Case Study 2 Markdown

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Preliminary

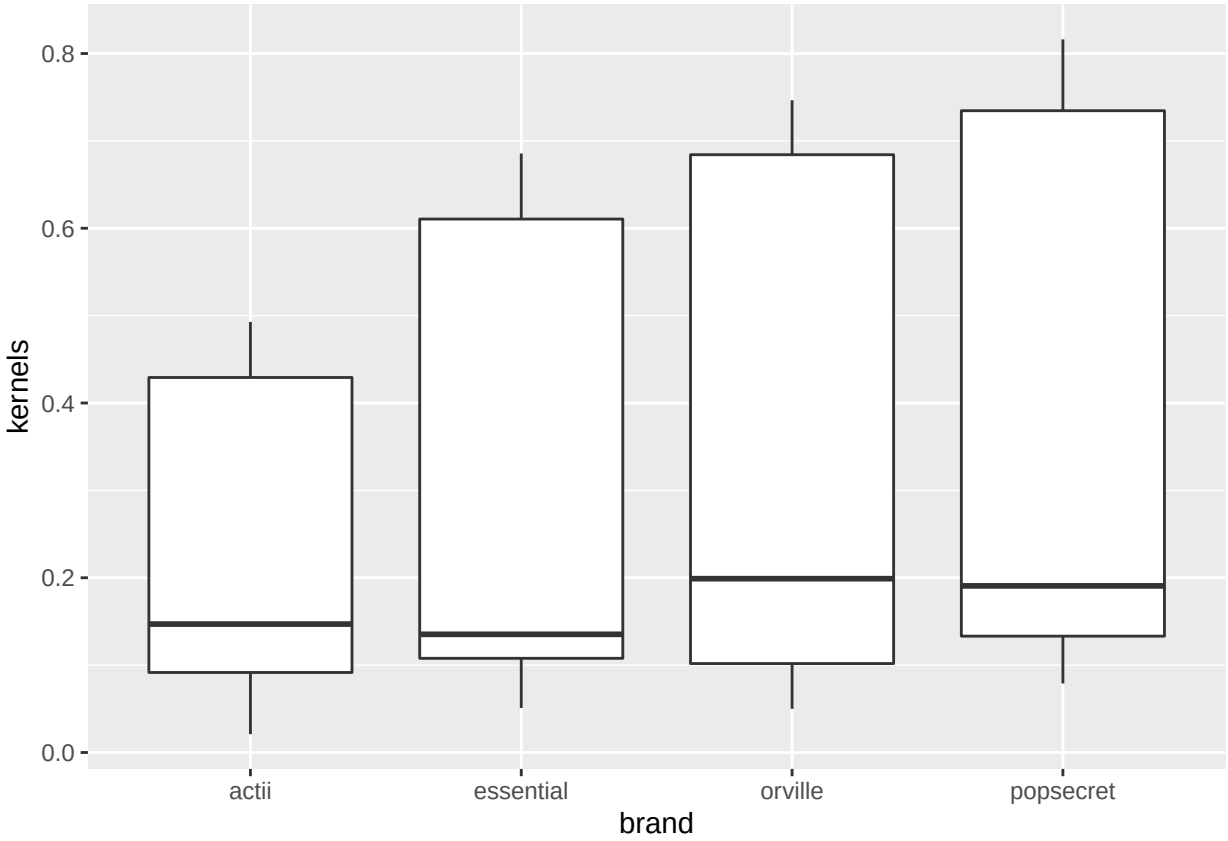
```
popcorn = read.csv('popcorn.csv', header = TRUE)
popcorn
```

```
##         brand time    kernels rep
## 1     orville   90 0.68000000   1
## 2   essential   90 0.58000000   1
## 3   popsecret   90 0.72000000   1
## 4       actii   90 0.42000000   1
## 5     orville  120 0.14000000   1
## 6   essential  120 0.11000000   1
## 7   popsecret  120 0.15000000   1
## 8       actii  120 0.11000000   1
## 9     orville  180 0.05000000   1
## 10  essential  180 0.05100000   1
## 11  popsecret  180 0.07900000   1
## 12      actii  180 0.02100000   1
## 13    orville   90 0.68282257   2
## 14  essential   90 0.58733613   2
## 15  popsecret   90 0.73434254   2
## 16      actii   90 0.42019946   2
## 17    orville  120 0.16405981   2
## 18  essential  120 0.11232562   2
## 19  popsecret  120 0.16876482   2
## 20      actii  120 0.11085630   2
## 21    orville  180 0.06170244   2
## 22  essential  180 0.05534956   2
## 23  popsecret  180 0.08062596   2
## 24      actii  180 0.03354835   2
## 25    orville   90 0.68464325   3
## 26  essential   90 0.61825618   3
## 27  popsecret   90 0.73459464   3
## 28      actii   90 0.43220439   3
## 29    orville  120 0.17401401   3
## 30  essential  120 0.12082717   3
## 31  popsecret  120 0.17553896   3
## 32      actii  120 0.12729181   3
## 33    orville  180 0.07028202   3
```

