AN EXPERIMENT ON CELL PHONE BATTERY LIFE

Abstract

The main goal of this experiment is to determine how specific factors affect the life of a cell phone battery and potentially which factor(s) has the greatest impact on it. In our experiment, we used 3 different types of cell phones. Therefore, one of the factors we took into account is the type of cell phone. We worked with IPhone 5s, Samsung Galaxy S6 and Sony Xperia M5. Other possible factors of interest are media and brightness. These factors were considered at two levels. For instance, media included music and video while brightness was tested at high and low levels. We created our design with a factor initial battery percentage "100%" and "50%" in order to investigate any possible deviations in average decrease of battery life at different levels of the battery percentage. To test all the factors with maximum efficiency, we used the design with both nested and factorial parts. The response variable of the experiment is the mean decrease in battery percentage. We expected to observe a larger decrease in battery percentage after listening to music and watching a video at high brightness. We assumed that the screen turned ON and at high brightness would have a significant impact on a charge of all cell phones. In addition, we thought that at an initial battery level of 50%, all cell phones would lose battery faster. The result of the experiment clearly showed that the three brands play a good role in determining the quality of battery life, but the brightness we choose our cell phone to run on shows a greater impact. Moreover, cell-phones indeed lose more power at a faster rate at 50% of the charge than at 100%. To sum up, every consumer has to pay attention to the brand when it is time to purchase a smartphone. She/he also has to keep in mind that there is no cell phone with battery that would not be affected by high brightness or extensive wasteful usage.

Introduction

The use of a cell phone is an integral part of our everyday lives in the 21st century. People use it for different purposes in their lives whether it's for communication purposes or personal entertainment. The market of cell phones offers a large variety of different brands to choose from. This makes the selection of phones difficult because the quality of the phone is important for consumers. If we assume that battery life is the determining factor of the quality of cell phones, then *how can we determine which brands offer the best battery life?* Upon thinking of different answers to this question, it came across our minds that it may not just be the different brands of phones that affect the battery life, but also how we use our phones. We can determine *which of our selected factors have the greatest effect on battery life*. This idea came from the experiences of many people who have had their cell phones run out of power at the most needed times. As we know, some tasks that can be done with our cell phones require more power than others. The problem may be that most people "ridicule smartphones for having rubbish-like battery capability" not realizing that the "blame doesn't necessarily always fall to the manufacturer, but rather on the user" stated an author named JM in the article *"Factors Affecting Phones Battery Life – How to Fix The Problem"*. That being said, it is very important to know what factors are the most significant. Thus, this experiment will address the problem by determining the effect of different factors on a cell phone's battery life. In his article, JM listed some factors that may affect the battery life, so we used some factors mentioned by JM as well as our own factors that may also contribute to the effect on battery life.

The decision was made to use the design with both nested and factorial factors as the most suitable design for the experiment. This design was taken from the book "Design and analysis of experiments" by Montgomery and Douglas C. In this project, we dealt with the four fixed factors: type of cell phone, starting battery level, media, and brightness. Of these factors, media and type of cell phone formed a factorial design. The remaining factors, initial battery level and brightness, differ among the cell phones, hence, were nested under cell phones. To make sure that the amount of observations was sufficient to draw reasonable conclusions, we used two replicates.

We concluded that the type of cell phone, brightness and the initial percentage affected the battery life the most whereas media seems to have less impact on battery consumption.

Methodology

For this experiment, we used a design with both nested and factorial factors. The factors we are interested in are initial battery percentage, type of cell phones, media and brightness.

The three types of cell phones that were used are Iphone, Sony and Samsung. The factor media has two levels, music and video. These two factors are fixed and will form a factorial design. The brightness is fixed too, but it varies among the cell phones, so it is a factor nested within the cell phones. The levels of brightness that were tested are high and low. The initial battery factor has two levels, 100 percent and 50 percent, and like brightness it is unique for each cell phone, so we nested it under the type of cell phone too. The model appropriate for this experiment is:

Model 1.1:

$$\mathbf{Y_{ijkld}=\mu+\tau_i+\beta_j+(\tau\beta)_{ij}+\gamma_{k(i)}+(\beta\gamma)_{jk(i)}+\theta_l+(\beta\theta)_{jl(i)}+\varepsilon_{(ilk)jd}} \quad (1)$$

Where

$\mathbf{Y}$ is a response variable: the change in a battery percentage

$\boldsymbol{\mu}$ is intercept (an estimator of grand mean)

$\boldsymbol{\tau}$ is a cell type factor with 3 levels IPhone, Samsung, Sony. i=1,2,3

$\boldsymbol{\beta}$ is a factor media with 2 levels video and music. j=1,2

$\boldsymbol{\tau\beta}$ is an interaction term between cell type and media

$\boldsymbol{\gamma}$ is a factor brightness nested under cell type with two levels: High and low

$\boldsymbol{\beta\gamma}$ an interaction between media and brightness nested under cell type

$\boldsymbol{\theta_l}$ a factor initial battery percentage nested within cell type with two levels: 100% and 50%

$\boldsymbol{\beta\theta}$ is an interaction term between media and initial battery percentage nested within cell type

$\boldsymbol{\varepsilon}$ is error of the model (residuals)

The first three factors of **model (1.1)** is a full factorial design of two factors and the second part of the model is nested design.

