

Supplement for Lecture 26: Two-Way ANOVA

```
Exams = read.csv("Exams4.csv")
Exams
```

```
##      Student Exam Grade
## 1      Barb    1    62
## 2      Barb    2    87
## 3      Barb    3    74
## 4      Barb    4    77
## 5     Betsy    1    94
## 6     Betsy    2    95
## 7     Betsy    3    86
## 8     Betsy    4    89
## 9      Bill    1    68
## 10     Bill    2    93
## 11     Bill    3    82
## 12     Bill    4    73
## 13     Bob     1    86
## 14     Bob     2    97
## 15     Bob     3    70
## 16     Bob     4    79
## 17     Bud     1    50
## 18     Bud     2    63
## 19     Bud     3    28
## 20     Bud     4    47
```

```
amodExam = aov(Grade~factor(Exam),data=Exams)
amodStudent = aov(Grade~Student,data=Exams)
amodBoth = aov(Grade~factor(Exam)+Student,data=Exams)
```

```
summary(amodExam)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)
## factor(Exam)  3   1030    343.3   1.056  0.395
## Residuals    16   5200    325.0
```

```
summary(amodStudent)
```

```
##              Df Sum Sq Mean Sq F value    Pr(>F)
## Student        4   4480   1120.0     9.6 0.000468 ***
## Residuals      15   1750    116.7
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
summary(amodBoth)
```

```
##              Df Sum Sq Mean Sq F value    Pr(>F)
## factor(Exam)  3   1030    343.3   5.722  0.0114 *
## Student        4   4480   1120.0  18.667 0.0000435 ***
## Residuals      12    720     60.0
```

