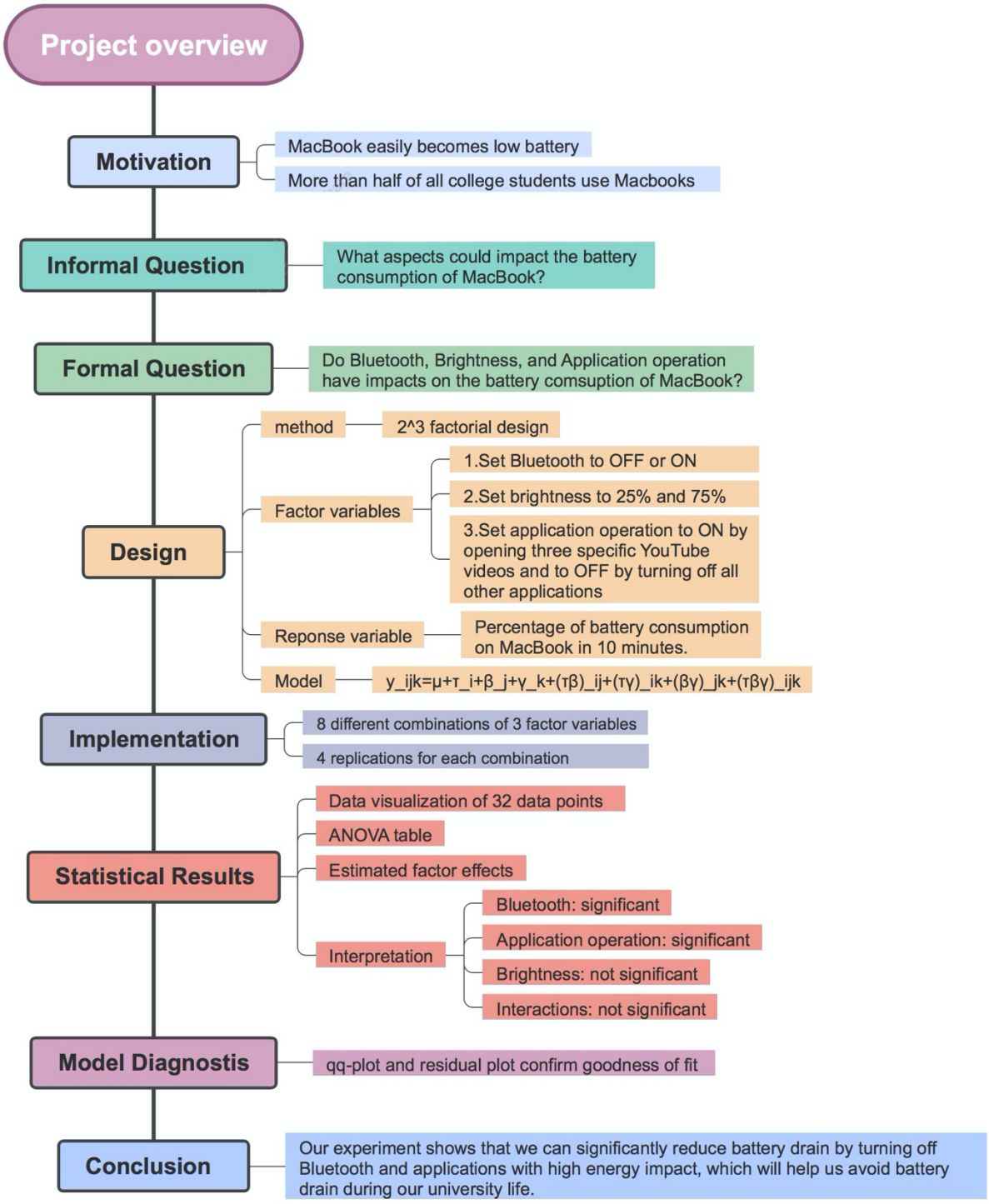
STAT 424 Project Milestone 4



Introduction and Motivation

Laptops are indispensable to every college student. Students need to bring their laptops to class to take notes and to the library to study. Especially due to the pandemic, laptops have become a necessity for students to participate in classes. According to our college experience, more than half of college students use MacBooks. However, MacBook easily becomes low battery and causes inconvenience. This motivated us to explore what aspects could impact the battery consumption of MacBooks. Then, we thought that Brightness, Bluetooth, and Application operation might affect battery consumption. Therefore, we designed an experiment to examine their effects on MacBook battery consumption.