For the factorial part of the design we had to consider all the possible combinations of all factors and their levels. According to information provided above we have 3*2*2*2=24 combinations in total. For the data, two replicates were considered, which gave a total of 48 observations.

2. Collection of the data

We gathered the data by running 24 combinations randomly twice. This was done by assigning numbers from 1 to 24 to each of the possible 24 combinations. We then ran the command *sample(1:24)* in R.

Output 2.2*:A random arrangement of numbers starting from 1 to 24.*

19 11 12 3 2 7 21 20 6 10 4 13 24 17 18 23 5 1 22 9 15 16 14 8 (2)

Output **(2.2)** shows the order in which our data was collected for first replicate. The second replicate was obtained in a similar fashion with the order shown in Output **(2.3)**.

Output 2.3: *A random arrangement of numbers starting from 1 to 24*

19 10 23 1 8 4 13 14 12 15 11 3 17 9 20 6 22 5 7 24 2 16 18 21 (3)

The phones were all put in airplane mode creating a closed environment so that no unknown or extraneous factors would affect the battery life of each phone. By putting the phone in airplane mode, we could then focus on the factors we selected and had a uniform test. To reduce the variability of the data, we all used the same video and music for the experiment, each level was used for twenty- three minutes and thirty seconds.

According to the article *"Why Do Smartphone Batteries Fail So Quickly?"* by James Hunt, the battery temperature can increase the rate of discharge at higher temperatures. With this in mind, we left cell phones for a cool down period of twenty minutes. By leaving the phone to cool down, its rate of reduction is restored to equilibrium and battery life can decrease at a regular rate. We also closed any background applications that were still running, as these applications may also contribute to the variability of the data.

Table 1. *Battery decrease for different cell phone types.*

Initial battery 100%				**Initial battery 50%**		
Phone Type	**IPhone**	**Samsung**	**Sony**	**IPhone**	**Samsung**	**Sony**
High brightness, Video	6 5	6 4	6 6	8 9	6 6	7 5
Low brightness Video	4 5	4 3	3 2	5 5	4 5	3 3
High brightness Music	6 5	4 3	5 5	10 10	5 6	5 5
Low brightness Music	5 5	3 3	3 2	6 5	4 4	3 3

3. Data Analysis

Using the model outlined above we tested the following hypothesis:

H_0: $\tau_i=\beta_j=(\tau\beta)_{ij}=\gamma_{k(i)}=(\beta\gamma)_{jk(i)}=\theta_l=(\beta\theta)_{jl(i)}=\varepsilon_{(ilk)jd}=0$

On the average neither of the mentioned factors have any effect on the battery life

Ha: at least one of these effects do not equal zero and on average have impact on the battery life

We obtained the following ANOVA table in **Output 3.1.**

Output 3.1: *Data output for Anova Table measuring factors differences.*

```
Analysis of Variance Table
Response: y
                            Df Sum Sq Mean Sq F value    Pr(>F)    
cell_type                    2 40.542 20.2708 28.4503 1.179e-07 ***
media                        1  0.521  0.5208  0.7310   0.39934    
cell_type:media              2  4.292  2.1458  3.0117   0.06428 .  
cell_type:brightness         3 59.063 19.6875 27.6316 9.028e-09 ***
cell_type:init_battery       3 24.563  8.1875 11.4912 3.488e-05 ***
cell_type:media:brightness   3  1.313  0.4375  0.6140   0.61124    
cell_type:media:init_battery 3  0.812  0.2708  0.3801   0.76802    
Residuals                   30 21.375  0.7125                      
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Output **(3.1)** shows that there are three factors that have a significant effect on battery consumption. These three factors are cell type, initial battery, and brightness which have the p-values **1.179*10^-7**, **9.028*10^ (-9)**, **3.488*10^(-5)** respectively. The p-values are smaller than $\alpha=0.05$, so we reject null hypothesis and conclude that these factors cause a significant decrease in a battery percentage.
Since the factor cell_type has three levels we proceeded with the analysis of each level and its significance using Tukey's confidence intervals. Moreover, we checked confidence intervals for all significant factors such as brightness and initial battery nested under cell type. As for interaction terms, since they have minimal impact on the mean battery consumption, they do not require further investigation.

Output 3.2 *95% confidence interval for all cell types*