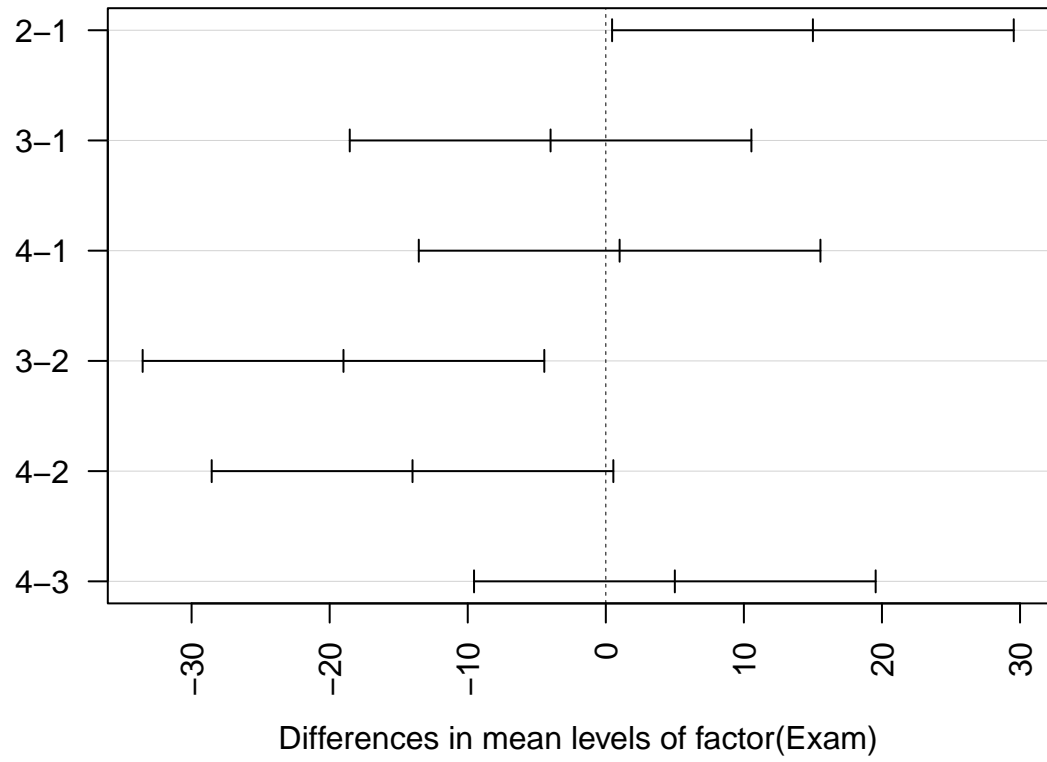
```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

TukeyHSD(amodBoth)

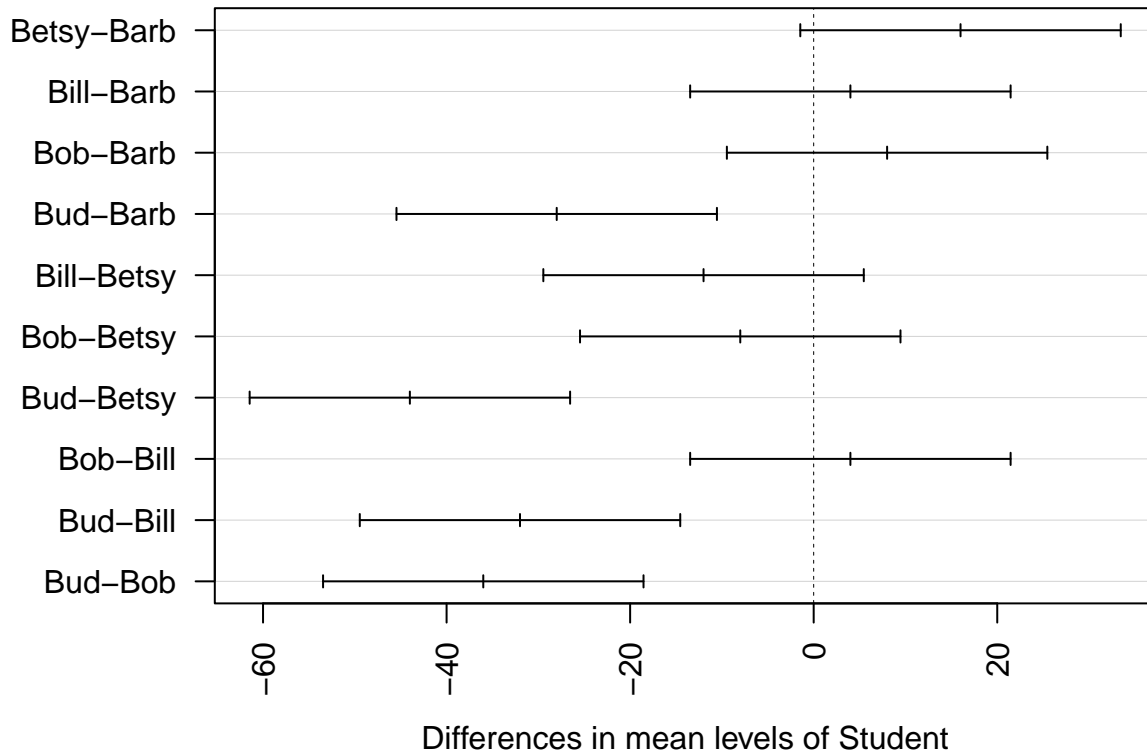
##    Tukey multiple comparisons of means
##      95% family-wise confidence level
##
## Fit: aov(formula = Grade ~ factor(Exam) + Student, data = Exams)
##
## $`factor(Exam)`
##      diff      lwr      upr      p adj
## 2-1    15    0.4554143 29.5445857 0.0425678
## 3-1    -4 -18.5445857 10.5445857 0.8455825
## 4-1     1 -13.5445857 15.5445857 0.9968212
## 3-2   -19 -33.5445857 -4.4554143 0.0102092
## 4-2   -14 -28.5445857  0.5445857 0.0605331
## 4-3     5  -9.5445857 19.5445857 0.7409734
##
## $Student
##      diff      lwr      upr      p adj
## Betsy-Barb   16  -1.458285 33.458285 0.0782719
## Bill-Barb     4 -13.458285 21.458285 0.9451946
## Bob-Barb      8  -9.458285 25.458285 0.6039841
## Bud-Barb    -28 -45.458285 -10.541715 0.0019421
## Bill-Betsy   -12 -29.458285  5.458285 0.2467758
## Bob-Betsy    -8 -25.458285  9.458285 0.6039841
## Bud-Betsy   -44 -61.458285 -26.541715 0.0000293
## Bob-Bill      4 -13.458285 21.458285 0.9451946
## Bud-Bill    -32 -49.458285 -14.541715 0.0006169
## Bud-Bob     -36 -53.458285 -18.541715 0.0002093

par(mar=c(4,7,3,1))
hsd=TukeyHSD(amodBoth)
plot(hsd,las=2)
```