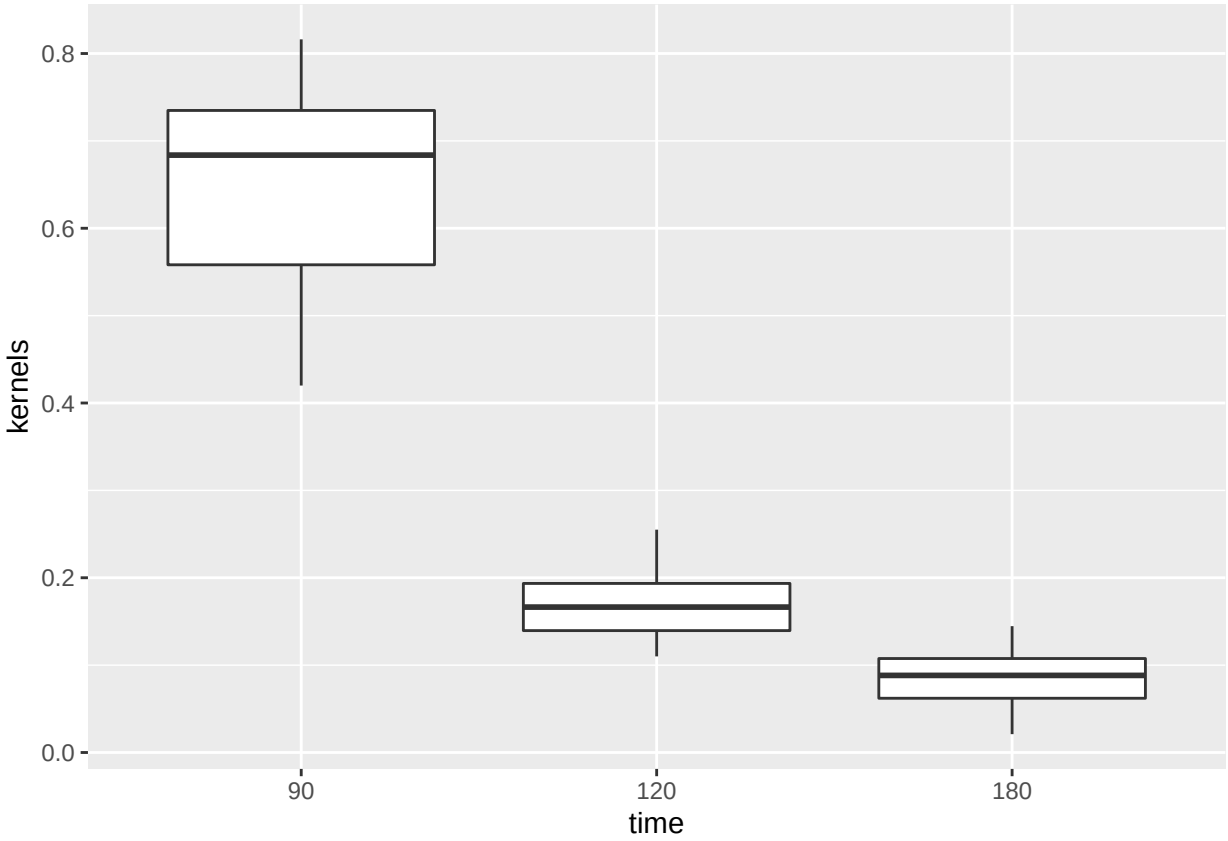
```
## 34  essential  180 0.06221971   3
## 35  popsecret  180 0.09307022   3
## 36      actii  180 0.04263688   3
## 37    orville   90 0.69288661   4
## 38  essential   90 0.62418408   4
## 39  popsecret   90 0.75240816   4
## 40      actii   90 0.43550969   4
## 41    orville  120 0.18293712   4
## 42  essential  120 0.12712435   4
## 43  popsecret  120 0.18349467   4
## 44      actii  120 0.13174822   4
## 45    orville  180 0.07480702   4
## 46  essential  180 0.07085893   4
## 47  popsecret  180 0.09867642   4
## 48      actii  180 0.05471743   4
## 49    orville   90 0.70457513   5
## 50  essential   90 0.64611202   5
## 51  popsecret   90 0.75732156   5
## 52      actii   90 0.46412372   5
## 53    orville  120 0.19340778   5
## 54  essential  120 0.12875955   5
## 55  popsecret  120 0.18764044   5
## 56      actii  120 0.14454946   5
## 57    orville  180 0.08274223   5
## 58  essential  180 0.08101219   5
## 59  popsecret  180 0.10906639   5
## 60      actii  180 0.05555177   5
## 61    orville   90 0.71953567   6
## 62  essential   90 0.65576833   6
## 63  popsecret   90 0.76675189   6
## 64      actii   90 0.47225029   6
## 65    orville  120 0.20445082   6
## 66  essential  120 0.13809210   6
## 67  popsecret  120 0.19377174   6
## 68      actii  120 0.14944681   6
## 69    orville  180 0.08733448   6
## 70  essential  180 0.08913556   6
## 71  popsecret  180 0.11799319   6
## 72      actii  180 0.06134364   6
## 73    orville   90 0.73080587   7
## 74  essential   90 0.65622801   7
## 75  popsecret   90 0.77450362   7
## 76      actii   90 0.47614515   7
## 77    orville  120 0.20453884   7
## 78  essential  120 0.15421049   7
## 79  popsecret  120 0.21546091   7
## 80      actii  120 0.16233336   7
## 81    orville  180 0.09693918   7
## 82  essential  180 0.10013683   7
## 83  popsecret  180 0.12601820   7
## 84      actii  180 0.07429438   7
## 85    orville   90 0.73563813   8
## 86  essential   90 0.66077368   8
## 87  popsecret   90 0.79375730   8
```

```
## 88      actii   90 0.48627604   8
## 89    orville  120 0.22387892   8
## 90  essential  120 0.16176720   8
## 91  popsecret  120 0.22800518   8
## 92      actii  120 0.16570804   8
## 93    orville  180 0.09911463   8
## 94  essential  180 0.10705754   8
## 95  popsecret  180 0.13126221   8
## 96      actii  180 0.08926441   8
## 97    orville   90 0.74116303   9
## 98  essential   90 0.68539371   9
## 99  popsecret   90 0.79645743   9
## 100     actii   90 0.48785897   9
## 101   orville  120 0.23624403   9
## 102 essential  120 0.17123473   9
## 103 popsecret  120 0.23013105   9
## 104     actii  120 0.16640093   9
## 105   orville  180 0.10977557   9
## 106 essential  180 0.12803151   9
## 107 popsecret  180 0.13888969   9
## 108     actii  180 0.09853561   9
## 109   orville   90 0.74649707  10
## 110 essential   90 0.68560841  10
## 111 popsecret   90 0.81621572  10
## 112     actii   90 0.49276644  10
## 113   orville  120 0.25504103  10
## 114 essential  120 0.17925657  10
## 115 popsecret  120 0.23635308  10
## 116     actii  120 0.16644548  10
## 117   orville  180 0.12816346  10
## 118 essential  180 0.13245892  10
## 119 popsecret  180 0.14462138  10
## 120     actii  180 0.10558092  10
```

```
popcorn$brand = as.factor(popcorn$brand)
popcorn$time = as.factor(popcorn$time)
popcorn$rep = as.factor(popcorn$rep)

contrasts(popcorn$brand) = contr.sum(4)
contrasts(popcorn$time) = contr.sum(3)


library(ggplot2)
ggplot(popcorn, aes(brand, kernels)) + geom_boxplot()
```