Design and Methodology

We conducted a 2^3 factorial experiment to test the impact of Brightness, Bluetooth, Application, and their second-order & third-order interactions on MacBook battery consumption.

Factor Variables Design:

- Factor1 (Bluetooth): 2 level --- OFF or ON. We believed that OFF would result in a lower battery consumption than ON, so assigning OFF as low level and ON as high level.
- Factor2 (Brightness): 2 level --- 25% or 75%. We believe that 25% would result in a lower battery consumption than 75%, so assigning 25% as low level and 75% as high level.
- Factor3 (Application operation): 2 level --- OFF or ON. We believe that OFF would result in a lower battery consumption than ON, so assigning OFF as low level and ON as high level.

Response Variables Design:

- Percentage of battery consumption on MacBook in 10 minutes.

Model:

- $y_{ijk} = \mu + \tau_i + \beta_j + \gamma_k + (\tau\beta)_{ij} + (\tau\gamma)_{ik} + (\beta\gamma)_{jk} + (\tau\beta\gamma)_{ijk}$, where τ represents the effect of Bluetooth, β represents the effect of Brightness, γ represents the effect of application operation.

Hypotheses:

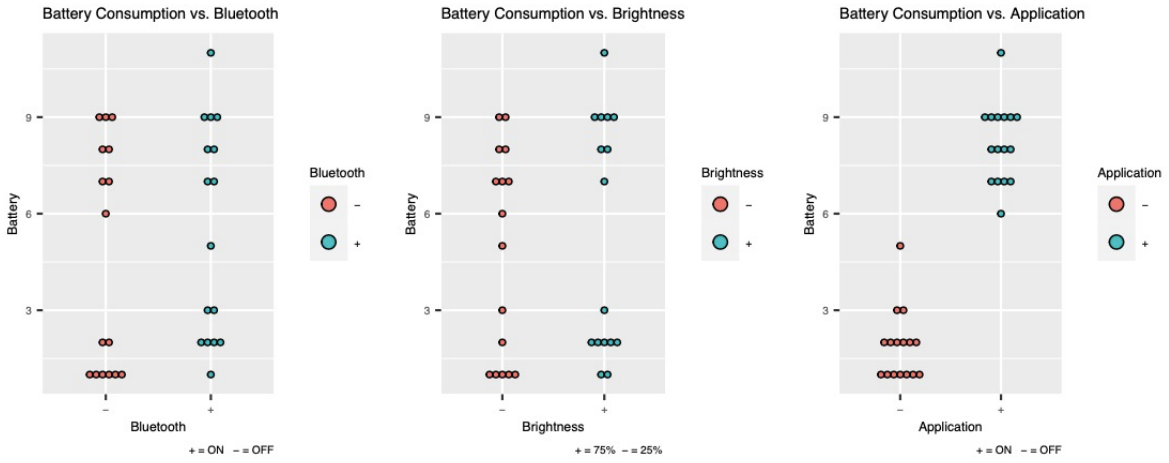
- H_0: $\tau_1 = \cdots = \tau_a = 0$; H_1: $\tau_i \neq 0$ for at least one i
- H_0: $\beta_1 = \cdots = \beta_b = 0$; H_1: $\beta_j \neq 0$ for at least one j
- H_0: $\gamma_1 = \cdots = \gamma_c = 0$; H_1: $\gamma_k \neq 0$ for at least one k
- H_0: $(\tau\beta)_{ij} = \cdots = (\tau\beta)_{ij} = 0, (\beta\gamma)_{jk} = \cdots = (\beta\gamma)_{jk} = 0, \tau\gamma_{ik} = \cdots = \tau\gamma_{ik} = 0, (\tau\beta\gamma)_{ijk} = \cdots = (\tau\beta\gamma)_{ijk} = 0$; H_1: $(\tau\beta)_{ij} \neq 0$ for at least one ij , $(\beta\gamma)_{jk} \neq 0$ for at least one jk, $\tau\gamma_{ik} \neq 0$ for at least one ik, $(\tau\beta\gamma)_{ijk} \neq 0$ for at least one ijk

