Math 3080 § 1.	**Circuit Data: Randomized**	Name: Example
Treibergs	**Block Design ANOVA**	March 29, 2010

Data File Used in this Analysis:

```
# math 3080 - 1            Circuits data            Marchy 30, 2010
# Treibergs
#
# From Levine, Ramsay & Smidt, "Applied statistics for Engineers and
# Scientists," (Prentice Hall 2001)
#
# Article "Shewhart-Type Charts in Nonstandard Situations," (Technometrics
# 1995) reported measurements of wafer thickness Y in an integrated circuit
# manufacturing process. For 30 wafers (Blocks B) the thickness was measured
# at different positions (factors A). Positions 1 aad 2 are on the outer circle,
# 18 and 19 are on the middle circle and 28 is on the inner circle.
#
# data given in form of matrix
#
"Wafer" "P1" "P2" "P18" "P19" "P28"
 1 240 243 250 253 248
 2 238 242 245 251 247
 3 239 242 246 250 248
 4 235 237 246 249 246
 5 240 241 246 247 249
 6 240 243 244 248 245
 7 240 243 244 249 246
 8 245 250 250 247 248
 9 238 240 245 248 246
10 240 242 246 249 248
11 240 243 246 250 248
12 241 245 243 247 245
13 247 245 255 250 249
14 237 239 243 247 246
15 242 244 245 248 245
16 237 239 242 247 245
17 242 244 246 251 248
18 243 245 247 252 249
19 243 245 248 251 250
20 244 246 246 250 246
21 241 239 244 250 246
22 242 245 248 251 249
23 242 245 248 243 246
24 241 244 245 249 247
25 236 239 241 246 242
26 243 246 247 252 247
27 241 243 245 248 246
28 239 240 242 243 244
29 239 240 250 252 250
30 241 243 249 255 253
```

