Math 3080 § 1. **Humidification Data: Two Factor ANOVA** Name: Example
Treibergs **with One Observation per Cell** March 23, 2010

Data File Used in this Analysis:

```
# Maqth 3080 - 1        Humidification Data       March 22, 2010
# Treibergs
#
# From Devore "Probability and Statistics for Engineering and the
# Sciences, 5th ed.,"
# From "Adiabatic Humidification of Air with Water in a Packed Tower,"
# (Chem. Eng. Prog. 1952)
#
# Experiment on the gas film heat transfer coefficient y (Btu/hr ft^2 on F)
# as a function of gas rate (factor A) and liquid rate (factor B)
#
"y", "A", "B"
200,1(200),1(190)
278,2(400),1(190)
369,3(700),1(190)
500,4(1100),1(190)
226,1(200),2(250)
312,2(400),2(250)
416,3(700),2(250)
575,4(1100),2(250)
240,1(200),3(300)
330,2(400),3(300)
462,3(700),3(300)
645,4(1100),3(300)
261,1(200),4(400)
381,2(400),4(400)
517,3(700),4(400)
733,4(1100),4(400)
```

R Session:

```
R version 2.10.1 (2009-12-14)
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  Natural language support but running in an English locale

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Type 'demo()' for some demos, 'help()' for on-line help, or
```
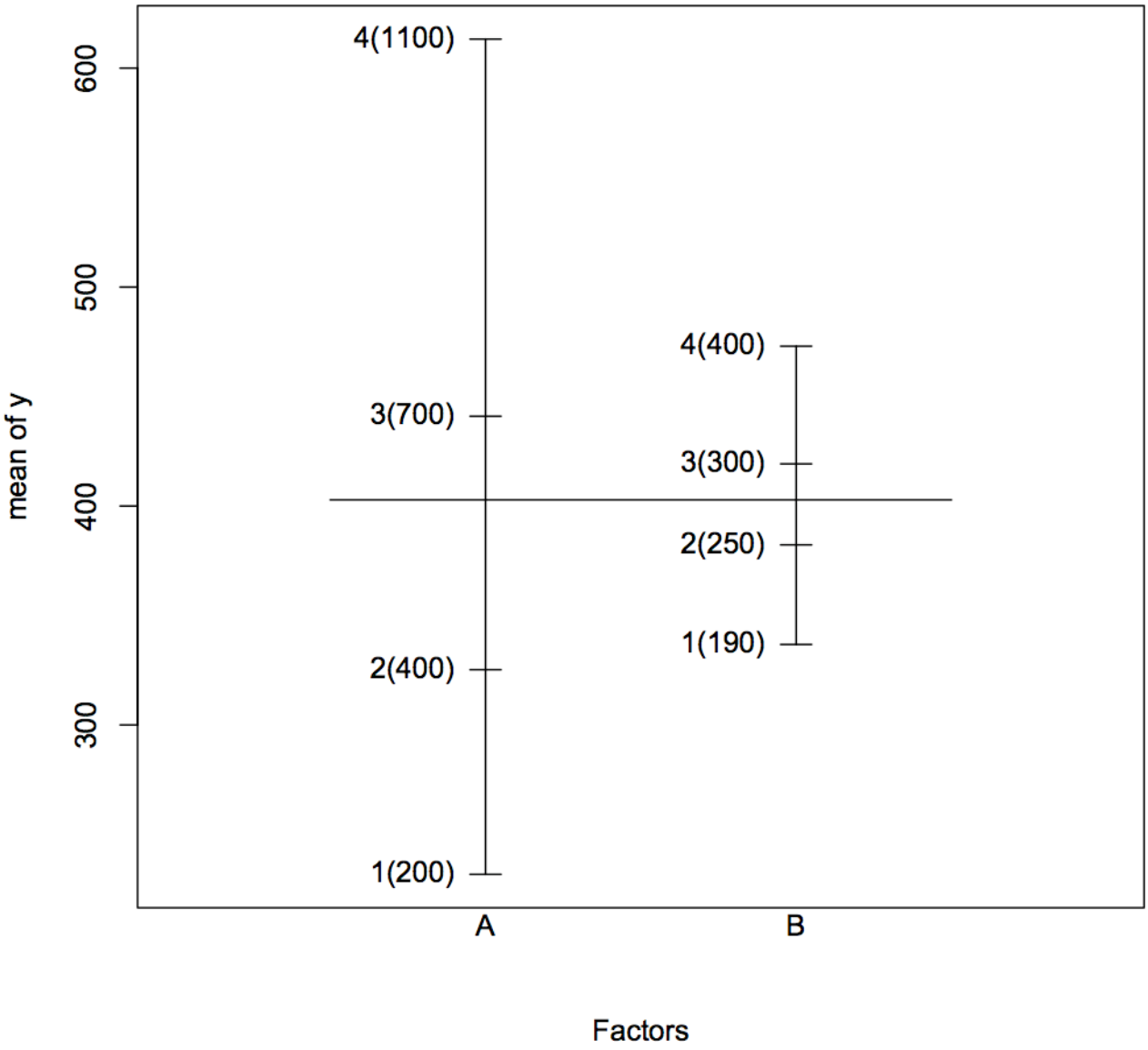
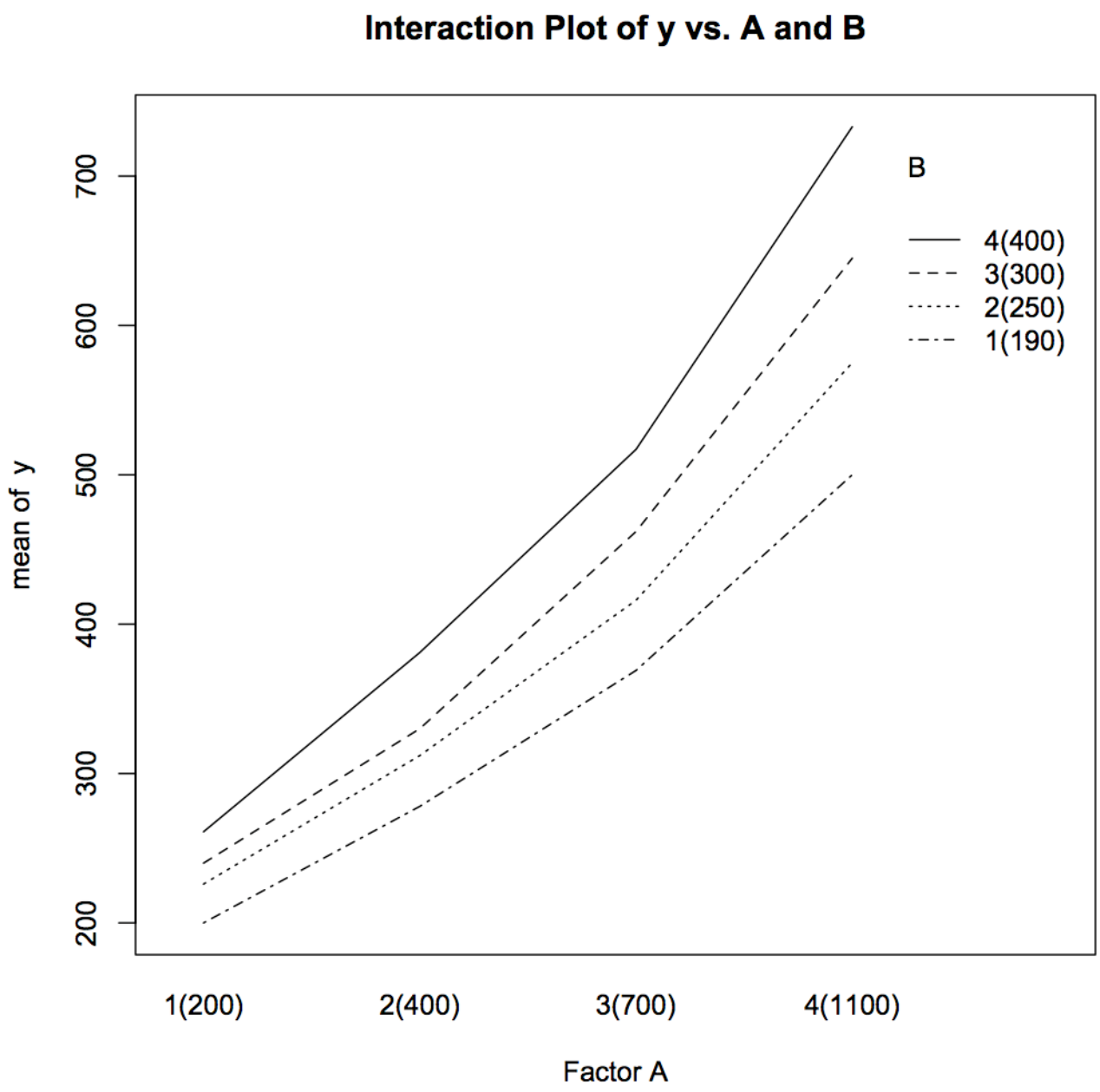
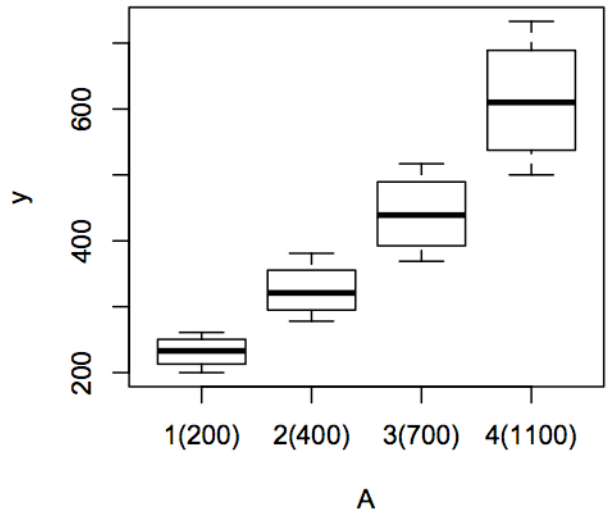

```
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

[R.app GUI 1.31 (5538) powerpc-apple-darwin8.11.1]

[Workspace restored from /Users/andrejstreibergs/.RData]


> tt <- read.table("M3081DataHumidification.txt",header=TRUE, sep=",")
> tt
     y       A      B
1  200  1(200) 1(190)
2  278  2(400) 1(190)
3  369  3(700) 1(190)
4  500 4(1100) 1(190)
5  226  1(200) 2(250)
6  312  2(400) 2(250)
7  416  3(700) 2(250)
8  575 4(1100) 2(250)
9  240  1(200) 3(300)
10 330  2(400) 3(300)
11 462  3(700) 3(300)
12 645 4(1100) 3(300)
13 261  1(200) 4(400)
14 381  2(400) 4(400)
15 517  3(700) 4(400)
16 733 4(1100) 4(400)
> attach(tt)
> A <- factor(A); B <- factor(B)
#======================PRELIMINARY PLOTS=============================================

> plot.design(tt)

> interaction.plot(A,B,y,main="Interaction Plot of y vs. A and B",xlab="Factor A")
```