Implementation

We conducted our experiment on one MacBook Air (13-inch, 2017). First, we set Bluetooth to OFF or ON through System Preferences. Second, we set brightness to 25% and 75% level through the brightness keys. Third, we set application operation to ON by opening three specific YouTube videos and to OFF by turning off all other applications. After setting factor levels for each trial, we charged the MacBook to 50% and set up a timer for 10 minutes. We then measured the percentage of battery consumption within 10 minutes. After each trial, we charged our laptop back to 50% and started another trial. Using all 3 factors, we had 8 different combinations of cases. We did 4 replications for each combination on this MacBook to eliminate the nuisance effect and test if there are any interactions among these 3 factors.

Statistical Results

Data visualization:



Estimated factor effects:

```
                (Intercept)                      Bluetooth                     Brightness
                    10.0625                         0.9375                         0.5625
                Application              Bluetooth:Brightness          Bluetooth:Application
                     6.3125                        -0.0625                        -0.3125
Brightness:Application Bluetooth:Brightness:Application
                     0.5625                         0.4375
```

ANOVA Table:

```
                              Df Sum Sq Mean Sq F value   Pr(>F)
Bluetooth                      1    7.0     7.0   6.553   0.0172 *
Brightness                     1    2.5     2.5   2.359   0.1376
Application                    1  318.8   318.8 297.117 5.07e-15 ***
Bluetooth:Brightness           1    0.0     0.0   0.029   0.8659
Bluetooth:Application          1    0.8     0.8   0.728   0.4019
Brightness:Application         1    2.5     2.5   2.359   0.1376
Bluetooth:Brightness:Application  1    1.5     1.5   1.427   0.2439
Residuals                     24   25.8     1.1
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

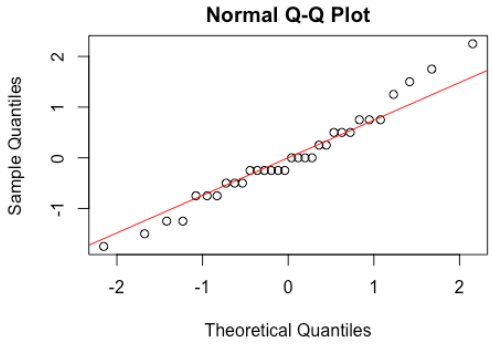
Interpretation:

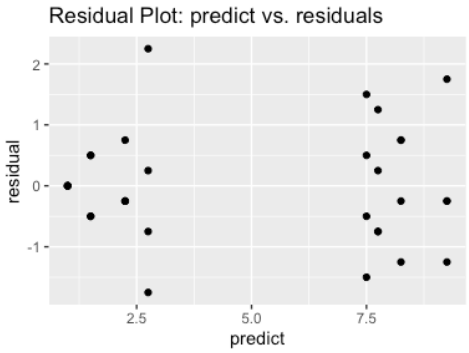
- Bluetooth: Bluetooth has a p-value of 0.0172, which is significant at 0.05 level. It has an estimated effect of 0.9375, so turning Bluetooth ON consumes a little more battery than turning it OFF.

- Application: Application has a p-value of 5.07e-15, which is very significant at 0.05 level. It has a huge estimated effect of 6.3125, so turning Application ON consumes much more battery than turning it OFF.
- Brightness: Brightness has a p-value of 0.1376, which is not significant at 0.05 level.
- Interaction: The second-order interaction effects, as well as the third-order interaction effects, are not significant at 0.05 level.

Overall, turning applications like videos ON and turning Bluetooth ON, consume more battery than OFF, adjusting for brightness.