R Session:

```
R version 2.10.1 (2009-12-14)
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Type 'q()' to quit R.

[R.app GUI 1.31 (5537) powerpc-apple-darwin9.8.0]

> tt <- read.table("M3081DataCircuits.txt",header=TRUE)
> tt
   Wafer  P1  P2 P18 P19 P28
1      1 240 243 250 253 248
2      2 238 242 245 251 247
3      3 239 242 246 250 248
4      4 235 237 246 249 246
5      5 240 241 246 247 249
6      6 240 243 244 248 245
7      7 240 243 244 249 246
8      8 245 250 250 247 248
9      9 238 240 245 248 246
10    10 240 242 246 249 248
11    11 240 243 246 250 248
12    12 241 245 243 247 245
13    13 247 245 255 250 249
14    14 237 239 243 247 246
15    15 242 244 245 248 245
16    16 237 239 242 247 245
17    17 242 244 246 251 248
18    18 243 245 247 252 249
19    19 243 245 248 251 250
20    20 244 246 246 250 246
21    21 241 239 244 250 246
22    22 242 245 248 251 249
23    23 242 245 248 243 246
24    24 241 244 245 249 247
```
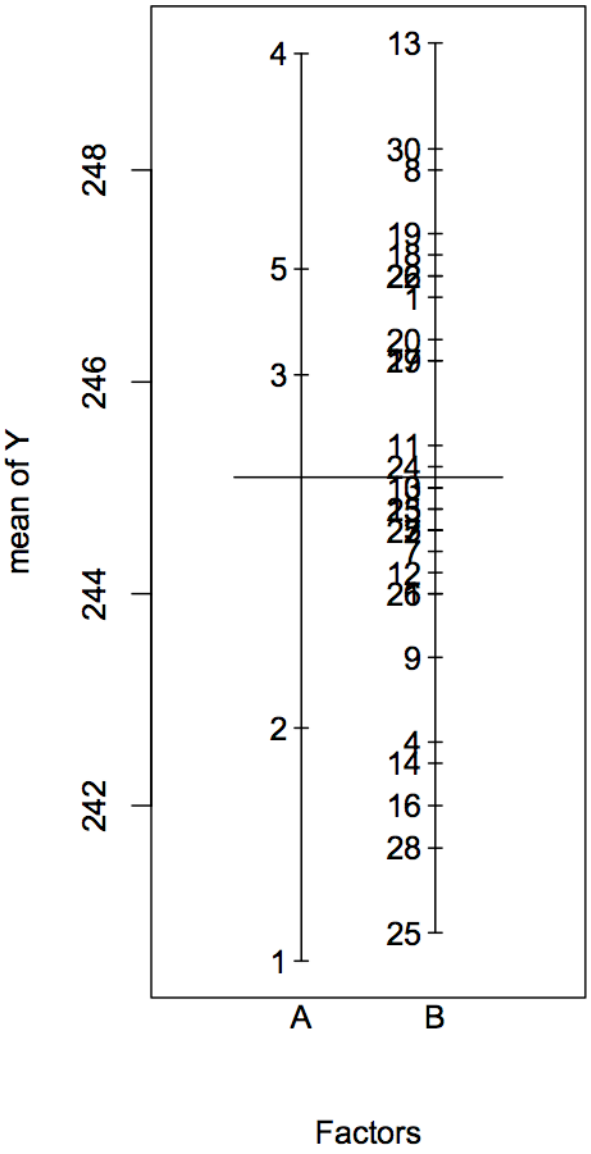

```
25    25 236 239 241 246 242
26    26 243 246 247 252 247
27    27 241 243 245 248 246
28    28 239 240 242 243 244
29    29 239 240 250 252 250
30    30 241 243 249 255 253
> attach(tt)
>#=====================================CREATE DATA VECTOR AND FACTORS FROM DATA TABLE=========
> Y <- c(P1,P2,P18,P19,P28)
> A <- factor(rep(1:5,each=30))
> B <- factor(rep(1:30,times=5))
> tt2 <- data.frame(A,B,Y)
> tt2
    A  B   Y
1   1  1 240
2   1  2 238
3   1  3 239
4   1  4 235
5   1  5 240
6   1  6 240
7   1  7 240
8   1  8 245
9   1  9 238
10  1 10 240
11  1 11 240
12  1 12 241
13  1 13 247
14  1 14 237
15  1 15 242
16  1 16 237
17  1 17 242
18  1 18 243
19  1 19 243
20  1 20 244
21  1 21 241
22  1 22 242
23  1 23 242
24  1 24 241
25  1 25 236
26  1 26 243
27  1 27 241
28  1 28 239
29  1 29 239
30  1 30 241
31  2  1 243
32  2  2 242
33  2  3 242
34  2  4 237
35  2  5 241
36  2  6 243
37  2  7 243
38  2  8 250
```