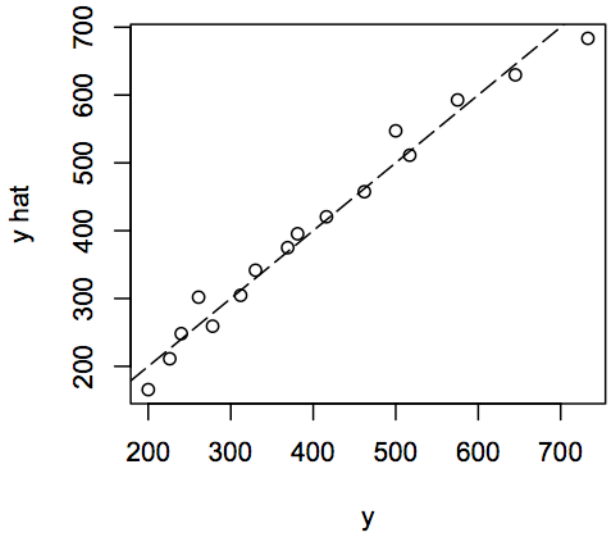

4(1100)
3(700)
2(400)
1(200)
4(400)
3(300)
2(250)
1(190)
600
500
400
300
mean of y
A
B
Factors

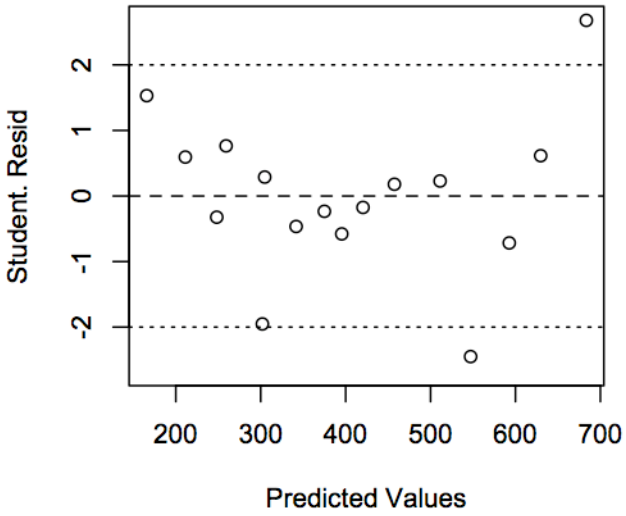

Interaction Plot of y vs. A and B
mean of y
200
300
400
500
600
700
1(200)
2(400)
3(700)
4(1100)
Factor A
B
4(400)
3(300)
2(250)
1(190)

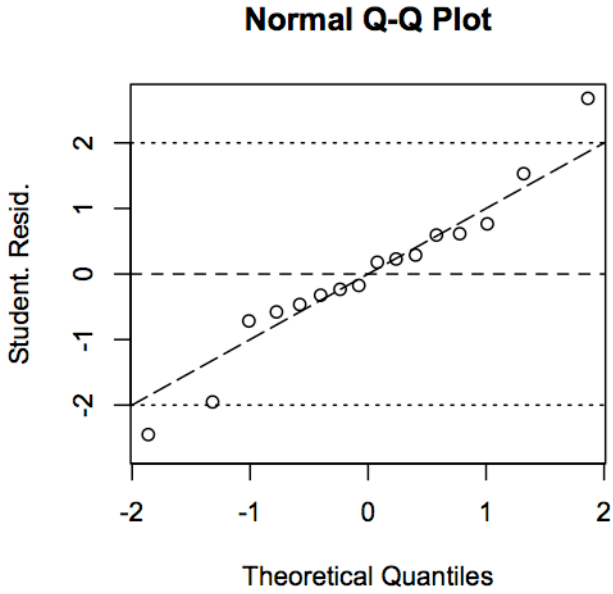
```
>#============================RUN "AOV": OUTPUT FROM "PRINT" AND "ANOVA"==============
> f1 <- aov(y~A+B);print(f1)
Call:
   aov(formula = y ~ A + B)

Terms:
                        A        B Residuals
Sum of Squares  324082.2  39934.2    9232.1
Deg. of Freedom         3        3         9

Residual standard error: 32.02787
Estimated effects may be unbalanced

> anova(f1)
Analysis of Variance Table

Response: y
          Df Sum Sq Mean Sq F value    Pr(>F)
A          3 324082  108027 105.312 2.505e-07 ***
B          3  39934   13311  12.977  0.001282 **
Residuals  9   9232    1026
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1   1
```

```
>#================================USUAL DIAGNOSTIC PLOTS==============================
> layout(matrix(1:4,ncol=2))

> plot(y~A)

> plot(rstudent(f1)~fitted(f1),xlab="Predicted Values",
  ylab="Student. Resid", ylim=max(abs(rstudent(f1)))*c(-1,1))
> abline(h=c(0,-2,2),lty=c(2,3,3))

> plot(fitted(f1)~y,ylab="y hat")
> abline(0,1,lty=5)

> qqnorm(rstudent(f1),ylim=max(abs(rstudent(f1)))*c(-1,1),ylab="Student. Resid.")
> abline(0,1,lty=5)
> abline(h=c(0,-2,2),lty=c(2,3,3))
>
```