95% family-wise confidence level



95% family-wise confidence level



```
par(mar=c(5,4,2,2))
```

```
glue= read.csv("Glue.csv")
glue
```

```
##      Force Thickness  Type
## 1      52      thin plastic
## 2      64      thin plastic
## 3      67 moderate plastic
## 4      55 moderate plastic
## 5      86      heavy plastic
## 6      72      heavy plastic
## 7      72      thin  wood
## 8      60      thin  wood
## 9      78 moderate  wood
## 10     68 moderate  wood
## 11     43      heavy  wood
## 12     51      heavy  wood
```

```
#Check if Balanced
table(glue$Thickness,glue$Type)
```

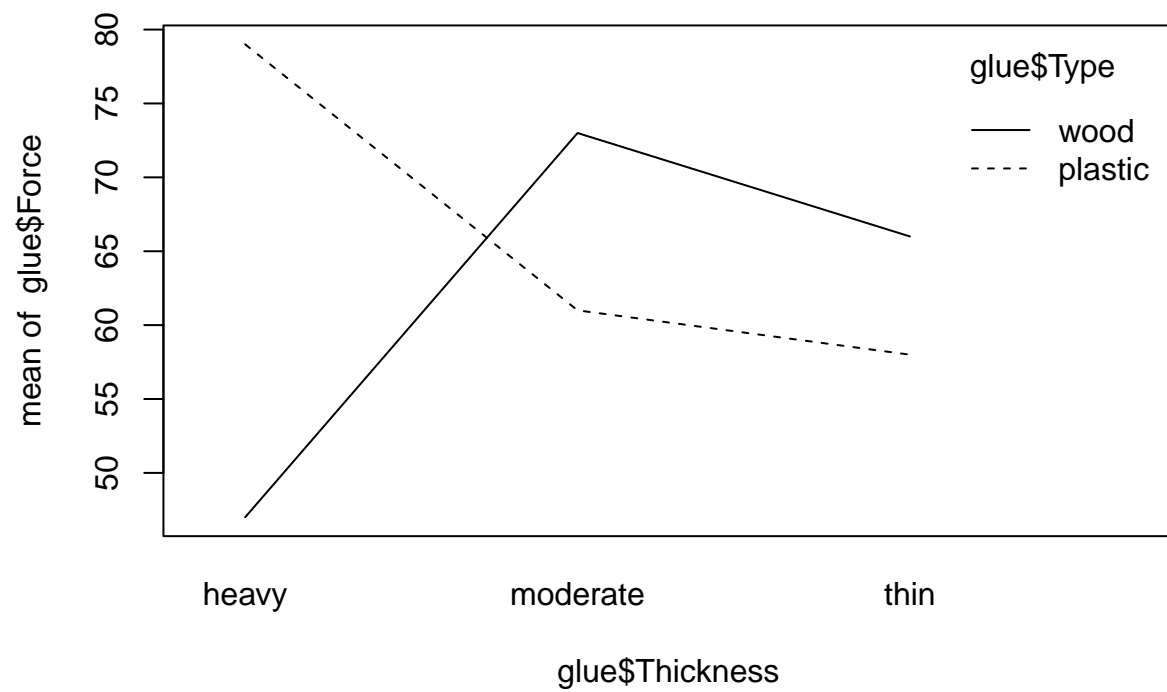
```
##
##           plastic wood
## heavy           2    2
## moderate        2    2
## thin            2    2
```

```
#Interaction Plots (Mean)
```

```
interaction.plot(glue$Type, glue$Thickness, glue$Force)
```