```
The 95% confidence interval for cell-types:
Samsung-IPhone (-3.570497;-0.05450255 )
Sony-Samsung (-2.007997; 1.507997)
Sony-IPhone (-3.820497;-0.3045025)
```

Output **(3.2)** suggests that there is a difference in average decrease of battery percentage between **(Samsung - IPhone)** and **(Sony - IPhone)** since the 95% confidence interval is (-3.57105,-0.05450) and (-3.8205; -0.30450) respectively, and they do not include zero. Because the confidence interval lies within negative range we can conclude that on average the Samsung have smaller decrease in battery life than IPhone. Another comparison does not show any difference in average decrease of battery percentage between **(Sony – Samsung)**. So it seems that IPhone loses its charge at a faster rate than Samsung and Sony.

Output 3.3 *95% confidence interval for brightness levels within cell types*

```
The 95% confidence interval for brightness level within cell_types:
IPhone high-IPhone low(-0.02353453;4.773535)
Samsung high-Samsung low(-1.148535;3.648535)
Sony high - Sony Low(0.3514655;5.148535)
```

Output **(3.3)** shows that when we fix cell type and compare levels of brightness (high and low) within each type there is no significant difference in average drop of battery life for IPhone and Samsung. In contrast, we cannot say the same for the Sony cell phone. With 95% confidence interval (0.3514655;5.148535) between Sony high brightness and Sony low brightness it indicates that Sony on average has a trend in losing battery faster when it's set with high brightness.

Output 3.4 *95% confidence interval for brightness levels within cell types*

```
The 95% confidence interval for brightness level within cell_types:
 IPhone:High-Samsung:High (-0.02353453;4.773535 )
 IPhone:High-Sony:High (-0.5235345;4.273535 )
 Samsung:High-Sony:High ( -2.898535;1.898535 )
```

```
The 95% confidence interval for brightness level within cell_types:
 Iphone:low-Samsung:low (-0.02353453;4.773535 )
 IPhone:low-Sony:low (-0.1485345;4.648535 )
 Samsung:low-Sony:low (-1.398535;3.398535 )
```

In output **(3.4)** we built confidence intervals for different cell phones fixing levels of brightness. As we can see from the codes we don't have any evidence that there is a significant difference in average battery decrease between different cell phones used with high brightness.We can say the same for low brightness, the consumption of battery life varies among cell phones, but is not strong enough to form any conclusions that there is a significant difference.

Output 3.5 *95% confidence interval for initial battery nested within cell types*

```
The 95% confidence interval for init_battery nested within cell_type
 100% Iphone- 50% IPhone ( -4.523535 ; 0.2735345 )
 100% Samsung - 50%Samsung( -3.648535 ; 1.148535 )
 100% Sony- 50% Sony( -2.648535 ; 2.148535 )
```

Output **(3.5)** shows the comparisons of initial battery percentage for each model of smartphones. According to the obtained results there is no significant difference in mean decrease of battery life between two levels of initial battery for each type of cell phone.

Output 3.6 *95% confidence interval for initial battery nested within cell types*

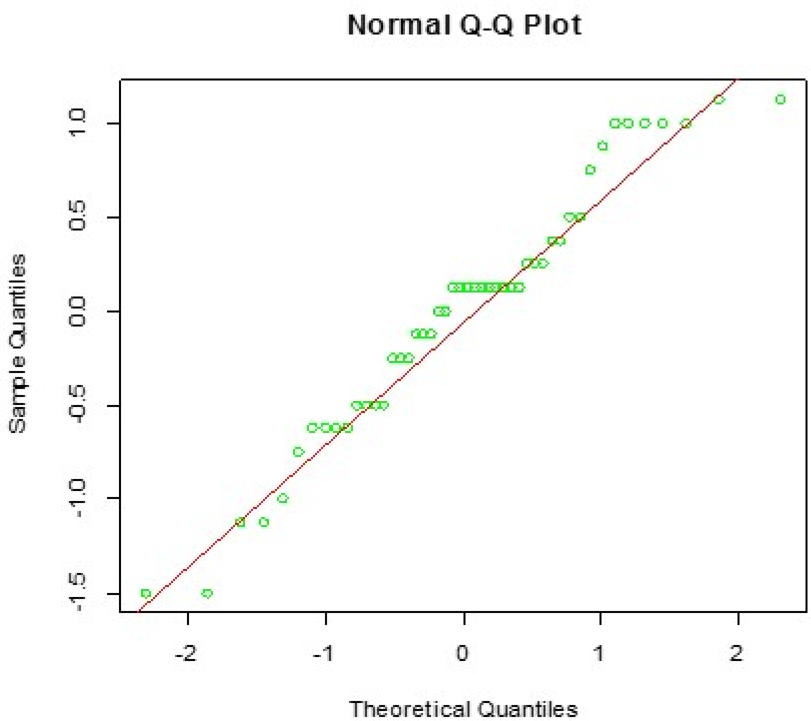
```
The 95% confidence interval for init_battery nested within cell_type
 100% Iphone- 100% Samsung (-1.023535 ; 3.773535)
 100% IPhone - 100%Sony(-1.273535 ; 3.523535)
 100% Samsung-100% Sony(-2.648535 ; 2.148535)

