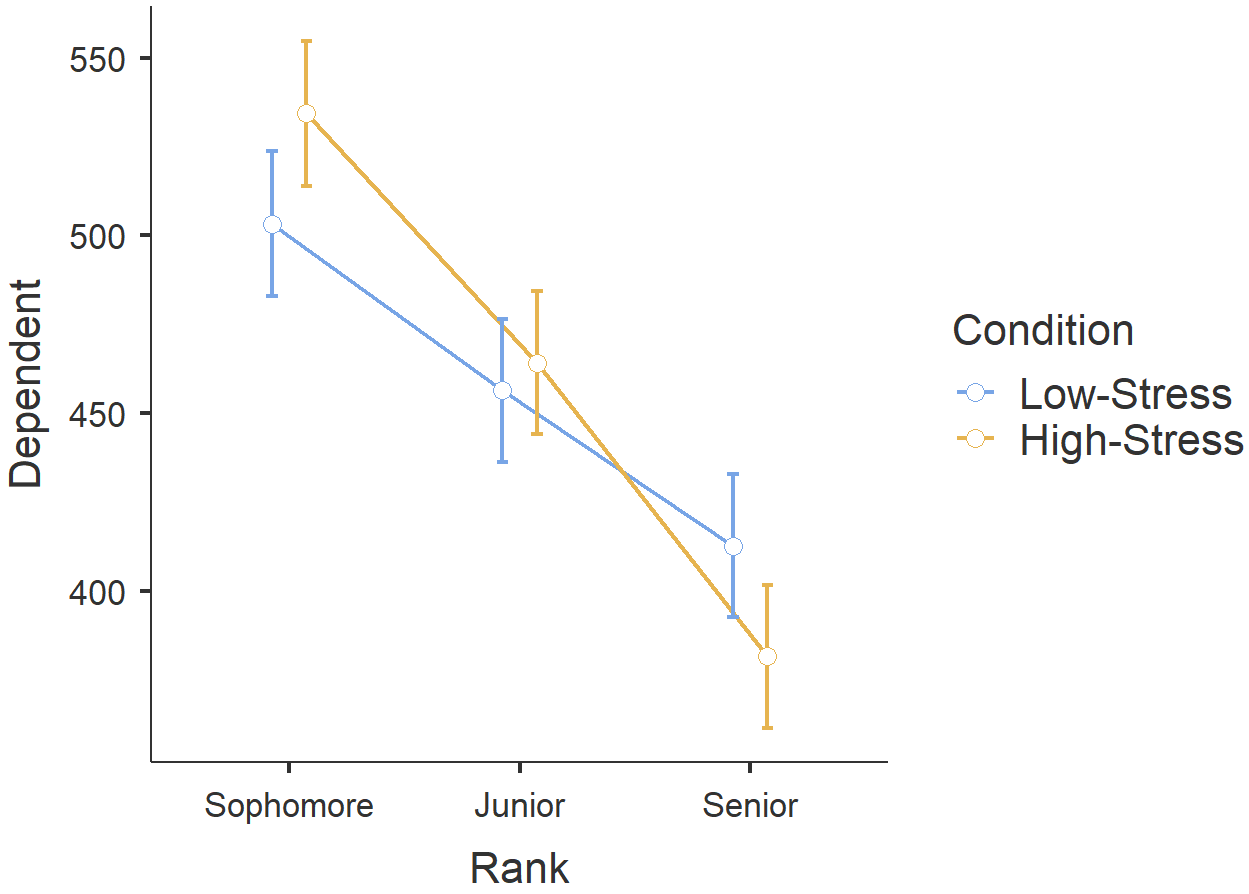
```
##
##  REPEATED MEASURES ANOVA
##
##  Within Subjects Effects
##  ──────────────────────────────────────────────────────────────────────────────
##                      Sum of Squares    df    Mean Square    F        p         η²-p
##  ──────────────────────────────────────────────────────────────────────────────
##    Rank                      222391     2         111195    158.4    < .001    0.850
##    Rank:Condition             14838     2           7419     10.6    < .001    0.274
##    Residual                   39316    56            702
##  ──────────────────────────────────────────────────────────────────────────────
##    Note. Type 3 Sums of Squares
##
##
##  Between Subjects Effects
##  ──────────────────────────────────────────────────────────────────────
##                 Sum of Squares    df    Mean Square    F         p        η²-p
##  ──────────────────────────────────────────────────────────────────────
##    Condition               150     1            150    0.0500    0.825    0.002
##    Residual              83645    28           2987
##  ──────────────────────────────────────────────────────────────────────
##    Note. Type 3 Sums of Squares
##
##
##  POST HOC TESTS
##
##  Post Hoc Comparisons - Rank
##  ──────────────────────────────────────────────────────────────────────────────────────
##    Rank              Rank      Mean Difference    SE      df      t       p-bonferroni
##  ──────────────────────────────────────────────────────────────────────────────────────
##    Sophomore    -    Junior              58.6    5.62    28.0    10.4    < .001
##                 -    Senior             121.7    8.54    28.0    14.2    < .001
##    Junior       -    Senior              63.2    5.98    28.0    10.6    < .001
##  ──────────────────────────────────────────────────────────────────────────────────────
##
##
##  Post Hoc Comparisons - Rank:Condition
##  ──────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────
──────────────────────────────
##    Rank         Condition           Rank         Condition      Mean Difference    SE       d
f      t         p-bonferroni
##  ──────────────────────────────────────────────────────────────────────────────────────────────────────────────────────────
──────────────────────────────
##    Sophomore    Low-Stress     -    Sophomore    High-Stress            -31.13    14.08    2
8.0    -2.211           0.530
##                                -    Junior       Low-Stress              46.87     7.95    2
8.0     5.893    < .001
##                                -    Junior       High-Stress             39.13    13.99    2
8.0     2.797           0.138
##                                -    Senior       Low-Stress              90.60    12.08    2
8.0     7.499    < .001
##                                -    Senior       High-Stress            121.73    14.00    2
```

```
8.0     8.694    < .001