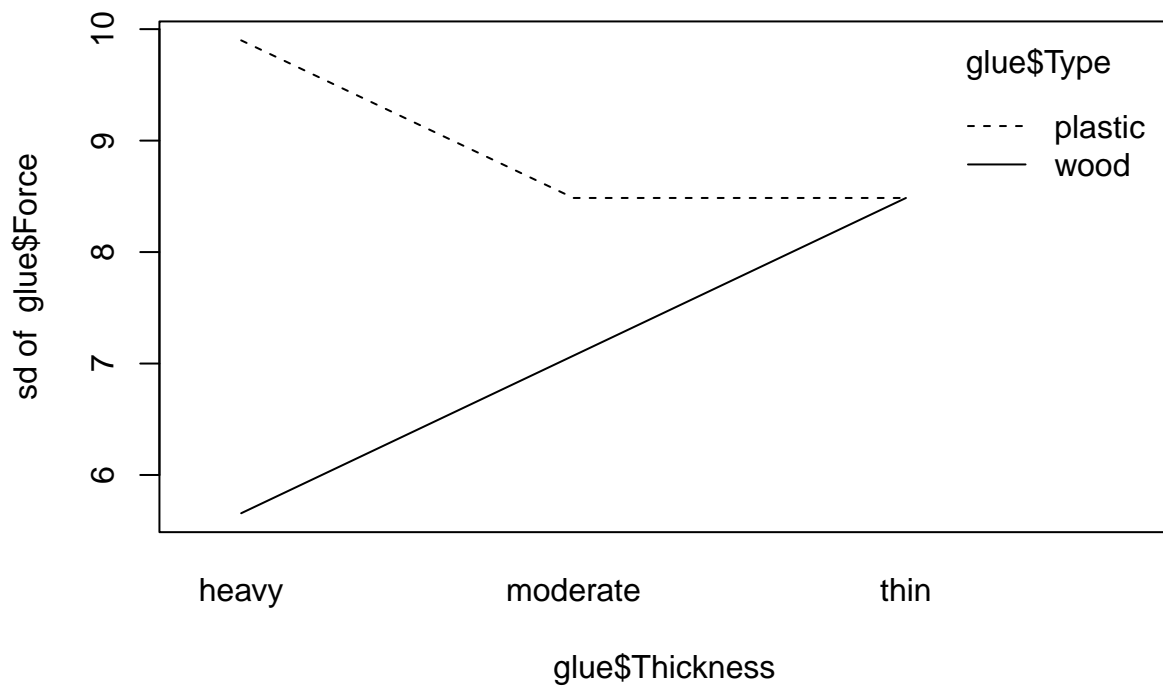
```
interaction.plot(glue$Thickness, glue$Type, glue$Force)
```



```
#Check Homoscedasticity  
interaction.plot(glue$Type, glue$Thickness, glue$Force, fun=sd)
```



```
interaction.plot(glue$Thickness, glue$Type, glue$Force, fun=sd)
```



#One-Way ANOVA

```
THICK = aov(Force~Thickness,data=glue)
summary(THICK)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)
## Thickness    2     56    28.0    0.155  0.859
## Residuals    9    1628   180.9
```

```
TYPE = aov(Force~Type,data=glue)
summary(TYPE)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)
## Type          1     48    48.0    0.293  0.6
## Residuals    10    1636   163.6
```

#Two-Way ANOVA

```
BOTH = aov(Force~Thickness+Type,data=glue)
summary(BOTH)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)
## Thickness    2     56    28.0    0.142  0.870
## Type          1     48    48.0    0.243  0.635
## Residuals    8    1580   197.5
```