The 95% confidence interval for init_battery nested within cell_type
 50% Iphone-50% Samsung (-0.1485345;4.648535)
 50% IPhone-50%Sony(0.6014655;5.398535)
 50% Samsung-50% Sony(-1.648535;3.148535)
```

Then we investigated if there is a difference among smartphones with different levels of battery charge. Output **(3.6)** demonstrates results that don't indicate significant difference at 100%, but show that at 50%, IPhone on average has a faster battery consumption rate than Sony at 50%.

4.Analysis of residuals

To determine the validity of our results, we must analyze our residuals. The first step in this process is to check the assumption of Normality by using normal QQ plot.

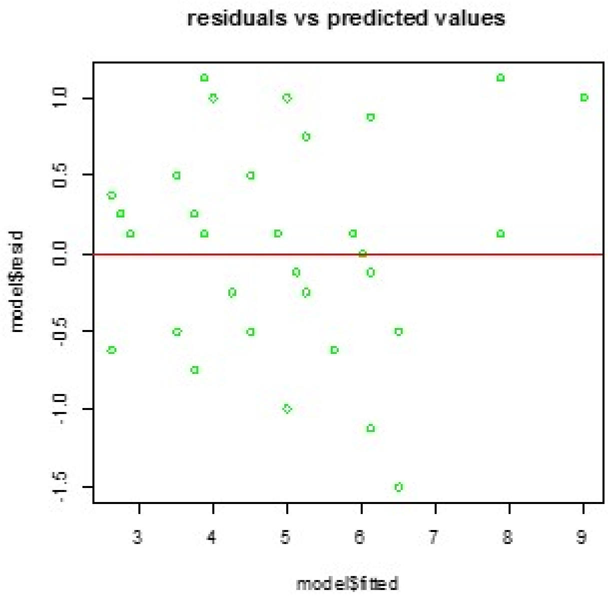
Figure 4.1: *Normal Q-Q plot of Residuals for Model (1.1)*



From **Figure (4.1)** we see that the residuals deviate from the line of best fit. The normality assumption is slightly violated but not enough to invalidate the results of the experiment.

We checked the crucial assumption of equal variances by using Bartlett and Levene's tests and plots of residuals versus predicted values, cell type, initial battery, brightness and media.

Figure 4.2*: Residuals vs predicted values for Model (1.1)*



Figure(4.2) does not indicate any violation of the Equal Variances assumption. However, this plot is not sufficient enough to ensure that this assumption holds. We created residual plots for each variable and checked the assumption for each of them. The plots can be found in **Appendix 2:Plots** To check this assumption we constructed the following hypothesis for Bartlett test.

H_0: $\sigma_{\tau 1}= \sigma_{\tau 2}= \sigma_{\tau 3}$ where $\sigma_{\tau 1}$ is variance for the cell type IPhone, $\sigma_{\tau 2}$ is variance for the cell type Samsung and $\sigma_{\tau 3}$ is variance for the cell type Sony

H_a: at least two variances are not equal.

Then we ran the Bartlett test. This procedure was repeated for each factor and the results showed that the assumption of equal variances hold for all factors except cell type.

Output 4.1 *Bartlett test for homogeneity of variances*

```
Bartlett test of homogeneity of variances
data:  model$resid and cell_type
Bartlett's K-squared = 8.6855, df = 2, p-value = 0.013

data:  model$resid and init_battery
Bartlett's K-squared = 0.11113, df = 1, p-value = 0.7389

data:  model$resid and brightness
Bartlett's K-squared = 0.61179, df = 1, p-value = 0.4341

data:  model$resid and media
Bartlett's K-squared = 0.037753, df = 1, p-value = 0.8459
```

Assuming α=0.05 we failed to reject the null hypothesis for factors initial battery, brightness and media with their p-values larger than α=0.05. For the factor cell type the p-value is 0.03 <α so we rejected the null hypothesis and said that the assumption does not hold.

However, the Bartlett test alone cannot be a reliable source of information because of its sensitivity to normality. Taking into account that in this experiment the Normality assumption was slightly violated, we used the Levene's test which is more robust, hence, more reliable.

The result from the Levene's tests below show that the p-values are larger than α=0.05 for each factor. We failed to reject the null hypothesis and there is no evidence to conclude the assumption of equal variances was violated for all factors.

Output 4.2:*Levene Tests for factors: Celltype, initial battery, media and brightness*