##                High-Stress    -    Junior       Low-Stress               78.00    13.99    2
8.0     5.574    < .001
##                                -    Junior       High-Stress              70.27     7.95    2
8.0     8.835    < .001
##                                -    Senior       Low-Stress              121.73    14.00    2
8.0     8.694    < .001
##                                -    Senior       High-Stress             152.87    12.08    2
8.0    12.653    < .001
##    Junior       Low-Stress     -    Junior       High-Stress              -7.73    13.91    2
8.0    -0.556          1.000
##                                -    Senior       Low-Stress               43.73     8.46    2
8.0     5.168    < .001
##                                -    Senior       High-Stress              74.87    13.92    2
8.0     5.380    < .001
##                High-Stress    -    Senior       Low-Stress               51.47    13.92    2
8.0     3.698          0.014
##                                -    Senior       High-Stress              82.60     8.46    2
8.0     9.761    < .001
##    Senior       Low-Stress     -    Senior       High-Stress              31.13    13.93    2
8.0     2.236          0.503
##  ──────────────────────────────────────────────────────────────────────────────────────────
──────────────────────────────
##
##
##  ESTIMATED MARGINAL MEANS
##
##  RANK
##
##  Estimated Marginal Means - Rank
##  ──────────────────────────────────────────────────
##    Rank          Mean    SE      Lower    Upper
##  ──────────────────────────────────────────────────
##    Sophomore      519    7.04      504      533
##    Junior         460    6.95      446      475
##    Senior         397    6.96      383      411
##  ──────────────────────────────────────────────────
##
##
##  CONDITION
##
##  Estimated Marginal Means - Condition
##  ──────────────────────────────────────────────────
##    Condition      Mean    SE      Lower    Upper
##  ──────────────────────────────────────────────────
##    Low-Stress      457    8.15      441      474
##    High-Stress     460    8.15      443      477
##  ──────────────────────────────────────────────────
##
##
##  RANK:CONDITION
##
```

```
##  Estimated Marginal Means - Rank:Condition
##  ──────────────────────────────────────────────────────────────────
##    Condition      Rank         Mean    SE      Lower    Upper
##  ──────────────────────────────────────────────────────────────────
##    Low-Stress     Sophomore     503    9.95      483      524
##                   Junior        456    9.83      436      477
##                   Senior        413    9.85      392      433
##    High-Stress    Sophomore     534    9.95      514      555
##                   Junior        464    9.83      444      484
##                   Senior        382    9.85      361      402
##  ──────────────────────────────────────────────────────────────────
```