y
200
400
600
1(200)
2(400)
3(700)
4(1100)
A

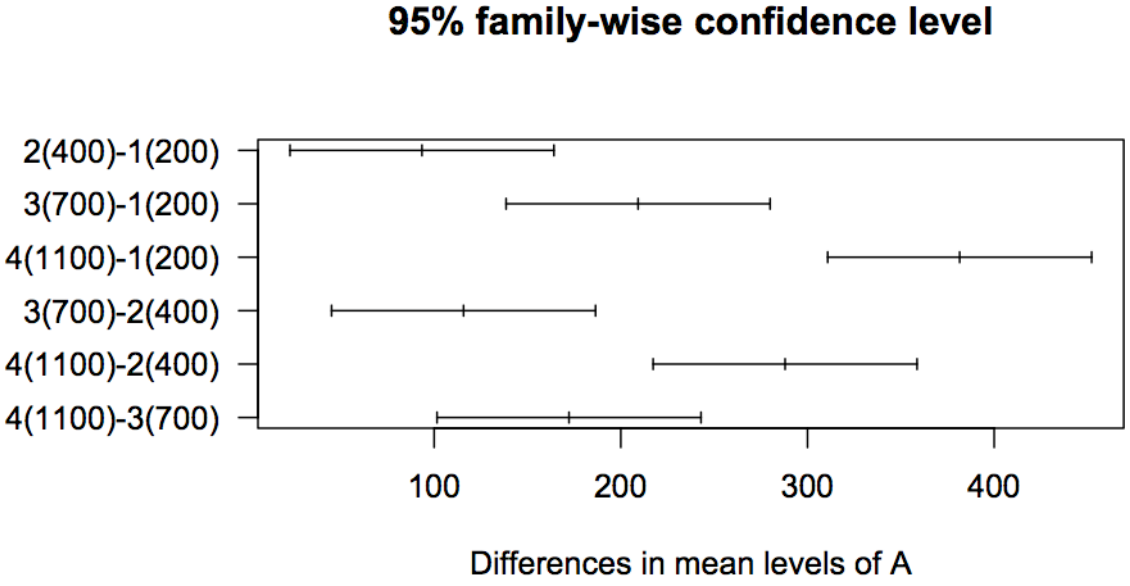

y hat
200
300
400
500
600
700
y

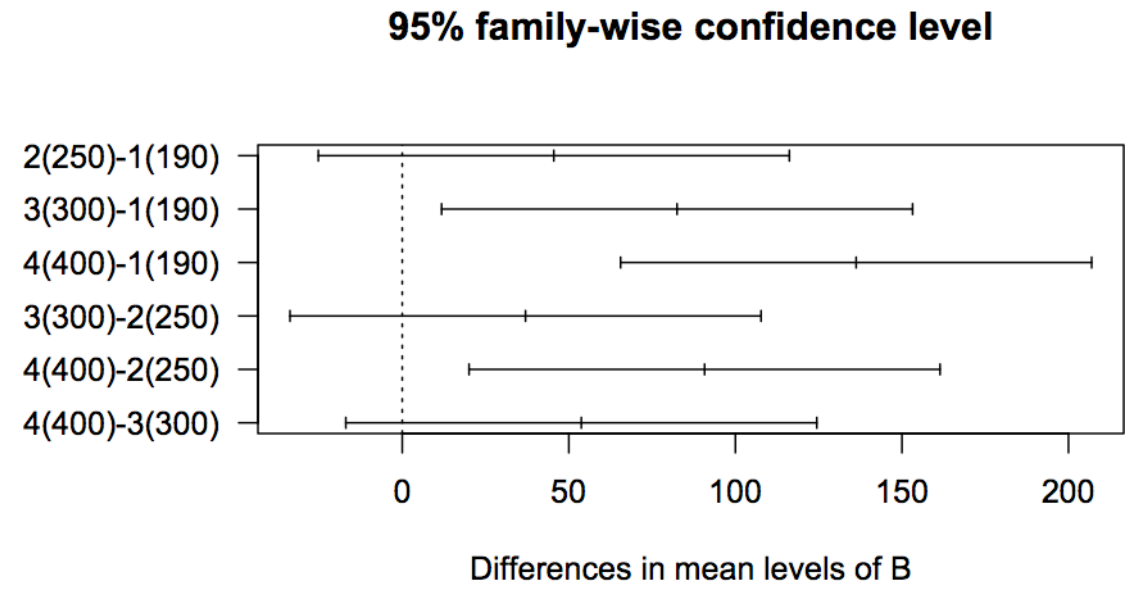

Student. Resid
-2
-1
0
1
2
200
300
400
500
600
700
Predicted Values


Normal Q-Q Plot
Student. Resid.
-2
-1
0
1
2
Theoretical Quantiles

```
>#====================================TABULATE MEANS (Mu's) AND EFFECTS (Alpha's)=====


> model.tables(f1,"means")
Tables of means
Grand mean

402.8125

 A
A
 1(200)  2(400)  3(700) 4(1100)
  231.8   325.2   441.0   613.2

 B
B
1(190) 2(250) 3(300) 4(400)
 336.8  382.2  419.2  473.0
> model.tables(f1,"effects",se=TRUE)
Tables of effects

 A
A
 1(200)  2(400)  3(700) 4(1100)
-171.06  -77.56   38.19  210.44

 B
B
1(190) 2(250) 3(300) 4(400)
-66.06 -20.56  16.44  70.19

Standard errors of effects
            A     B
        16.01 16.01
replic.     4     4
```

```
>#================================TUKEY HSD FOR BOTH FACTORS AND PLOTS================
> TukeyHSD(f1,"A")
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = y ~ A + B)

$A
                  diff       lwr      upr     p adj
2(400)-1(200)   93.50  22.80023 164.1998 0.0112706
3(700)-1(200)  209.25 138.55023 279.9498 0.0000332