```
cell_type
Analysis of Variance Table
Response: y.d
          Df Sum Sq Mean Sq F value Pr(>F)
factor     2  2.375  1.1875  0.7983 0.4564
Residuals 45 66.938  1.4875

init_battery
Analysis of Variance Table
Response: y.d
          Df Sum Sq Mean Sq F value Pr(>F)
factor     1  1.021  1.0208    0.74 0.3941
Residuals 46 63.458  1.3795

media
Analysis of Variance Table
Response: y.d
          Df Sum Sq Mean Sq F value Pr(>F)
factor     1  0.021 0.02083  0.0127 0.9108
Residuals 46 75.458 1.64040

brightness
Analysis of Variance Table
Response: y.d
          Df Sum Sq Mean Sq F value Pr(>F)
factor     1  1.021 1.02083  1.0723 0.3058
Residuals 46 43.792 0.95199
```

Summary

This experiment was conducted to find out whether battery consumption differs between different cell phones and how various factors influence the rate of discharge. We conducted this experiment by using our cell phones to test four factors at different levels. More specifically, the factors were type of cell phone, brightness level, media and initial battery percentage. This was tested using a design with both nested and factorial factors: type of cell phone and media formed a factorial design and brightness and initial battery percentage were nested in the type of cell phone. This experiment showed that the factors that mattered in battery consumption were the type of cell phone, brightness level and initial battery

percentage; only media was insignificant. Because the levels of media we tested were video and music, we can only conclude that listening to music and watching a video for the same amount of time consumes the same amount of power. Keeping in mind that we tested music with the screen turned ON, having the screen turned off in a real world situation will affect the battery consumption differently. This brings us to the conclusion of brightness having a significant effect on battery consumption. Having the cell phones on high brightness drains more power than it would on low brightness. These two conclusions from our results tell us that it is the screen that uses more power rather than the processors.

We also concluded that the power consumption differs between the types of cell phones which agree with the assumption that manufacturers are not necessarily responsible for the difference in battery capability, in the article "*Factors Affecting Phones Battery Life – How to Fix The Problem*". We confirmed that the usage of cell phones affects battery life just as much as the difference in brands if not more. Based on our results, the Iphone drains the battery the most, followed by Sony and Samsung. There is no significant difference between Sony and Samsung. Initial battery was tested at two levels: 100% and 50%. For 100%, we did not observe any differences between cell type batteries. This means that all phones generally decrease at the same rate at this initial battery percentage. At 50% we noticed a difference between IPhone and Sony, IPhone battery life decreased at a faster rate than Sony battery life. We also tried to investigate if there was any difference between the two levels of initial battery percentage with each brand of cell phone. Tukey's confidence intervals showed that for Iphone and Samsung, the initial level of battery charge doesn't matter, while Sony tends to lose battery at a faster rate once it hits 50% point of its charge. These results are consistent with the main idea expressed in the article "*Why Do Smartphone Batteries Fail So Quickly?*" by James Hunt.

Limitations

Taking into account that we conducted our experiment in an isolated environment by enabling Airplane mode on all the used smartphones, our experiment was very simple in comparison to what would be an ideal experiment in the real world. For example, we can use mobile data, location tracking, take pictures and play games that consume a huge anount of battery life. Also, we could have changed the response variable to the time it takes for the battery to drain to a certain percentage, so we would be able to draw different conclusions. Unfortunately, given the amount of time we had, it was hard to achieve. We also could have tested more factors that may affect power consumption but again, the issue of time still persists. Testing more phones was also an option that would reduce the variability of the data. Temperature was also a potential factor but we didn't test it.Warm spring weather with little variation in temperature was not enough to create different temperature conditions.

References

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Hunt, James. Why Do Smartphone Batteries Fail So Quickly?. Mentall_floss., 22 Jan. 2015. Web. 8 April 2016.
< http://mentalfloss.com/uk/technology/27009/why-do-smartphone-batteries-fail-so-quickly >

Montgomery, Douglas C. Design and analysis of experiments. 8th ed. Hoboken, NJ: John Wiley & Sons, Inc. 2013. Print.

Appendix 1

R codes used in the experiment

Randomness of data collection

```
sample(1:24)
sample(1:24)
```

Input of collected data

```
y=c(6,4,6,5,5,5,5,5,6,4,4,3,4,3,3,3,6,3,5,3,6,2,5,2,

8,5,10,6,9,5,10,5,6,4,5,4,6,5,6,4,7,3,5,3,5,3,5,3)