Model Diagnostis and Follow up





According to the qq-plot, since most points are following the line, we can say that the normality assumption is mostly satisfied. According to the residual plot of predicted values vs residuals, we can say that the residual plot shows a relatively randomly scattered pattern and there are no clear outliers. Thus, we can conclude that the homoskedasticity assumption is mostly satisfied. In conclusion, our diagnostic plots satisfied the goodness-of-fit, and we did not need further refinement for our model.

There are still many things that we could have approved. Instead of using a 2^3 factorial design, we should probably use general factorial design by setting 3 levels of brightness and

applications. We could also do the experiment on different Macbooks to check whether we have the same result on different Macbooks. However, both ways will dramatically increase our workload --- we need to do 18*4=72 trails in total for general factorial design and we need to double or triple the time if we do it on 2 or 3 laptops.

Discussion and Conclusion

According to our ANOVA table, if we set the significant level of 0.05, only Bluetooth and Application have significant main effects. The main effect of brightness and all interaction effects are not significant. This shows that whether turning Blue booth ON or whether opening applications have significant effects on battery consumption. This might give us a hint on how to decrease the speed of battery consumption when we are outside—instead of lowering the brightness, what we should first do is to turn off the Bluetooth and applications with high energy impact (e.g. YouTube, R-studio, any type of gaming).

This result is somewhat surprising. As most people believe, brightness is one of the most influential aspects of battery loss. However, the result shows that the main effect on Brightness is not significant under 0.05 significant level. Nevertheless, we do not reject the hypothesis that Brightness affects battery loss. The number of trials that we can do is very limited, so we might detect a significant effect from brightness if we increase the number of replication (especially when the p-value of Brightness is 0.1376, which is not so far away from 0.05).

In general, we believe that our experiment indicates that we can significantly lower our battery loss by turning off our Bluetooth and closing Apps with high energy impacts, and this will help us to avoid the situation of running out of battery in our college lives.

Appendix

```
library(dplyr)
```

```
##
## Attaching package: 'dplyr'

## The following objects are masked from 'package:stats':
##
##     filter, lag

## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union
```

```
library(readr)
library(ggplot2)
```

Data

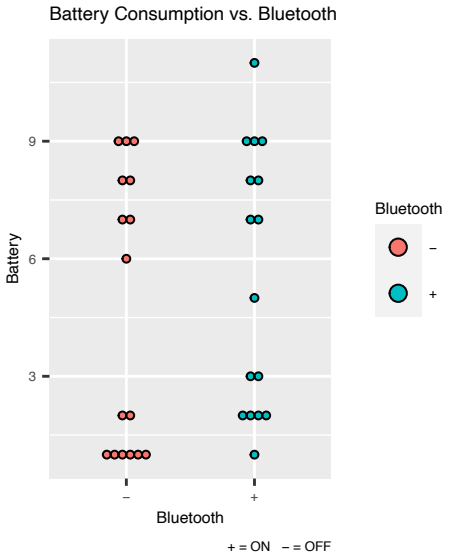
```
data = read_csv("data.csv",show_col_types = FALSE)
print(data,n=nrow(data))
```