Dependent
500
450
400
Sophomore
Junior
Senior
Rank


Dependent
470
460
450
440
Low-Stress
High-Stress
Condition



Mixed Factorial ANOVA | ANOVA Output: Interaction Simple Effects

```
one.way <- dat_MF %>%
  group_by(Condition) %>%
  anova_test(dv = Time,
             wid = Subject,
             within = Rank,
             effect.size = 'ges') %>%
  get_anova_table() %>%
  adjust_pvalue(method = "bonferroni")

one.way
```

```
## # A tibble: 2 × 9
##   Condition   Effect   DFn   DFd     F        p `p<.05`   ges    p.adj
##   <fct>       <chr>  <dbl> <dbl> <dbl>    <dbl> <chr>   <dbl>    <dbl>
## 1 Low-Stress  Rank    2     28    86.5 1.04e-12 *       0.469 2.08e-12
## 2 High-Stress Rank    1.33  18.6  83.8 4.9 e- 9 *       0.768 9.8 e- 9
```

```
one.way2 <- dat_MF %>%
  group_by(Rank) %>%
  anova_test(dv = Time,
             between = Condition,
             effect.size = 'ges') %>%
  get_anova_table() %>%
  adjust_pvalue(method = "bonferroni")

one.way2
```

```
## # A tibble: 3 × 9
##   Rank      Effect      DFn   DFd     F     p `p<.05`   ges p.adj
##   <fct>     <chr>     <dbl> <dbl> <dbl> <dbl> <chr>   <dbl> <dbl>
## 1 Sophomore Condition     1    28 4.89  0.035 "*"     0.149 0.105
## 2 Junior    Condition     1    28 0.309 0.583 ""      0.011 1
## 3 Senior    Condition     1    28 5.00  0.034 "*"     0.151 0.102
```

Demonstrates that there are significant differences between the Ranks for participants in the Low-Stress [$F(2, 28) = 86.50$, $p < .001$] and High-Stress [$F(1.33, 18.64) = 83.79$, $p < .001$] conditions—furthermore, there is an issue of Sphericity demonstrated for the High-Stress condition (note the degrees of freedom!).

Mixed Factorial ANOVA | Professional ANOVA Visualization Code

```
# Generates Marginal Means for Visualization--the p-values here are more appropriate to interpre
t compared to the chunk above!
pair <- dat_MF %>%
  group_by(Rank) %>%
  pairwise_t_test(Time~Condition,
                  p.adjust.method = "bonferroni") %>%
  add_xy_position(x = "Rank",
                  group = "Condition")

pair
```

```
## # A tibble: 3 × 15
##   Rank      .y.   group1  group2    n1    n2      p p.signif  p.adj p.adj.signif
##   <fct>     <chr> <chr>   <chr>  <int> <int>  <dbl> <chr>     <dbl> <chr>
## 1 Sophomore Time  Low-St… High-…    15    15 0.0353 *        0.0353 *
## 2 Junior    Time  Low-St… High-…    15    15 0.583  ns       0.583  ns
## 3 Senior    Time  Low-St… High-…    15    15 0.0335 *        0.0335 *
## # ℹ 5 more variables: y.position <dbl>, groups <named list>, x <dbl>,
## #   xmin <dbl>, xmax <dbl>
```