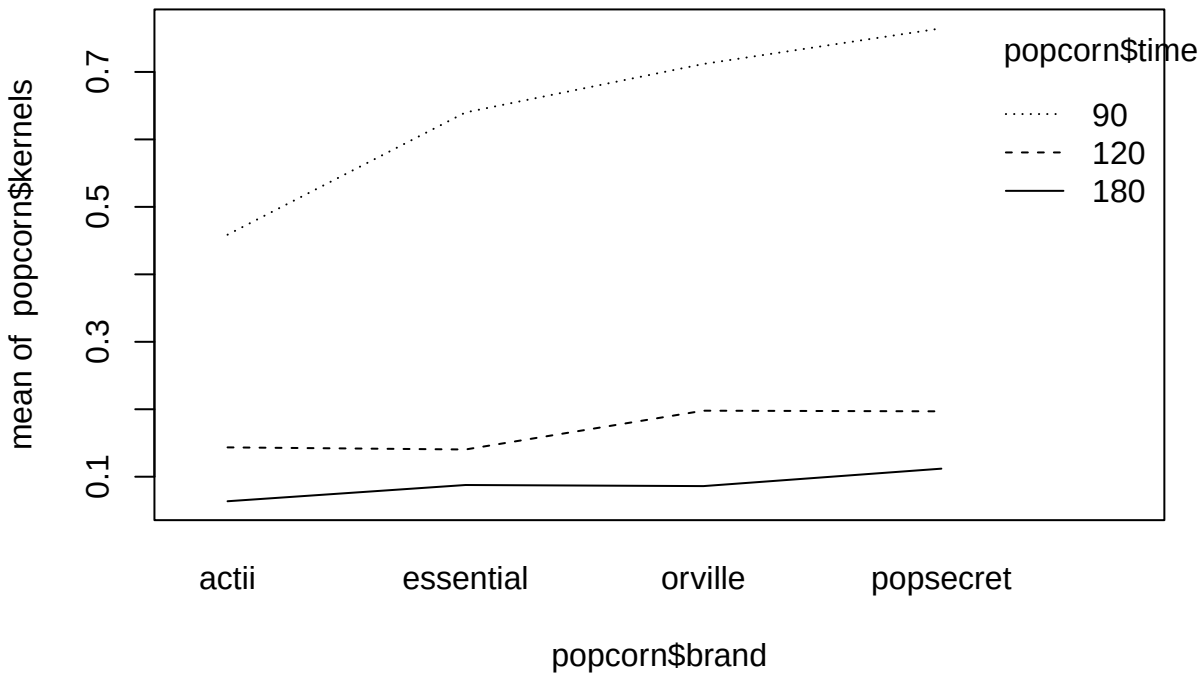



```
ggplot(popcorn, aes(time, kernels)) + geom_boxplot()
```