4(1100)-1(200) 381.50 310.80023 452.1998 0.0000002
3(700)-2(400)  115.75  45.05023 186.4498 0.0029047
4(1100)-2(400) 288.00 217.30023 358.6998 0.0000023
4(1100)-3(700) 172.25 101.55023 242.9498 0.0001577


> TukeyHSD(f1,"B",ordered=TRUE)
  Tukey multiple comparisons of means
    95% family-wise confidence level
    factor levels have been ordered

Fit: aov(formula = y ~ A + B)

$B
                 diff       lwr      upr     p adj
2(250)-1(190)  45.50 -25.19977 116.1998 0.2535346
3(300)-1(190)  82.50  11.80023 153.1998 0.0229218
4(400)-1(190) 136.25  65.55023 206.9498 0.0009269
3(300)-2(250)  37.00 -33.69977 107.6998 0.4084725
4(400)-2(250)  90.75  20.05023 161.4498 0.0134309
4(400)-3(300)  53.75 -16.94977 124.4498 0.1521835

> layout(1:2)
> par(las=1,mai=c(1,2,1,0.5))
>
> plot(TukeyHSD(f1,"A",ordered=TRUE))
> abline(v=0,lty=3)
> plot(TukeyHSD(f1,"B",ordered=TRUE))
> abline(v=0,lty=3)
>
>
```


95% family-wise confidence level
2(400)-1(200)
3(700)-1(200)
4(1100)-1(200)
3(700)-2(400)
4(1100)-2(400)
4(1100)-3(700)
100
200
300
400
Differences in mean levels of A


95% family-wise confidence level
2(250)-1(190)
3(300)-1(190)
4(400)-1(190)
3(300)-2(250)
4(400)-2(250)
4(400)-3(300)
0
50
100
150
200
Differences in mean levels of B