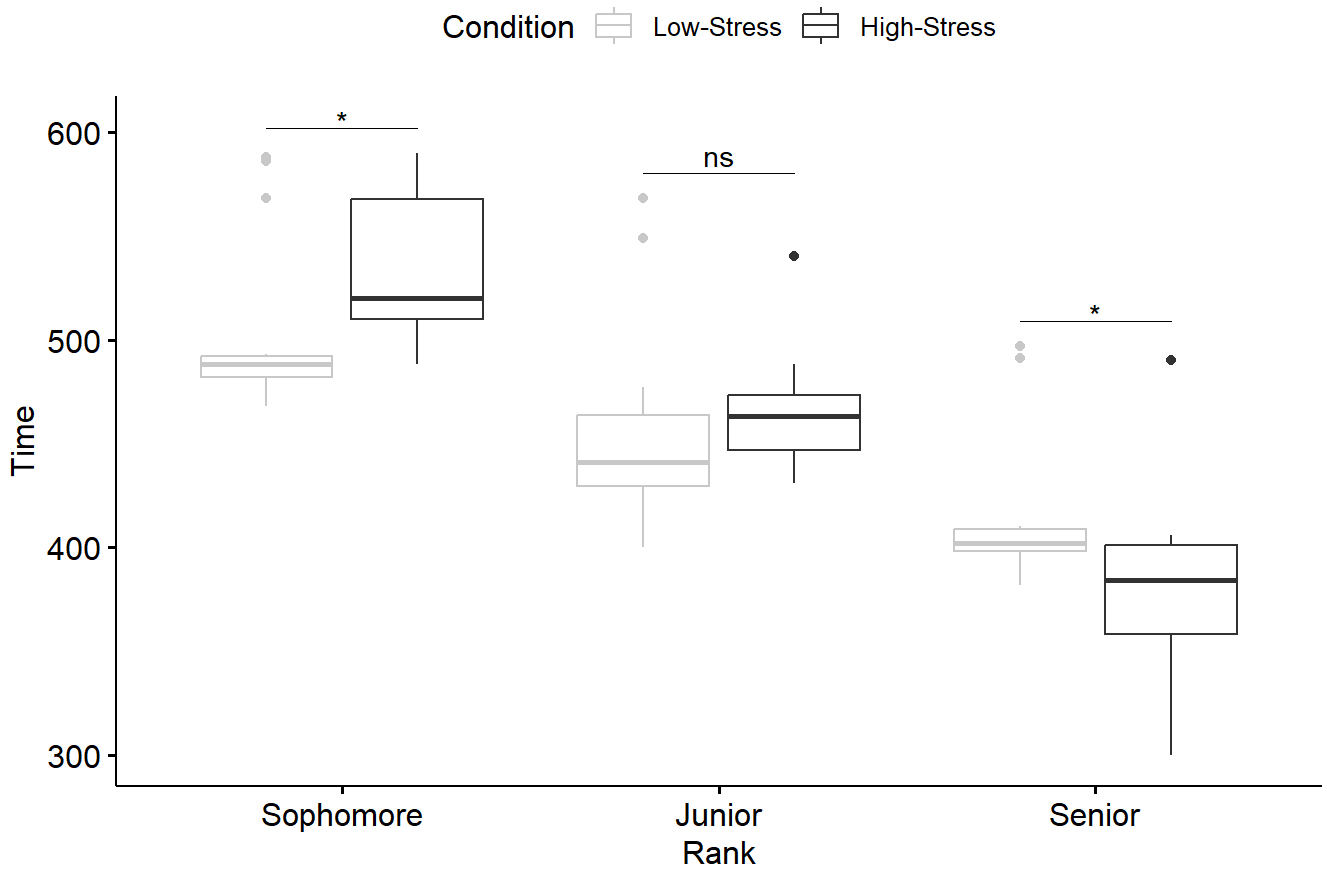
```
pair2 <- dat_MF %>%
  group_by(Condition) %>%
  pairwise_t_test(Time~Rank,
                  p.adjust.method = "bonferroni") %>%
  add_xy_position(x = "Condition",
                  group = "Rank")

pair2
```

```
## # A tibble: 6 × 15
##   Condition   .y.   group1    group2    n1    n2        p p.signif    p.adj
##   <fct>       <chr> <chr>     <chr>  <int> <int>    <dbl> <chr>       <dbl>
## 1 Low-Stress  Time  Sophomore Junior    15    15 3.02e- 3 **       9.05e- 3
## 2 Low-Stress  Time  Sophomore Senior    15    15 2.98e- 7 ****     8.94e- 7
## 3 Low-Stress  Time  Junior    Senior    15    15 5.34e- 3 **       1.6 e- 2
## 4 High-Stress Time  Sophomore Junior    15    15 2.8 e- 6 ****     8.41e- 6
## 5 High-Stress Time  Sophomore Senior    15    15 7.04e-15 ****     2.11e-14
## 6 High-Stress Time  Junior    Senior    15    15 1.21e- 7 ****     3.64e- 7
## # ℹ 6 more variables: p.adj.signif <chr>, y.position <dbl>,
## #   groups <named list>, x <dbl>, xmin <dbl>, xmax <dbl>
```