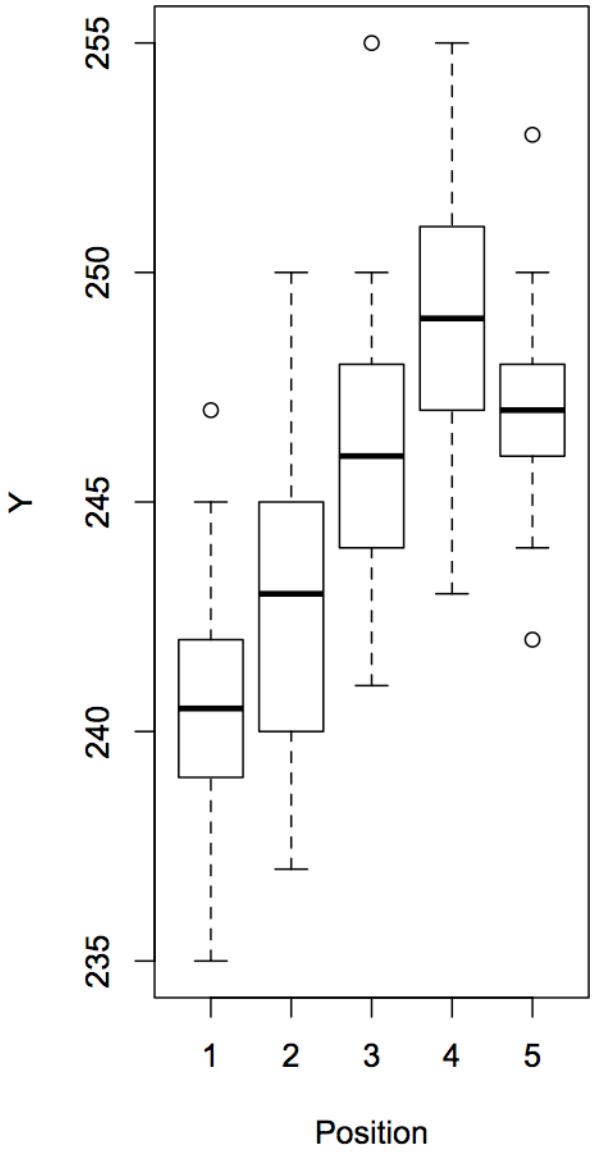
39	2	9	240
40	2	10	242
41	2	11	243
42	2	12	245
43	2	13	245
44	2	14	239
45	2	15	244
46	2	16	239
47	2	17	244
48	2	18	245
49	2	19	245
50	2	20	246
51	2	21	239
52	2	22	245
53	2	23	245
54	2	24	244
55	2	25	239
56	2	26	246
57	2	27	243
58	2	28	240
59	2	29	240
60	2	30	243
61	3	1	250
62	3	2	245
63	3	3	246
64	3	4	246
65	3	5	246
66	3	6	244
67	3	7	244
68	3	8	250
69	3	9	245
70	3	10	246
71	3	11	246
72	3	12	243
73	3	13	255
74	3	14	243
75	3	15	245
76	3	16	242
77	3	17	246
78	3	18	247
79	3	19	248
80	3	20	246
81	3	21	244
82	3	22	248
83	3	23	248
84	3	24	245
85	3	25	241
86	3	26	247
87	3	27	245
88	3	28	242
89	3	29	250
90	3	30	249