#Two-Way ANOVA with Interaction

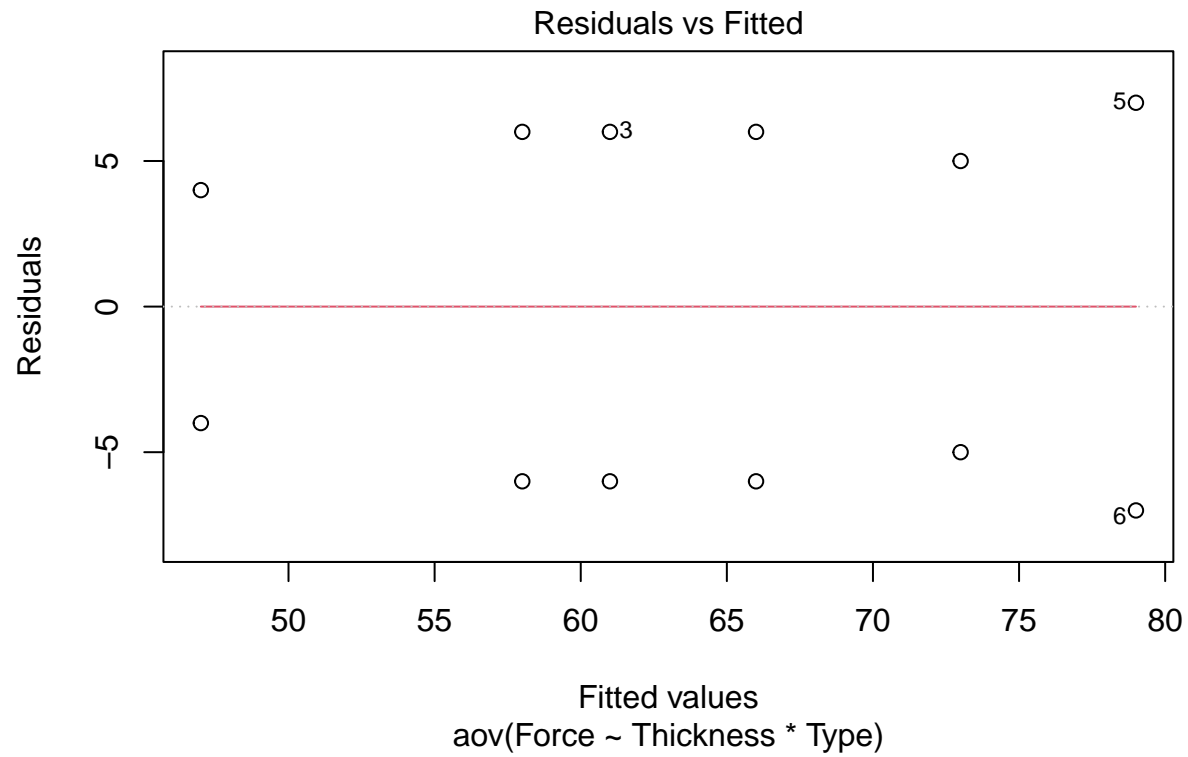
```
INTERACT = aov(Force~Thickness*Type,data=glue)
summary(INTERACT)
```