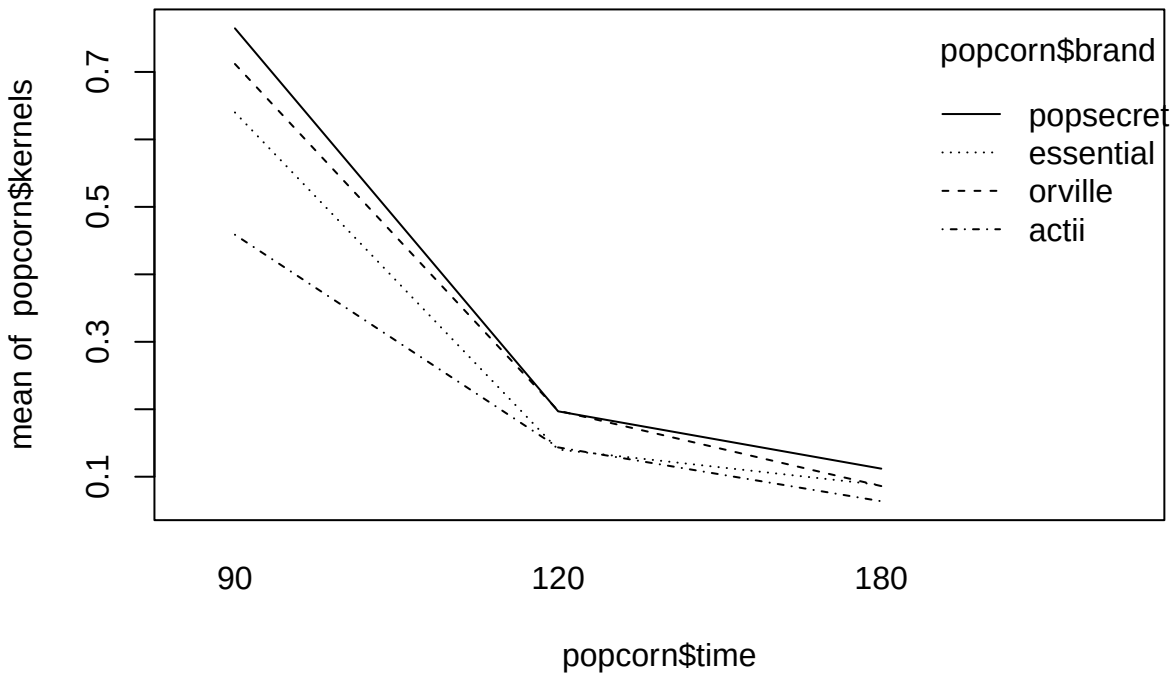


Looks as if brands are very similar and percentage goes down as time increases.

```
interaction.plot(popcorn$brand, popcorn$time, popcorn$kernels)
```




```
interaction.plot(popcorn$time, popcorn$brand, popcorn$kernels)
```



There seems to be some interaction here due to the intersection of lines.