```
## # A tibble: 32 x 5
##    Bluetooth Brightness Application Replication Battery
##    <chr>     <chr>      <chr>              <dbl>   <dbl>
##  1 -         -          -                      1       1
##  2 -         +          -                      1       1
##  3 -         -          +                      1       6
##  4 -         +          +                      1       7
##  5 +         -          -                      1       5
##  6 +         +          -                      1       2
##  7 +         -          +                      1       7
##  8 +         +          +                      1       8
##  9 -         -          -                      2       1
## 10 -         +          -                      2       2
## 11 -         -          +                      2       8
## 12 -         +          +                      2       8
## 13 +         -          -                      2       1
## 14 +         +          -                      2       2
## 15 +         -          +                      2       8
## 16 +         +          +                      2       9
## 17 -         -          -                      3       1
```

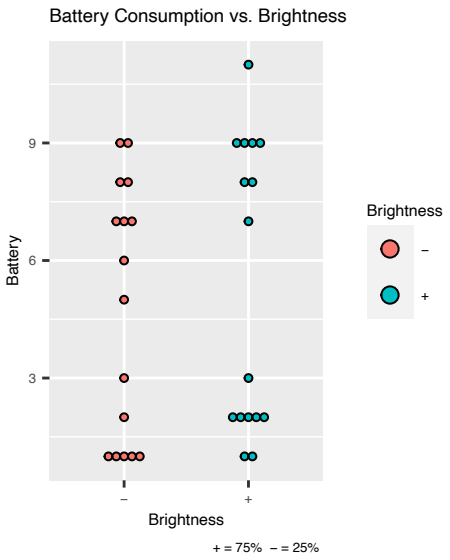
```
## 18 -         +           -                   3       1
## 19 -         -           +                   3       9
## 20 -         +           +                   3       9
## 21 +         -           -                   3       3
## 22 +         +           -                   3       2
## 23 +         -           +                   3       9
## 24 +         +           +                   3      11
## 25 -         -           -                   4       1
## 26 -         +           -                   4       2
## 27 -         -           +                   4       7
## 28 -         +           +                   4       9
## 29 +         -           -                   4       2
## 30 +         +           -                   4       3
## 31 +         -           +                   4       7
## 32 +         +           +                   4       9
```

Data Visualization

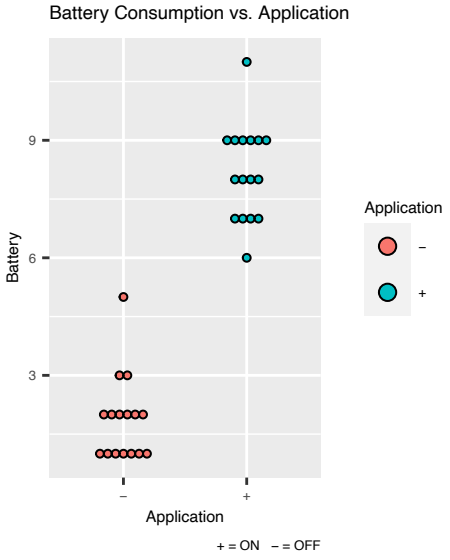
```
ggplot(data, aes(x = Bluetooth, y = Battery,fill=Bluetooth)) +
  geom_dotplot(binaxis='y', stackdir='center',binwidth = 0.2)+
  labs(caption = "+ = ON   - = OFF", title = "Battery Consumption vs. Bluetooth")+
  theme(text = element_text(size = 6))
```




```
ggplot(data, aes(x = Brightness, y = Battery,fill=Brightness)) +
  geom_dotplot(binaxis='y', stackdir='center',binwidth = 0.2)+
  labs(caption = "+ = 75%  - = 25% ", title = "Battery Consumption vs. Brightness")+
  theme(text = element_text(size = 6))
```




```
ggplot(data, aes(x = Application, y = Battery,fill=Application)) +
  geom_dotplot(binaxis='y', stackdir='center',binwidth = 0.2)+
  labs(caption = "+ = ON   - = OFF", title = "Battery Consumption vs. Application")+
  theme(text = element_text(size = 6))
```



Model