Demonstrates that the difference between high- and low-stress conditions only materialized when participants were in their Sophomore (p = .04) and Senior (p = .03) years, but not when they were Juniors (p = .58)

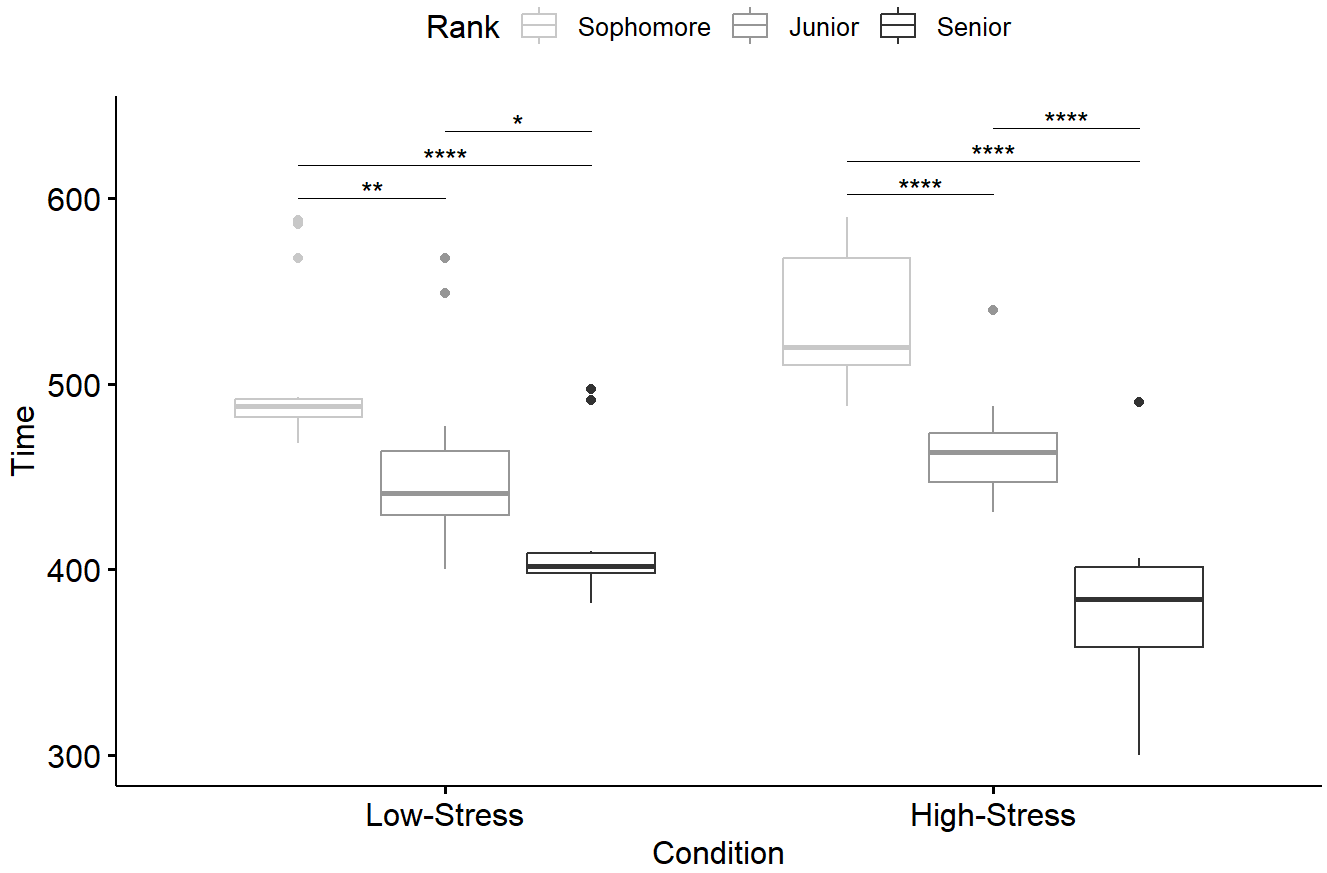
Mixed Factorial ANOVA | Professional ANOVA Visualization Code

```
ggboxplot(dat_MF,
          x = "Rank",
          y = "Time",
          color = "Condition",
          palette = "grey")+
  stat_pvalue_manual(pair,
                     hide.ns = FALSE,
                     tip.length = 0)+
  labs(
    caption = get_pwc_label(pair)
  )
```