Model Selection

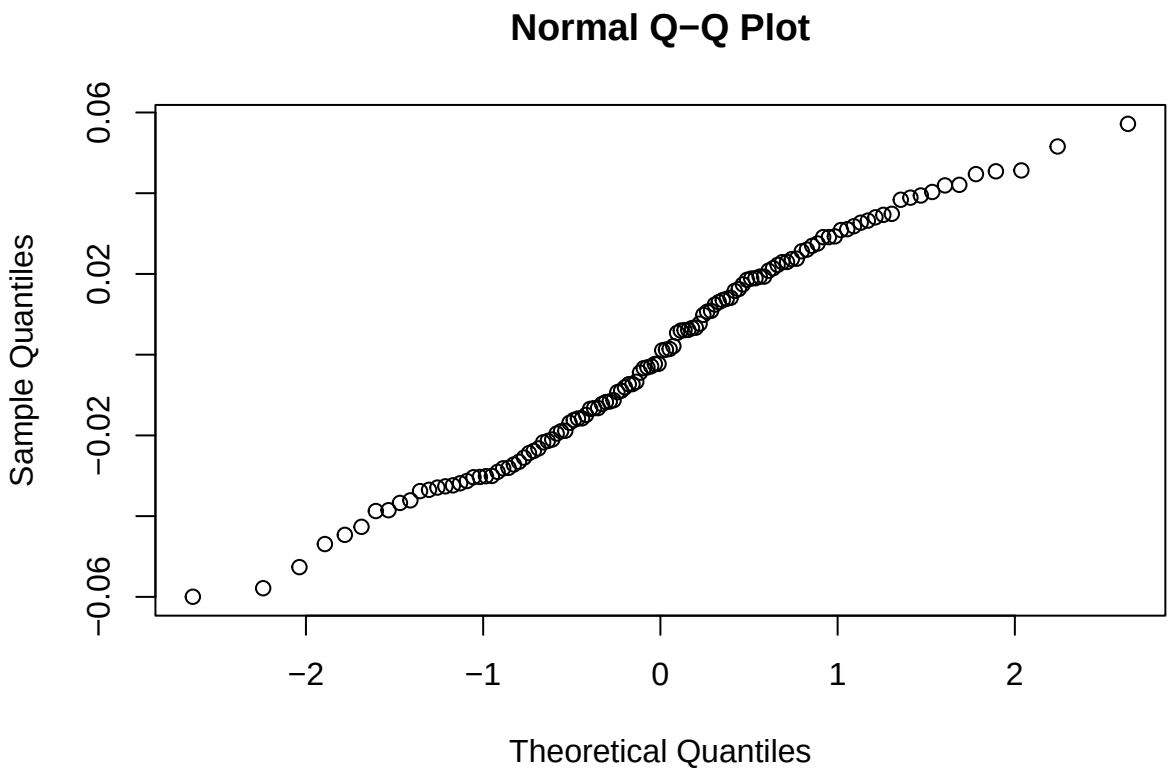
```
popcorn_full = lm(kernels ~ brand * time, data = popcorn)

anova(popcorn_full)
```

```
## Analysis of Variance Table
##
## Response: kernels
##             Df Sum Sq Mean Sq  F value    Pr(>F)
## brand        3 0.3170  0.1057  130.473 < 2.2e-16 ***
## time         2 7.2164  3.6082 4454.722 < 2.2e-16 ***
## brand:time   6 0.2604  0.0434   53.588 < 2.2e-16 ***
## Residuals  108 0.0875  0.0008
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

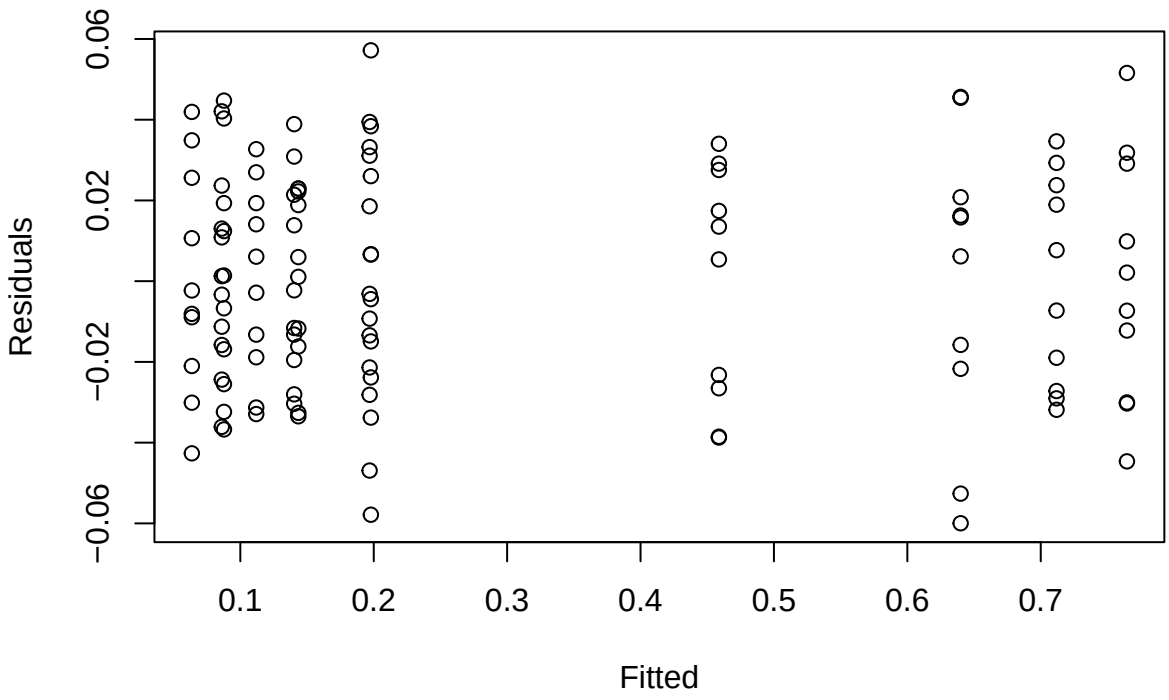
With the interaction being significant, we stop and select the full model.

Diagnostics

```
#Checks Normality:
qqnorm(popcorn_full$residuals)
```




```
#Checks Constant Variance:
plot(popcorn_full$fitted, popcorn_full$residuals, xlab="Fitted", ylab="Residuals")
```

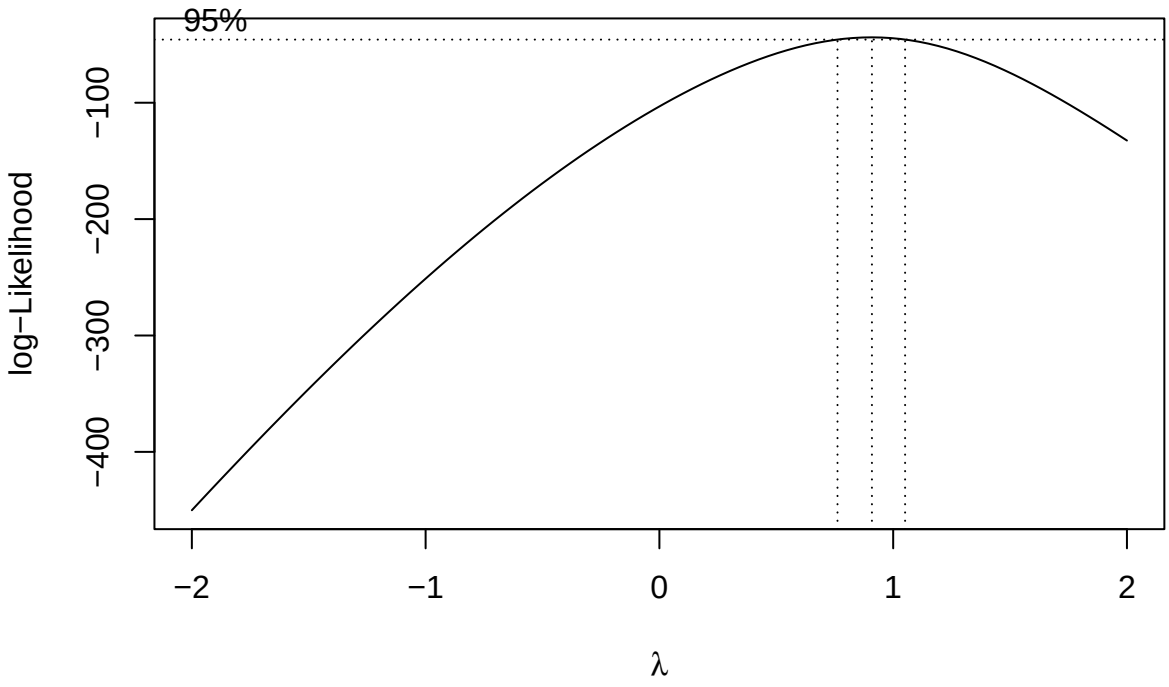


Variance seems to be constant. Normally may have some issues, let us try box-cox.