```
code = function(x) ifelse(x == '-', -1, 1)
Data = data %>%
  mutate_at(vars(Bluetooth:Application), code)
fit = lm(Battery~Bluetooth*Brightness*Application, Data)
summary(aov(fit))
```

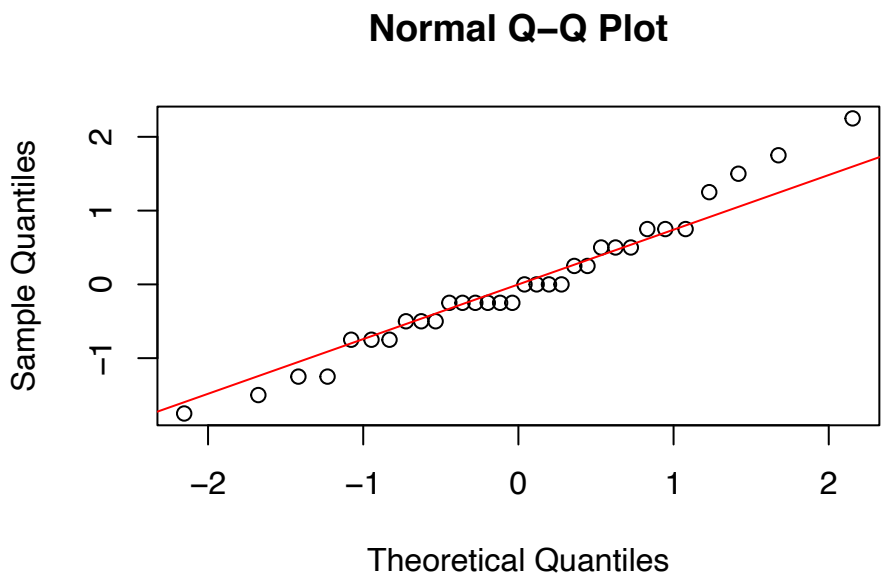
```
##                                  Df Sum Sq Mean Sq F value   Pr(>F)
## Bluetooth                         1    7.0     7.0   6.553   0.0172 *
## Brightness                        1    2.5     2.5   2.359   0.1376
## Application                       1  318.8   318.8 297.117 5.07e-15 ***
## Bluetooth:Brightness              1    0.0     0.0   0.029   0.8659
## Bluetooth:Application             1    0.8     0.8   0.728   0.4019
## Brightness:Application            1    2.5     2.5   2.359   0.1376
## Bluetooth:Brightness:Application  1    1.5     1.5   1.427   0.2439
## Residuals                        24   25.8     1.1
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
2 * coef(fit)
```

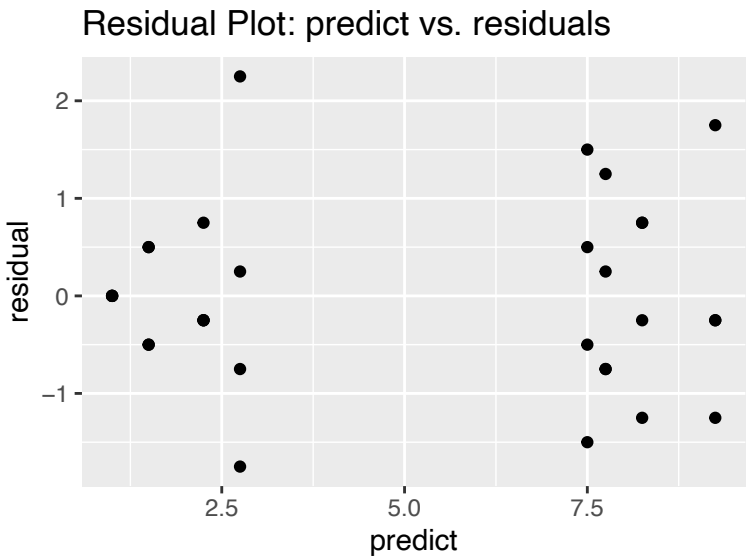
```
##                       (Intercept)                        Bluetooth
##                           10.0625                           0.9375
##                        Brightness                      Application
##                            0.5625                           6.3125
##              Bluetooth:Brightness            Bluetooth:Application
##                           -0.0625                          -0.3125
##           Brightness:Application Bluetooth:Brightness:Application
##                            0.5625                           0.4375
```

Model Diagnostics

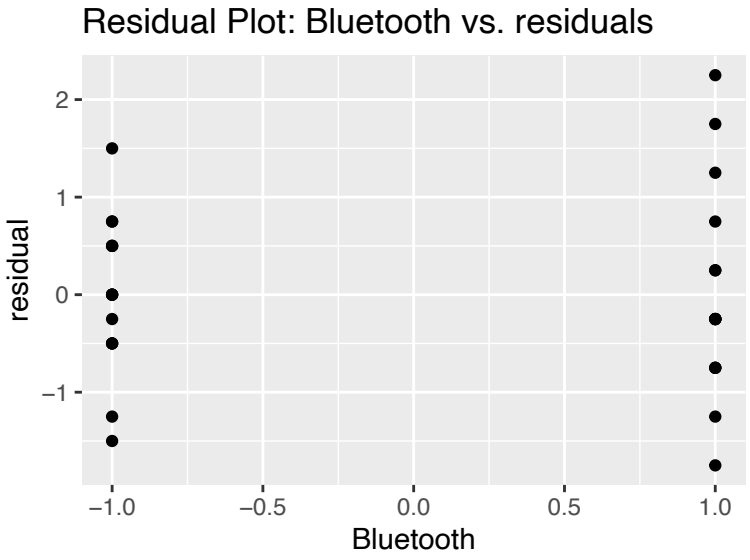
```r
qqnorm(resid(fit))
qqline(resid(fit),col="red")
```