pwc: **T test**; p.adjust: **Bonferroni**

```
ggboxplot(dat_MF,
          x = "Condition",
          y = "Time",
          color = "Rank",
          palette = "grey")+
  stat_pvalue_manual(pair2,
                     hide.ns = FALSE,
                     tip.length = 0)+
  labs(
    caption = get_pwc_label(pair2)
  )
```



pwc: **T test**; p.adjust: **Bonferroni**

Mixed Factorial ANOVA | APA Style ANOVA Tables

```
res.aov <- dat_MF %>% ezANOVA(dv = .(Time),
                              wid = .(Subject),
                              between= Condition,
                              within = .(Rank),
                              detailed = TRUE)

res.aov$ANOVA$ges <- res.aov$ANOVA$SSn/(res.aov$ANOVA$SSn+res.aov$ANOVA$SSd)

res.aov$ANOVA<-res.aov$ANOVA[c(1:3,6:7,9)]


apa.ezANOVA.table(res.aov,
                  table.title = "Mixed Factorial ANOVA",
                  correction="GG",
                  filename = "This is my file.doc",
                  table.number=7)
```

```
##
##
## Table 7
##
## Mixed Factorial ANOVA
##
##         Predictor df_num df_den Epsilon       F    p  ges
##       (Intercept)   1.00  28.00         6339.90 .000 1.00
##         Condition   1.00  28.00            0.05 .825  .00
##              Rank   1.52  42.57    0.76  158.38 .000  .85
##  Condition x Rank   1.52  42.57    0.76   10.57 .001  .27
##
## Note. df_num indicates degrees of freedom numerator. df_den indicates degrees of freedom deno
minator.
## Epsilon indicates Greenhouse-Geisser multiplier for degrees of freedom,
## p-values and degrees of freedom in the table incorporate this correction.
## ges indicates generalized eta-squared.
##
```

```
#Generate Marginal Means Table
apa.2way.table(Rank,
               Condition,
               Time,
               dat_MF,
               table.number=8,
               show.conf.interval = TRUE)
```

```
##
##
## Table 8
##
## Means and standard deviations for Time as a function of a 3(Rank) X 2(Condition) design
##
##                              M         M_95%_CI    SD
##   Condition:Low-Stress
##                     Rank
##              Sophomore 503.27 [480.65, 525.88] 40.84
##                 Junior 456.40 [430.56, 482.24] 46.66
##                 Senior 412.67 [393.96, 431.37] 33.77
##
##  Condition:High-Stress
##                     Rank
##              Sophomore 534.40 [514.39, 554.41] 36.13
##                 Junior 464.13 [449.23, 479.04] 26.91
##                 Senior 381.53 [358.24, 404.82] 42.05
##
## Note. M and SD represent mean and standard deviation, respectively.
## LL and UL indicate the lower and upper limits of the
## 95% confidence interval for the mean, respectively.
## The confidence interval is a plausible range of population means
## that could have created a sample mean (Cumming, 2014).
```