```
library(MASS)
```

```
## Warning: package 'MASS' was built under R version 4.2.2
```

```
boxcox(popcorn_full)
```



This suggests lambda = 1, so we will NOT be going through with a transformation.

```
#Checking serial dependence
library(lmtest)
```

```
## Loading required package: zoo
```

```
##
## Attaching package: 'zoo'
```

```
## The following objects are masked from 'package:base':
##
##     as.Date, as.Date.numeric
```

```
dwtest(popcorn_full$residuals ~ popcorn$rep)
```

```
##
##  Durbin-Watson test
##
## data:  popcorn_full$residuals ~ popcorn$rep
## DW = 2.3831, p-value = 0.9033
## alternative hypothesis: true autocorrelation is greater than 0
```

With DW > 2, there is no serial dependence here.

Finding MUs and Alphas

```
summary(popcorn_full)
```

```
##
## Call:
## lm(formula = kernels ~ brand * time, data = popcorn)
##
## Residuals:
##       Min        1Q    Median        3Q       Max
## -0.059966 -0.022088 -0.000598  0.022403  0.057184
##
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)
## (Intercept)   0.300265   0.002598 115.574  < 2e-16 ***
## brand1       -0.078312   0.004500 -17.403  < 2e-16 ***
## brand2       -0.010915   0.004500  -2.426  0.01694 *
## brand3        0.031668   0.004500   7.037 1.88e-10 ***
## time1         0.343532   0.003674  93.500  < 2e-16 ***
## time2        -0.130613   0.003674 -35.549  < 2e-16 ***
## brand1:time1 -0.106752   0.006364 -16.775  < 2e-16 ***
## brand2:time1  0.007083   0.006364   1.113  0.26818
## brand3:time1  0.036391   0.006364   5.718 9.68e-08 ***
## brand1:time2  0.052138   0.006364   8.193 5.63e-13 ***
## brand2:time2 -0.018378   0.006364  -2.888  0.00469 **
## brand3:time2 -0.003464   0.006364  -0.544  0.58739
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 0.02846 on 108 degrees of freedom
## Multiple R-squared:  0.9889, Adjusted R-squared:  0.9878
## F-statistic: 874.8 on 11 and 108 DF,  p-value: < 2.2e-16
```

```
mu = .3003


#A's
actili = -.0783                                #1
essential = -.0109                             #2
orville = .0317                                #3
(popsecret = -(essential + orville + actili)) #4
```

```
## [1] 0.0575
```

```
#actili is the lowest for brand
mu+actili
```

```
## [1] 0.222
```

```r
time_90 = .3435                       #1
time_120 = -.1306                     #2
(time_180 = -(time_120 + time_90))    #3
```

```
## [1] -0.2129
```

```r
#180 is the lowest for time
mu+time_180
```

```
## [1] 0.0874
```

```r
#Interaction A's
actili_90 = -.1068                                          # (1-1)
essential_90 = .0071                                        # (2-1)
orville_90 = .0364                                          # (3-1)
(popsecret_90 = -(actili_90 + essential_90 + orville_90))   # (4-1)
```

```
## [1] 0.0633
```

```r
actili_120 = .0521                                          # (1-2)
essential_120 = -.0184                                      # (2-2)
orville_120 = -.0035                                        # (3-2)
(popsecret_120 = -(actili_120 + essential_120 + orville_120)) # (4-2)
```