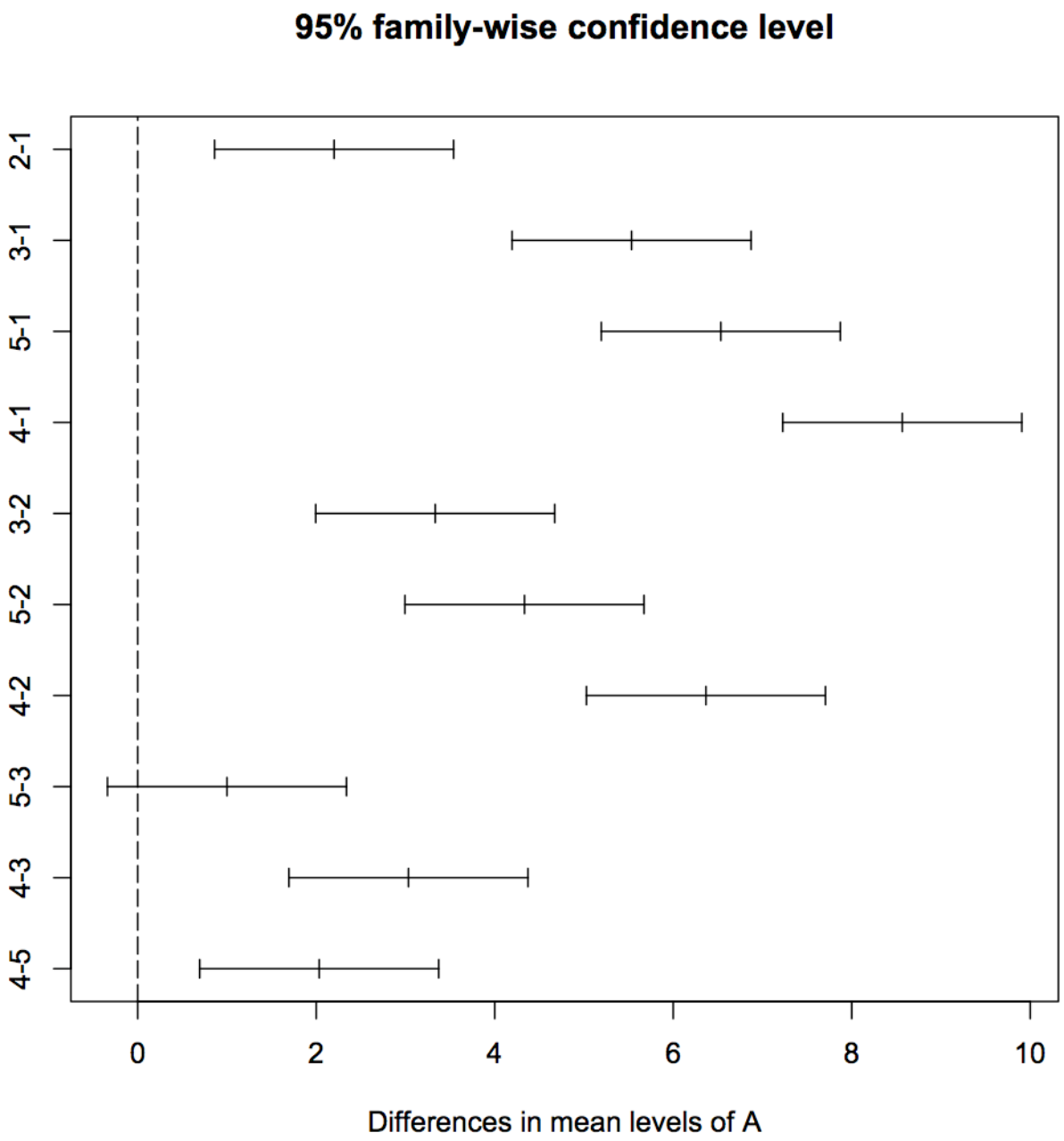
91	4	1	253
92	4	2	251
93	4	3	250
94	4	4	249
95	4	5	247
96	4	6	248
97	4	7	249
98	4	8	247
99	4	9	248
100	4	10	249
101	4	11	250
102	4	12	247
103	4	13	250
104	4	14	247
105	4	15	248
106	4	16	247
107	4	17	251
108	4	18	252
109	4	19	251
110	4	20	250
111	4	21	250
112	4	22	251
113	4	23	243
114	4	24	249
115	4	25	246
116	4	26	252
117	4	27	248
118	4	28	243
119	4	29	252
120	4	30	255
121	5	1	248
122	5	2	247
123	5	3	248
124	5	4	246
125	5	5	249
126	5	6	245
127	5	7	246
128	5	8	248
129	5	9	246
130	5	10	248
131	5	11	248
132	5	12	245
133	5	13	249
134	5	14	246
135	5	15	245
136	5	16	245
137	5	17	248
138	5	18	249
139	5	19	250
140	5	20	246
141	5	21	246
142	5	22	249