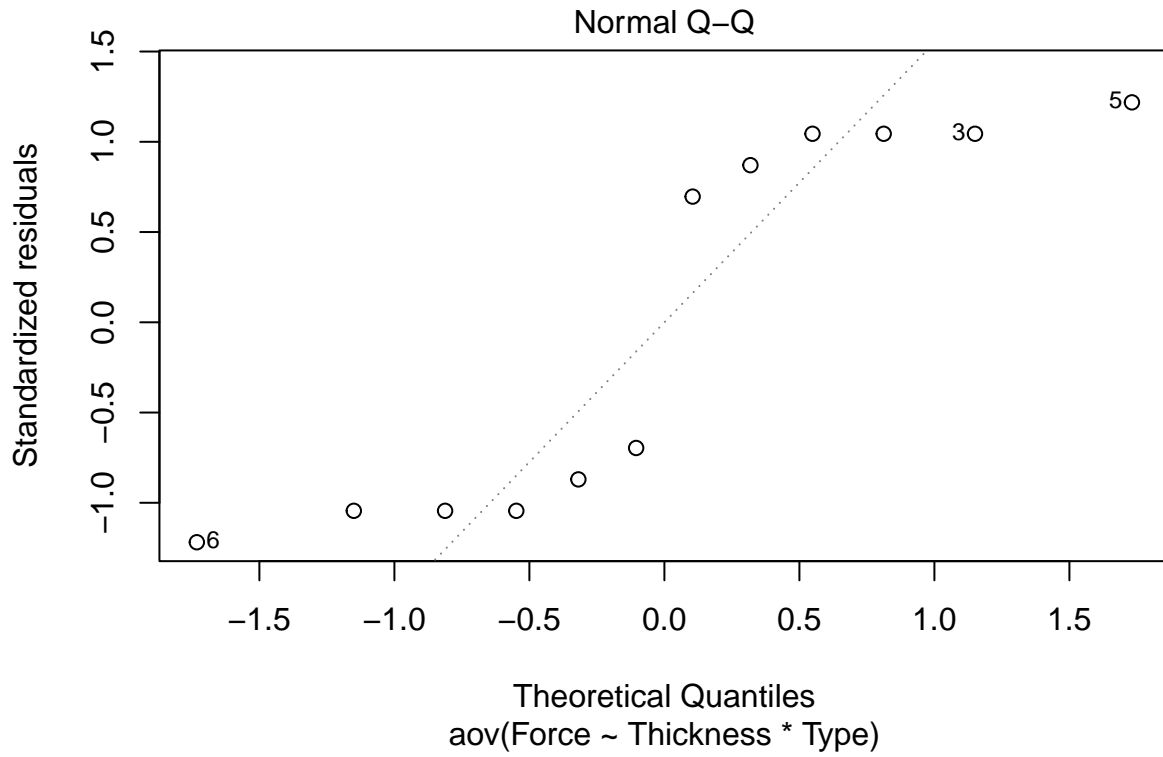
```
##              Df Sum Sq Mean Sq F value Pr(>F)
```



```
## Thickness      2      56      28  0.424 0.6725
## Type           1      48      48  0.727 0.4265
## Thickness:Type  2    1184     592  8.970 0.0157 *
## Residuals      6     396      66
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
plot(INTERACT,1:2)
```





TukeyHSD(INTERACT) [[3]]

| ## | diff | lwr | upr | p adj |
|-----------------------------------|------|------------|------------|------------|
| ## moderate:plastic-heavy:plastic | -18 | -50.332428 | 14.3324278 | 0.34807983 |
| ## thin:plastic-heavy:plastic | -21 | -53.332428 | 11.3324278 | 0.23314331 |
| ## heavy:wood-heavy:plastic | -32 | -64.332428 | 0.3324278 | 0.05221773 |
| ## moderate:wood-heavy:plastic | -6 | -38.332428 | 26.3324278 | 0.96899179 |
| ## thin:wood-heavy:plastic | -13 | -45.332428 | 19.3324278 | 0.62593788 |
| ## thin:plastic-moderate:plastic | -3 | -35.332428 | 29.3324278 | 0.99859074 |
| ## heavy:wood-moderate:plastic | -14 | -46.332428 | 18.3324278 | 0.56373264 |
| ## moderate:wood-moderate:plastic | 12 | -20.332428 | 44.3324278 | 0.68900279 |
| ## thin:wood-moderate:plastic | 5 | -27.332428 | 37.3324278 | 0.98556366 |
| ## heavy:wood-thin:plastic | -11 | -43.332428 | 21.3324278 | 0.75096887 |
| ## moderate:wood-thin:plastic | 15 | -17.332428 | 47.3324278 | 0.50393184 |
| ## thin:wood-thin:plastic | 8 | -24.332428 | 40.3324278 | 0.90749729 |
| ## moderate:wood-heavy:wood | 26 | -6.332428 | 58.3324278 | 0.11707970 |
| ## thin:wood-heavy:wood | 19 | -13.332428 | 51.3324278 | 0.30526529 |
| ## thin:wood-moderate:wood | -7 | -39.332428 | 25.3324278 | 0.94318574 |