cell_type=as.factor(rep(c("Iphone","Samsung","Sony"),each=8,times=2))
```

```
init_battery=as.factor(rep(c("100%","50%"),each=24))
media=as.factor(rep(c("Video","Music"),each=2,times=12))
brightness=as.factor(rep(c("High","Low"),times=24))
data=data.frame(cell_type,init_battery,brightness,media,y)
data
cell_type init_battery brightness media  y
1     Iphone          100%       High Video  6
2     Iphone          100%       Low Video  4
3     Iphone          100%       High Music  6
4     Iphone          100%       Low Music  5
5     Iphone          100%       High Video  5
6     Iphone          100%       Low Video  5
7     Iphone          100%       High Music  5
8     Iphone          100%       Low Music  5
9     Samsung         100%       High Video  6
10   Samsung          100%       Low Video  4
11   Samsung          100%       High Music  4
12   Samsung          100%       Low Music  3
13   Samsung          100%       High Video  4
14   Samsung          100%       Low Video  3
15   Samsung          100%       High Music  3
16   Samsung          100%       Low Music  3
17    Sony       100%       High Video  6
18    Sony       100%       Low Video  3
19    Sony       100%       High Music  5
20    Sony       100%       Low Music  3
21    Sony       100%       High Video  6
22    Sony       100%       Low Video  2
23    Sony       100%       High Music  5
24    Sony       100%       Low Music  2
25    Iphone          50%        High Video  8
26    Iphone          50%        Low Video  5
27    Iphone          50%        High Music 10
28    Iphone          50%        Low Music  6
29    Iphone          50%        High Video  9
```

30	Iphone	50%	Low	Video	5
31	Iphone	50%	High	Music	10
32	Iphone	50%	Low	Music	5
33	Samsung	50%	High	Video	6
34	Samsung	50%	Low	Video	4
35	Samsung	50%	High	Music	5
36	Samsung	50%	Low	Music	4
37	Samsung	50%	High	Video	6
38	Samsung	50%	Low	Video	5
39	Samsung	50%	High	Music	6
40	Samsung	50%	Low	Music	4
41	Sony	50%	High	Video	7
42	Sony	50%	Low	Video	3
43	Sony	50%	High	Music	5
44	Sony	50%	Low	Music	3
45	Sony	50%	High	Video	5
46	Sony	50%	Low	Video	3
47	Sony	50%	High	Music	5
48	Sony	50%	Low	Music	3

Building the model

```
model=lm(y~(cell_type+media)^2+(brightness+brightness*media)%in%
cell_type+(init_battery+media*init_battery)%in%cell_type)
anova(model)
```

95% Confidence intervals

```
model_a=anova(model)
ms=as.vector(model_a[[3]])
ms_A=ms[1]
ms_B=ms[2]
ms_AB=ms[3]
ms_CinA=ms[4]
ms_DinA=ms[5]
ms_BCinA=ms[6]
ms_BDinA=ms[7]
ms_err=ms[8]
```

```
df=as.vector(model_a[[1]])
df_A=df[1]
df_B=df[2]
df_AB=df[3]
df_CinA=df[4]
df_DinA=df[5]
df_BCinA=df[6]
df_BDinA=df[7]
a=3
n=2
b=2
c=2
d=2
alpha=0.05
```

Confidence Intervals for Cell phone types

```
r = n*b*c*d
mean_diff = tapply(y,cell_type,mean)
ME <- qtukey(1-alpha,a,df_A)*sqrt(ms_err/r)
cat("The three cell-type means are", mean_diff,"\n", "The Margin of
Error is",ME, "\n")
subt_diff1=c(mean_diff[2]-mean_diff[1])
subt_diff2=c(mean_diff[3]-mean_diff[2])
subt_diff3=c(mean_diff[3]-mean_diff[1])

cat("The 95% confidence interval for cell-types:\n",
     "Samsung-IPhone (", subt_diff1-ME,";",subt_diff1+ME,")\n",
"Sony-Samsung (", subt_diff2-ME,";",subt_diff2+ME,")\n",
"Sony-IPhone (", subt_diff3-ME,";",subt_diff3+ME,")\n")
```

Brightness nested under cell type

```
mean_diff = c(tapply(y,cell_type:brightness,mean))
l=a*c
r=b*d*n
ME <- qtukey(1-alpha,l,df_CinA)*sqrt(ms_err/r)
```

Fixed cell type

```
subt_diff1=c(mean_diff[1]-mean_diff[2])  #iPhone high-IPhone low
subt_diff2=c(mean_diff[3]-mean_diff[4])   #Samsung high Sumsung low
subt_diff3=c(mean_diff[5]-mean_diff[6])     #Sony high - Sony Low
cat("The 95% confidence interval for brightness within cell_types:\n",
     "IPhone high-IPhone low(", subt_diff1-ME,";",subt_diff1+ME,")\n",
"Samsung high-Samsung low(", subt_diff2-ME,";",subt_diff2+ME,")\n",
"Sony high - Sony Low(", subt_diff3-ME,";",subt_diff3+ME,")\n")
```

Fixed level of brightness