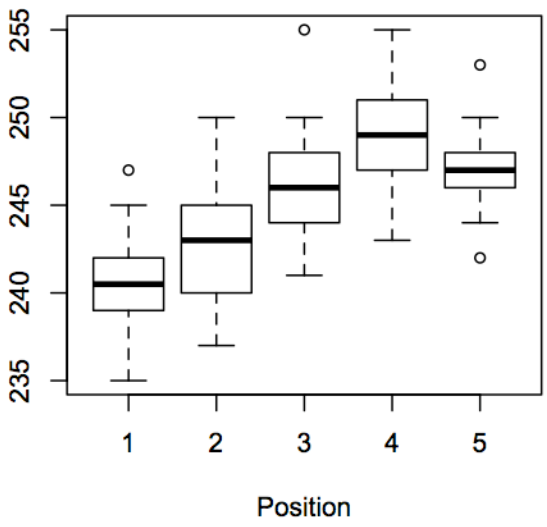
```
143 5 23 246
144 5 24 247
145 5 25 242
146 5 26 247
147 5 27 246
148 5 28 244
149 5 29 250
150 5 30 253
>#=================================================RUN RANDOMIZED BLOCK ANOVA================
> f1 <- aov(Y~A+B);anova(f1);print(f1)
Analysis of Variance Table

Response: Y
           Df  Sum Sq Mean Sq  F value    Pr(>F)
A           4 1417.73  354.43 101.2002 < 2.2e-16 ***
B          29  601.50   20.74   5.9222 1.928e-12 ***
Residuals 116  406.27    3.50
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1   1
Call:
   aov(formula = Y ~ A + B)

Terms:
                         A         B Residuals
Sum of Squares  1417.7333  601.5000  406.2667
Deg. of Freedom         4        29       116

Residual standard error: 1.871443
Estimated effects may be unbalanced

>#=============================================COMPARE TO SINGLE FACTOR ANOVA==================
>#======FOR COMPARISON ONLY=========================================================================
>#====SAME WAFER IS MEASURED IN MULTIPLE PLACES SO ASSUMP. ON MODEL DON'T HOLD=================
> f2 <- aov(Y~A);anova(f2);print(f2)
Analysis of Variance Table

Response: Y
           Df Sum Sq Mean Sq F value    Pr(>F)
A           4 1417.7  354.43  50.997 < 2.2e-16 ***
Residuals 145 1007.8    6.95
---
Signif. codes:  0 *** 0.001 ** 0.01 * 0.05 . 0.1   1
Call:
   aov(formula = Y ~ A)

Terms:
                       A Residuals
Sum of Squares  1417.733  1007.767
Deg. of Freedom        4       145

Residual standard error: 2.636307
Estimated effects may be unbalanced
```

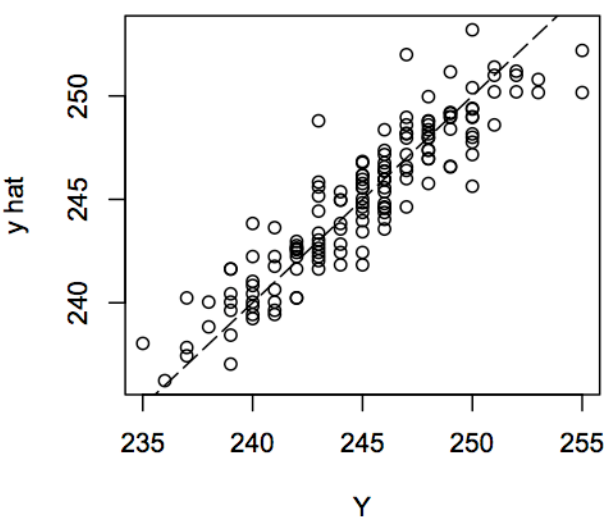
```
>#==================================TUKEY HSD ON RANDOMIZED BLOCK MODEL=====================
> sort(tapply(Y,A,mean))
       1        2        3        5        4
240.5333 242.7333 246.0667 247.0667 249.1000
> TukeyHSD(f1,which="A",ordered=TRUE)
  Tukey multiple comparisons of means
    95% family-wise confidence level
    factor levels have been ordered

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

$A
        diff        lwr      upr     p adj
2-1 2.200000  0.8609661 3.539034 0.0001266
3-1 5.533333  4.1942994 6.872367 0.0000000
5-1 6.533333  5.1942994 7.872367 0.0000000
4-1 8.566667  7.2276327 9.905701 0.0000000
3-2 3.333333  1.9942994 4.672367 0.0000000
5-2 4.333333  2.9942994 5.672367 0.0000000
4-2 6.366667  5.0276327 7.705701 0.0000000
5-3 1.000000 -0.3390339 2.339034 0.2403962
4-3 3.033333  1.6942994 4.372367 0.0000001
4-5 2.033333  0.6942994 3.372367 0.0004830

>#============================SHAPIRO-WILK TEST FOR NORMALITY OF STANDARDIZED RESIDUALS=====
> shapiro.test(rstandard(f1))

Shapiro-Wilk normality test

data:  rstandard(f1)
W = 0.9862, p-value = 0.1427

>#=====PLOT DESIGN, BOXES, TUKEY HSD, AND STANDARD DIAGNOSTICS================================
> layout(matrix(1:2,ncol=2))
> plot.design(tt2)
> plot(Y~A,xlab="Position")
> layout(1)
> plot(TukeyHSD(f1,which="A",ordered=TRUE))
> abline(v=0,lty=5)
> layout(matrix(1:4,ncol=2))
> plot(A,Y,xlab="Position")
> plot(rstandard(f1)~fitted(f1),ylab="Standard. Resid.",xlab="Predicted Values",
  ylim=max(abs(rstandard(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(rstandard(f1),ylab="Standard. Resid.",
  ylim=max(abs(rstandard(f1)))*c(-1,1))
> abline(0,1)
> layout(1)
> interaction.plot(A,B,Y)
```