```
## [1] -0.0302
```

```r
(actili_180 = -(actili_90 + actili_120))                    # (1-3)
```

```
## [1] 0.0547
```

```r
(essential_180 = -(essential_90 + essential_120))           # (2-3)
```

```
## [1] 0.0113
```

```r
(orville_180 = -(orville_90 + orville_120))                 # (3-3)
```

```
## [1] -0.0329
```

```r
(popsecret_180 = -(actili_180 + essential_180 + orville_180)) # (4-3)
```

```
## [1] -0.0331
```

```r
#OK, but these interaction combinations cannot be interpreted.
```

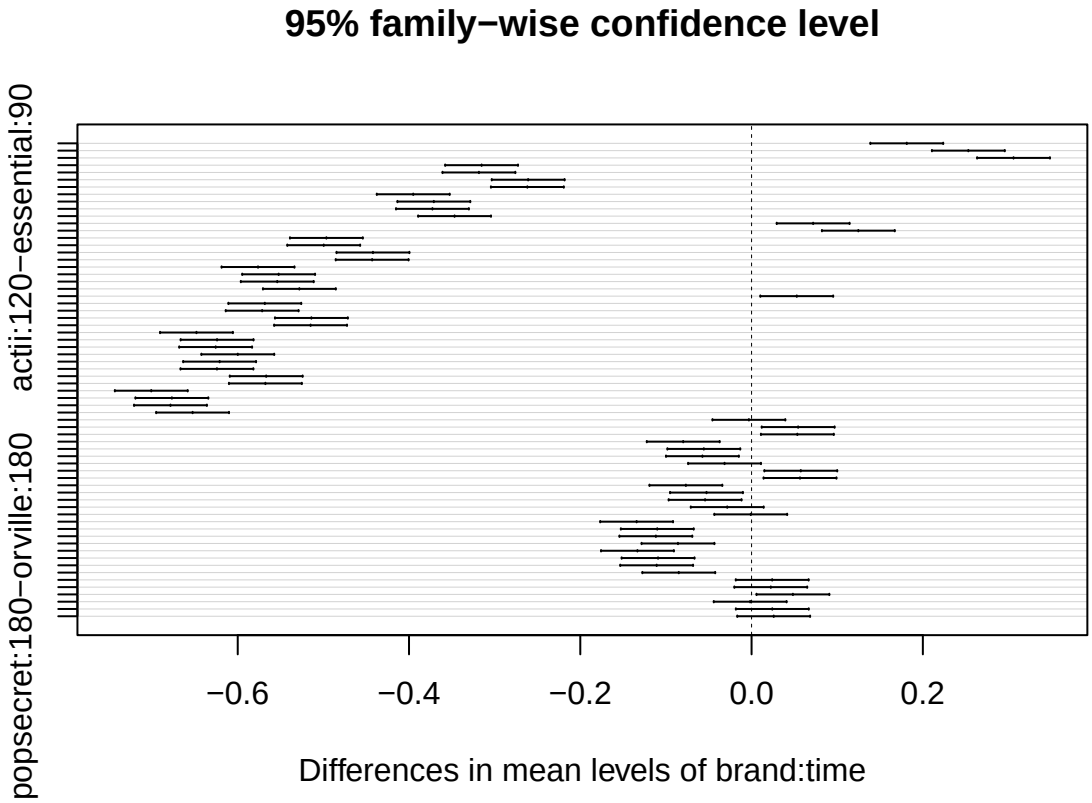
Family Tests

```r
popcorn_aov = aov(kernels ~ brand * time, data = popcorn)