```
subt_diff1=c(mean_diff[1]-mean_diff[3])  #iPhone high-samsung high
subt_diff2=c(mean_diff[1]-mean_diff[5])   #IPhone high sony high
subt_diff3=c(mean_diff[6]-mean_diff[5])     #Samsung high - sony high
cat("The 95% confidence interval for brightness within cell_types:\n",
     "IPhone:High-Samsung:High (", subt_diff1- ME,";", subt_diff1+
ME,")\n",
"IPhone:High-Sony:High (", subt_diff2-ME,";",subt_diff2+ME,")\n",
"Samsung:High-Sony:High (", subt_diff3-ME,";",subt_diff3+ME,")\n")

subt_diff1=c(mean_diff[2]-mean_diff[4])  #Iphone:low-Samsung:low
subt_diff2=c(mean_diff[2]-mean_diff[6])   #IPhone:low-Sony:low
subt_diff3=c(mean_diff[4]-mean_diff[6])     #Samsung:low-Sony:low
cat("The 95% confidence interval for brightness within cell_types:\n",
     "Iphone:low-Samsung:low (", subt_diff1-
ME,";",subt_diff1+ME,")\n",
"IPhone:low-Sony:low(", subt_diff2-ME,";",subt_diff2+ME,")\n",
"Samsung:High-Sony:High (", subt_diff3-ME,";",subt_diff3+ME,")\n")
```

Brightness general

```
mean_diff = tapply(y,brightness,mean)
r=a*b*d*n
ME <- qtukey(1-alpha,c,df_CinA)*sqrt(ms_err/r)
subt_diff1=c(mean_diff[1]-mean_diff[2])
cat("The 95% confidence interval for brightness:\n",
```

```
     " High brightness-Low brightness (", subt_diff1-
ME,";",subt_diff1+ ME,")\n")
```

Initial battery percentage in general

```
mean_diff = tapply(y,init_battery,mean)
r=a*b*c*n
ME <- qtukey(1-alpha,c,df_DinA)*sqrt(ms_err/r)
subt_diff1=c(mean_diff[1]-mean_diff[2])
cat("The 95% confidence interval for initiall battery percentage:\n",
     " 100% init_ battery - 50% init_battery(", subt_diff1-ME,";",
subt_diff1+ME,")\n")
```

Initial battery % nested under cell type

```
mean_diff = tapply(y,cell_type:init_battery,mean)
r=b*c*n
ME <- qtukey(1-alpha,l,df_DinA)*sqrt(ms_err/r)
subt_diff1=c(mean_diff[1]-mean_diff[3])  #100% Iphone- 100% Samsung
subt_diff2=c(mean_diff[1]-mean_diff[5])   #100% IPhone - 100%Sony
subt_diff3=c(mean_diff[3]-mean_diff[5])     #100% Samsung-100% Sony

cat("The 95% confidence interval for init_battery nested within
cell_type\n",
     "100% Iphone- 100% Samsung (", subt_diff1-ME,";",subt_diff1+
ME,")\n",
"100% IPhone - 100%Sony(", subt_diff2-ME,";",subt_diff2+ME,")\n",
"100% Samsung-100% Sony(", subt_diff3-ME,";",subt_diff3+ME,")\n")

subt_diff1=c(mean_diff[2]-mean_diff[4])  #50% Iphone- 50% Samsung
subt_diff2=c(mean_diff[2]-mean_diff[6])   #50% IPhone - 50%Sony
subt_diff3=c(mean_diff[4]-mean_diff[6])     #50% Samsung-50% Sony

cat("The 95% confidence interval for init_battery nested within
cell_type\n",
     "50% Iphone-50% Samsung (", subt_diff1-
ME,";",subt_diff1+ME,")\n",
"50% IPhone-50%Sony(",subt_diff2-ME,";",subt_diff2+ME,")\n",
```

```
"50% Samsung-50% Sony(",subt_diff3-ME,";",subt_diff3+ME,")\n")
```

Analysis of residuals

Plots

```
qqnorm(model$resid,col="green")
qqline(model$resid,col="red")
plot(model$fitted,model$resid,col="green",main="residuals vs predicted values")
abline(0,0,col="red")
windows()
par(mfrow=c(2,2))
plot(c(cell_type),model$resid,col="green", main="Residuals vs cell type")
abline(0,0,col="red")
plot(c(init_battery),model$resid,col="green", main="Residuals vs initial battery")
abline(0,0,col="red")
plot(c(brightness),model$resid,col="green", main="Residuals vs brightness")
abline(0,0,col="red")
plot(c(media),model$resid,col="green", main="Residuals vs media")
abline(0,0,col="red")
```

Bartlett tests