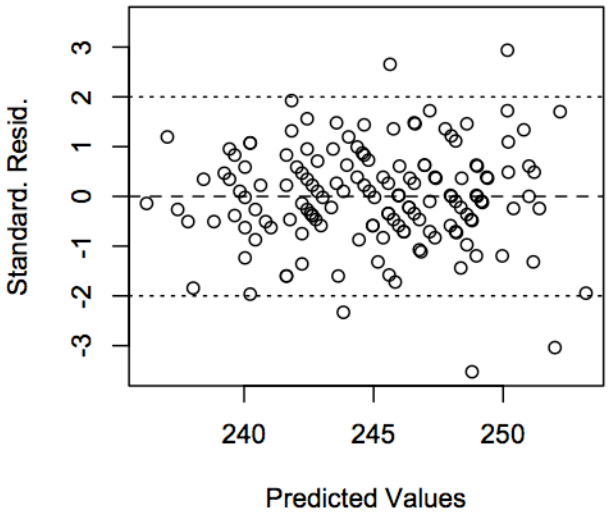

mean of Y
248
246
244
242
4
5
3
2
1
13
30
8
19
18
26
1
20
29
11
24
10
25
22
7
12
26
9
4
14
16
28
25
A
B
Factors

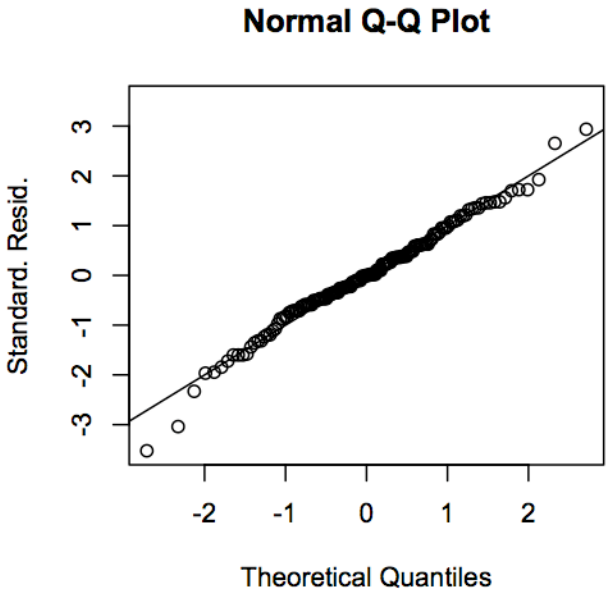

Y
255
250
245
240
235
1
2
3
4
5
Position

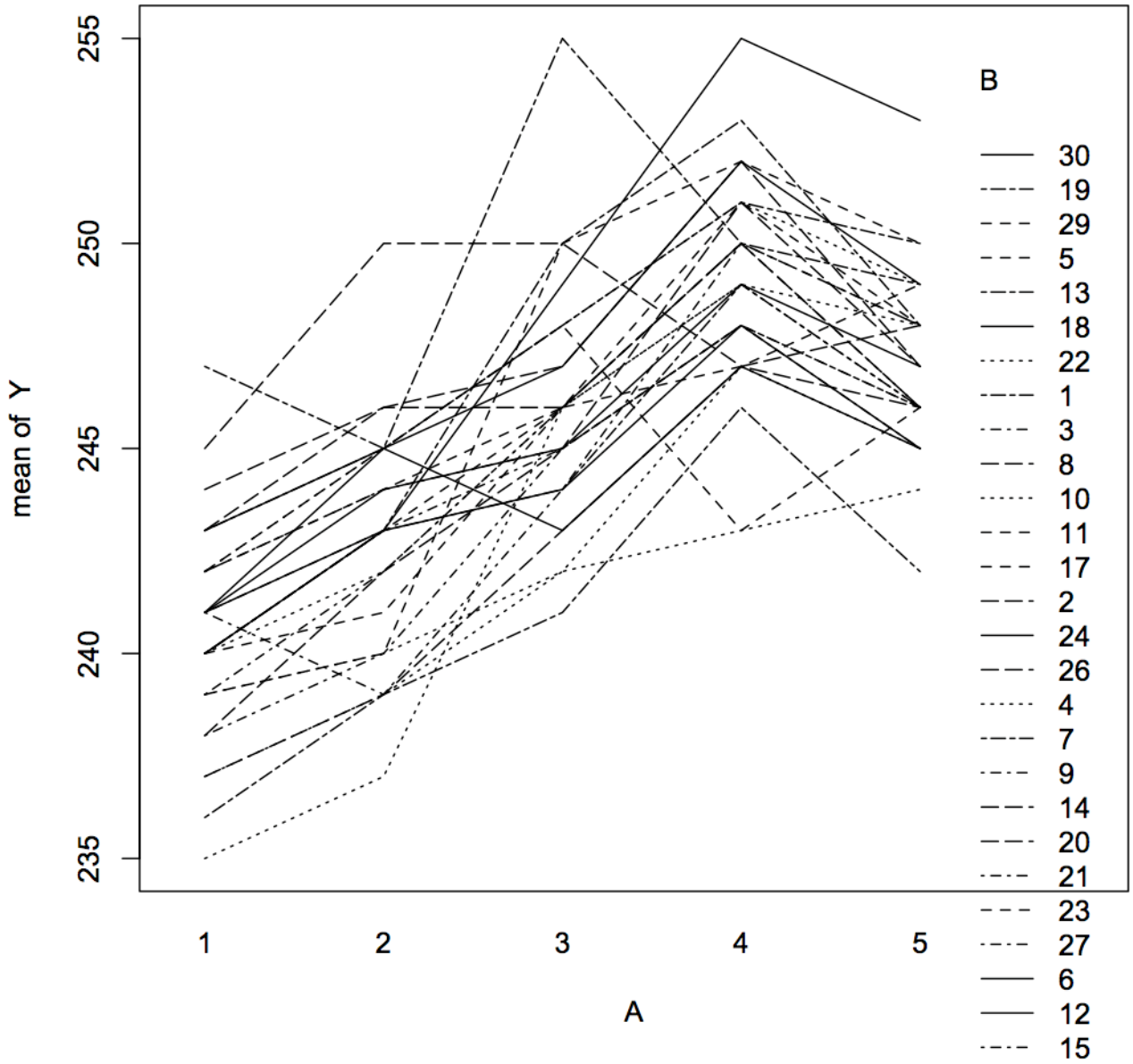

95% family-wise confidence level
2-1
3-1
5-1
4-1
3-2
5-2
4-2
5-3
4-3
4-5
0
2
4
6
8
10
Differences in mean levels of A


255
250
245
240
235
1
2
3
4
5
Position


y hat
250
245
240
235
240
245
250
255
Y


Standard. Resid.
3
2
1
0
-1
-2
-3
240
245
250
Predicted Values


Normal Q-Q Plot
Standard. Resid.
3
2
1
0
-1
-2
-3
-2
-1
0
1
2
Theoretical Quantiles


mean of Y
255
250
245
240
235
1
2
3
4
5
A
B
30
19
29
5
13
18
22
1
3
8
10
11
17
2
24
26
4
7
9
14
20
21
23
27
6
12
15