(tukey_popcorn = TukeyHSD(popcorn_aov, 'brand:time'))
```

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = kernels ~ brand * time, data = popcorn)
##
## $`brand:time`
##                                        diff          lwr         upr     p adj
## essential:90-actii:90          0.1812326391  0.138710432  0.22375485 0.0000000
## orville:90-actii:90            0.2531233178  0.210601111  0.29564552 0.0000000
## popsecret:90-actii:90          0.3059018698  0.263379663  0.34842408 0.0000000
## actii:120-actii:90            -0.3152553757 -0.357777583 -0.27273317 0.0000000
## essential:120-actii:90        -0.3183736392 -0.360895846 -0.27585143 0.0000000
## orville:120-actii:90          -0.2608761801 -0.303398387 -0.21835397 0.0000000
## popsecret:120-actii:90        -0.2618173306 -0.304339538 -0.21929512 0.0000000
## actii:180-actii:90            -0.3950860773 -0.437608284 -0.35256387 0.0000000
## essential:180-actii:90        -0.3710073396 -0.413529547 -0.32848513 0.0000000
## orville:180-actii:90          -0.3726473129 -0.415169520 -0.33012511 0.0000000
## popsecret:180-actii:90        -0.3468110496 -0.389333257 -0.30428884 0.0000000
## orville:90-essential:90        0.0718906787  0.029368472  0.11441289 0.0000085
## popsecret:90-essential:90      0.1246692307  0.082147024  0.16719144 0.0000000
## actii:120-essential:90        -0.4964880148 -0.539010222 -0.45396581 0.0000000
## essential:120-essential:90    -0.4996062783 -0.542128485 -0.45708407 0.0000000
## orville:120-essential:90      -0.4421088192 -0.484631026 -0.39958661 0.0000000
## popsecret:120-essential:90    -0.4430499697 -0.485572177 -0.40052776 0.0000000
## actii:180-essential:90        -0.5763187164 -0.618840923 -0.53379651 0.0000000
## essential:180-essential:90    -0.5522399787 -0.594762186 -0.50971777 0.0000000
## orville:180-essential:90      -0.5538799520 -0.596402159 -0.51135774 0.0000000
## popsecret:180-essential:90    -0.5280436887 -0.570565896 -0.48552148 0.0000000
## popsecret:90-orville:90        0.0527785520  0.010256345  0.09530076 0.0037216
## actii:120-orville:90          -0.5683786935 -0.610900901 -0.52585649 0.0000000
## essential:120-orville:90      -0.5714969570 -0.614019164 -0.52897475 0.0000000
## orville:120-orville:90        -0.5139994979 -0.556521705 -0.47147729 0.0000000
## popsecret:120-orville:90      -0.5149406484 -0.557462855 -0.47241844 0.0000000
## actii:180-orville:90          -0.6482093951 -0.690731602 -0.60568719 0.0000000
## essential:180-orville:90      -0.6241306574 -0.666652864 -0.58160845 0.0000000
## orville:180-orville:90        -0.6257706307 -0.668292838 -0.58324842 0.0000000
## popsecret:180-orville:90      -0.5999343674 -0.642456574 -0.55741216 0.0000000
## actii:120-popsecret:90        -0.6211572455 -0.663679453 -0.57863504 0.0000000
## essential:120-popsecret:90    -0.6242755090 -0.666797716 -0.58175330 0.0000000
## orville:120-popsecret:90      -0.5667780499 -0.609300257 -0.52425584 0.0000000
## popsecret:120-popsecret:90    -0.5677192004 -0.610241407 -0.52519699 0.0000000
## actii:180-popsecret:90        -0.7009879471 -0.743510154 -0.65846574 0.0000000
## essential:180-popsecret:90    -0.6769092094 -0.719431416 -0.63438700 0.0000000
## orville:180-popsecret:90      -0.6785491827 -0.721071390 -0.63602698 0.0000000
## popsecret:180-popsecret:90    -0.6527129194 -0.695235126 -0.61019071 0.0000000
## essential:120-actii:120       -0.0031182635 -0.045640471  0.03940394 1.0000000
## orville:120-actii:120          0.0543791956  0.011856989  0.09690140 0.0023604
## popsecret:120-actii:120        0.0534380451  0.010915838  0.09596025 0.0030895
## actii:180-actii:120           -0.0798307016 -0.122352909 -0.03730849 0.0000005
```

```
## essential:180-actii:120     -0.0557519639 -0.098274171 -0.01322976 0.0015826
## orville:180-actii:120       -0.0573919372 -0.099914144 -0.01486973 0.0009712
## popsecret:180-actii:120     -0.0315556739 -0.074077881  0.01096653 0.3641754
## orville:120-essential:120    0.0574974591  0.014975252  0.10001967 0.0009408
## popsecret:120-essential:120  0.0565563086  0.014034102  0.09907852 0.0012473
## actii:180-essential:120     -0.0767124381 -0.119234645 -0.03419023 0.0000015
## essential:180-essential:120 -0.0526337004 -0.095155907 -0.01011149 0.0038759
## orville:180-essential:120   -0.0542736737 -0.096795881 -0.01175147 0.0024332
## popsecret:180-essential:120 -0.0284374104 -0.070959617  0.01408480 0.5290872
## popsecret:120-orville:120   -0.0009411505 -0.043463358  0.04158106 1.0000000
## actii:180-orville:120       -0.1342098972 -0.176732104 -0.09168769 0.0000000
## essential:180-orville:120   -0.1101311595 -0.152653367 -0.06760895 0.0000000
## orville:180-orville:120     -0.1117711328 -0.154293340 -0.06924893 0.0000000
## popsecret:180-orville:120   -0.0859348695 -0.128457077 -0.04341266 0.0000000
## actii:180-popsecret:120     -0.1332687467 -0.175790954 -0.09074654 0.0000000
## essential:180-popsecret:120 -0.1091900090 -0.151712216 -0.06666780 0.0000000
## orville:180-popsecret:120   -0.1108299823 -0.153352189 -0.06830778 0.0000000
## popsecret:180-popsecret:120 -0.0849937190 -0.127515926 -0.04247151 0.0000001
## essential:180-actii:180      0.0240787377 -0.018443469  0.06660094 0.7615711
## orville:180-actii:180        0.0224387644 -0.020083443  0.06496097 0.8339027
## popsecret:180-actii:180      0.0482750277  0.005752821  0.09079723 0.0125231
## orville:180-essential:180   -0.0016399733 -0.044162180  0.04088223 1.0000000
## popsecret:180-essential:180  0.0241962900 -0.018325917  0.06671850 0.7559271
## popsecret:180-orville:180    0.0258362633 -0.016685944  0.06835847 0.6722245
```

```
plot(tukey_popcorn)
```



```
#Shows 9 are NOT statistically significant, so we cannot say there is a
#difference of how much they affect the percentage of unpopped kernels
#between the following:

#essential_120 & actili_120
#popsecret_180 & actili_120
#popsecret_180 & essential_120
#popsecret_120 & orville_120

#essential_180 & actili_180*
#orville_180 & essential_180*
#orville_180 & actili_180*
#popsecret_180 & essential_180
#popsecret_180 & orville_180
```

Based on the output, brand Actili and time 180 interaction results in the smallest percentage of unpopped kernels compared to every other interaction. Although this is the case, the difference between actili_180 and both essential_180 & orville_180 was not statistically significant.Thus, we can say that either of these three produce the lowest percentage. Note there are also a series of differences that were not statistically significant, so that one can choose either of the brand combinations with time 180 and Actili or Essential with time 120 and there is no statistically significant difference between such. Thus, any of these could lead to the lowest lowest percentage of kernels unpopped.