```
bartlett.test(model$resid,cell_type)
bartlett.test(model$resid,init_battery)
bartlett.test(model$resid,brightness)
bartlett.test(model$resid,media)
```

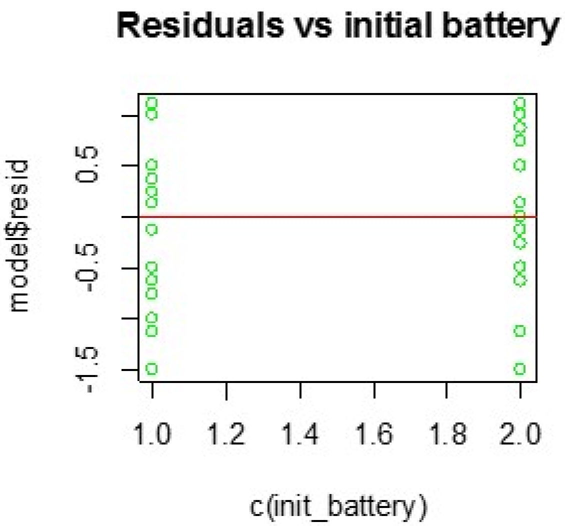
Levene's tests

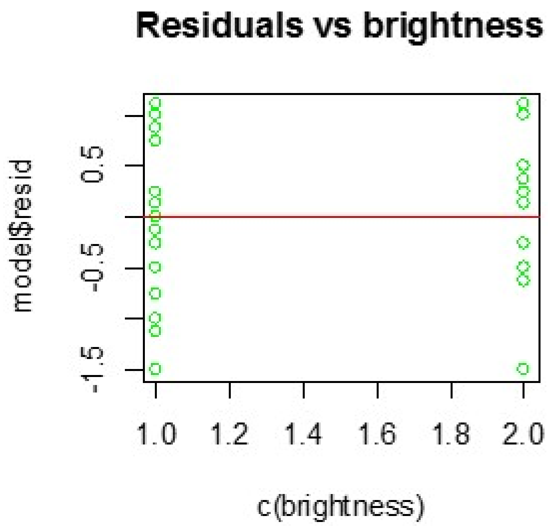
```
my.levene.test = function(y, v, factor)
{ y.d <- vector()
  for(j in v)  y.d[factor==j] = abs(y[factor==j]-median(y[factor==j]))
model.d <- lm(y.d ~ factor)
anova(model.d)
}
```

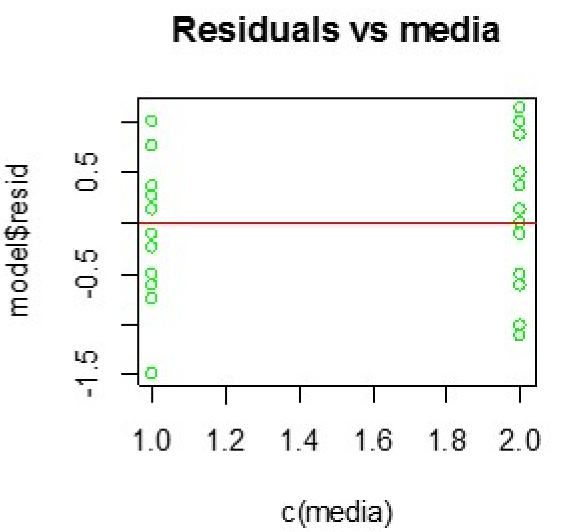
```
v=c("Iphone","Samsung","Sony")
my.levene.test(y,v,cell_type)
v=c("100%","50%")
my.levene.test(y,v,init_battery)
v=c("Video","Music")
my.levene.test(y,v,media)
v=c("High","Low")
my.levene.test(y,v,brightness)
```

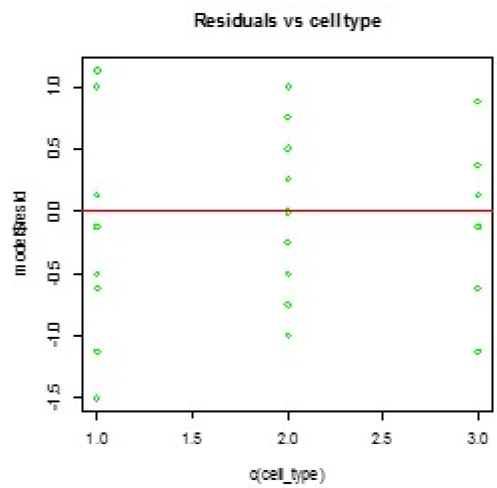
Appendix 2

Plots


Residuals vs initial battery
model$resid
0.5
-0.5
-1.5
1.0
1.2
1.4
1.6
1.8
2.0
c(init_battery)


Residuals vs brightness
model$resid
0.5
-0.5
-1.5
1.0
1.2
1.4
1.6
1.8
2.0
c(brightness)


Residuals vs media
model$resid
0.5
-0.5
-1.5
1.0
1.2
1.4
1.6
1.8
2.0
c(media)


Residuals vs cell type
model$resid
1.0
0.5
0.0
-0.5
-1.0
-1.5
1.0
1.5
2.0
2.5
3.0
c(cell_type)