```
Data$residual = resid(fit)
Data$predict = predict(fit)
# predict vs. residuals
ggplot(Data)+
  geom_point(aes(predict,residual))+
  labs(title = "Residual Plot: predict vs. residuals")
```

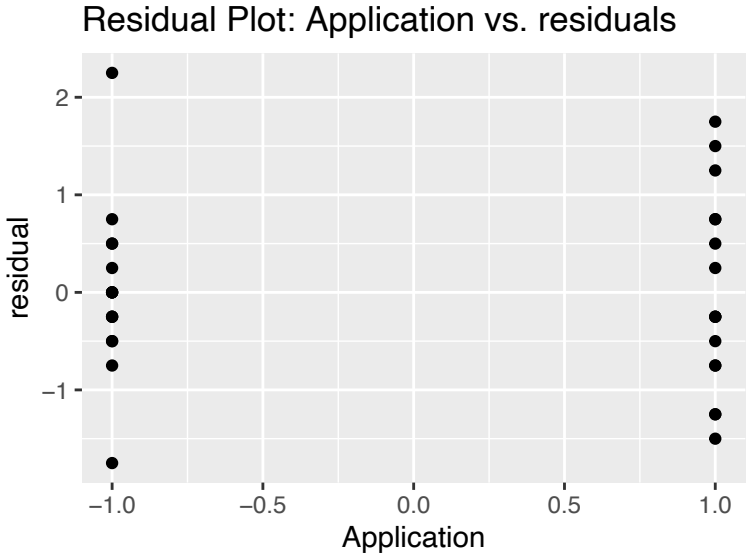



```
# Bluetooth vs. residuals
ggplot(Data)+
  geom_point(aes(Bluetooth,residual))+
  labs(title = "Residual Plot: Bluetooth vs. residuals")
```




```
# Application vs. residuals
ggplot(Data)+
```

```
  geom_point(aes(Application,residual))+
  labs(title = "Residual Plot: Application vs. residuals")
```




```
# Brightness vs. residuals
ggplot(Data)+
  geom_point(aes(Brightness,residual))+
  labs(title = "Residual Plot: Brightness vs. residuals")
```