Statistical Analysis of the Physiological Effect of Lighting Frequency on Humans that Suffer from Optical Photosensitivity

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Preface:

I am not a neurologist or electrical engineer, but that does not mean the following research paper does not have worth. The information in this paper is scientific research done over many years by neurologists, engineers, and through my personal observations. I am a 20-year veteran of Law Enforcement, Fire Service, Emergency Medicine and Military Service, which means my daily function is fueled by nicotine, caffeine, sarcasm and dry dark humor. With that being said, this topic is very personal to me and it needs more public attention. I dedicate this research to my better half, Nicole, who suffers the effects of epilepsy and is very much affected by photosensitivity. Over the last two years, we have seen the effects of light and more specifically the "flicker factor" on her and even one of her sons. I attend church on Sundays and on occasion Nicole has attended with me. For a very long time our Sunday afternoons would be very quiet and awkward. It was not until her son attended with us one Sunday that we really began to understand what was really going on. He began complaining of a migraine headache and being nauseous. He complained of the lights at church causing this issue. The lights he was referring to are blue and violet LED lights that change the intensity with the beat of the music. Nicole and I looked at each other in that moment and realized two things. First, I was not the cause of the awkward Sunday afternoons and second, that she was experiencing the exact same thing but on a more severe scale. Lights were causing the problems and more research needed to be done. Over the next few months, we found LED lighting contributed to most of the physiological issues. Christmas lights became the largest problem simply because Nicole loved going to look at all the lights during the Christmas season. We needed to find a solution

to the lighting problem she was experiencing. In the conclusion, this topic will be discussed further.

Abstract:

The following study was conducted as a statistical analysis of the “flicker factor” from AC power to eight of the most commonly used lighting sources found in homes and commercial buildings and the relationship they have with negative human physiological responses. The study showed there is a statistically significant relationship between the “flicker factor” and most commonly used lighting sources. The study also found that there needs to be additional research on this topic, with a further in-depth study in human testing to establish quantitative data on the ten listed physiological responses. Overall, the study was successful, however it needs additional research.

Introduction:

Can you see the flicker? Most humans are not affected by light flicker. That is, the frequency at which the AC or Alternating Current affects different lighting [8]. According to recent studies, 1 in 4,000 people have photosensitive epilepsy or 1 in 3 epileptics are affected by the flicker factor from lighting [2,6]. To bring this into perspective, in 2018, there was an estimated 327,620,705 people living in the United States and 3,931,448 doctor diagnosed epileptics. This is where the numbers get tricky. According to one source, 1 in 4,000 people have optical photosensitive epilepsy [2], and according to another source, 1 in 3 epileptics are photosensitive epileptics [6]. When calculating these two numbers, the totals are vastly different, 1 in 4,000 = 81,905 and 1 in 3 = 1,310,483 creating a difference of 1,228,578 people. This is a significant difference and for the purpose of this analysis not relevant because the

number of people affected by light flicker is not the focus of this study, only the statistical significance of the lighting spectrum frequency range that humans can be affected by this issue. Light is measured by its frequency and intensity [1]. Visible light is a very small portion of the light spectrum, 400-789THz, respectively [1]. However, to better understand how this affects humans, we need to look at how light is measured. When wavelength and frequency are known, the formula of [speed = (wavelength X frequency)] is used, and we can better understand how different visible colors in the visible light spectrum affect humans. Chart 1 below shows the visible light spectrum in its wavelength and frequency range.

Color	Wavelength in nanometers (nm)	Frequency in terahertz (THz)
Red	~620-750 nm	~400-484 THz
Orange	~590-620 nm	~484-508 THz
Yellow	~570-590 nm	~508-526 THz
Green	~495-570 nm	~526-606 THz
Blue	~450-495 nm	~606-668 THz
Violet	~380-450 nm	~668-789 THz

Chart 1: Chart 1 shows the visible light spectrum in relation to their wavelength and frequency. Wavelength is the measurement of the distance between each crest and the Frequency is the measurement of how fast these waves are traveling [1].

As shown in Chart 1, as the wavelength slows down the frequency speeds up. This is an important measurement because the frequency can also be described as intensity. In other words, in the blue and violet range the intensity of the frequency is at its highest, therefore it is my hypothesis that lighting in the blue and violet range combined with the flicker factor will

cause more issues for people affected by photosensitivity. Except in this study, I will only be able to test the "flicker factor" if the frequency falls into the human affected range by lighting source. **H:** The lighting sources fall into the affected human frequency range and can cause any of the ten (10) listed symptoms.

Data

The flicker factor, as mentioned above, is commonly found in Alternating Currents (AC). AC power is the power that comes from a power plant and runs through the power lines overhead or underground. The flicker is caused by the current running in waves. The frequency that runs through power lines is normally around 50 or 60 Hz [4]. Understanding how individual lights are affected by this frequency is how we figure out what lights affect humans that suffer from optical photosensitivity. To do this, I have taken the most commonly used household and commercial lights and compiled a dataset that shows the "flicker frequency" of each. In that same dataset, I compiled a list of known physiological effects that humans who suffer from optical photosensitivity experience when subjected to these frequencies and gave them values of yes (2), no (1), and possible (3) on Chart 2 listed below. Eye strain, eye pain, blurred vision, headache, migraine, nauseousness, malaise, numbness or tingling in extremities, simple partial seizure, tonic-clonic seizure are the ten (in order of severity) variables used in this analysis.

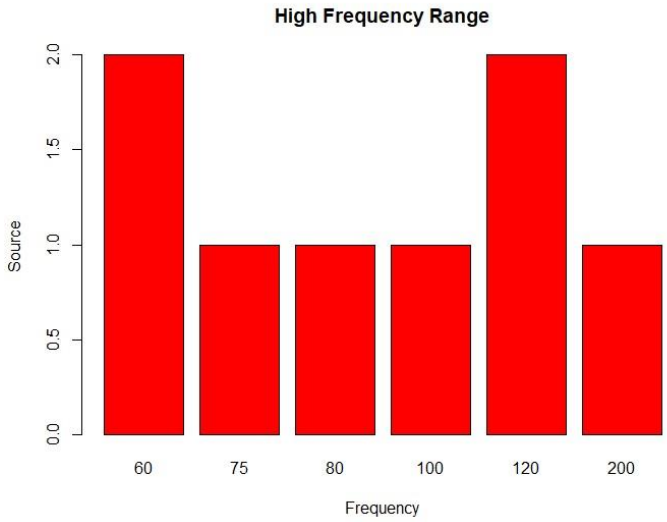
Light Source	Low Frequency Range (Hz)	High Frequency Range (Hz)	Eye Strain	Eye pain	Blurred Vision	Headache	Migraine	nauseousness	malaise	numbness in extremities	Simple partial seizure	Tonic-clonis seizure
Cathode Ray Tube	50	100	2	2	2	2	2	3	3	3	1	1
Computer Monitor	42.5	75	2	2	2	2	2	3	3	3	3	3
Functioning Fluorescent	100	120	2	2	2	2	3	3	3	1	1	2
Incandescent	100	120	2	2		3	3		3	3	1	1
Light-emitting diode (LED)	50	200	2	2	2	2	2	2	2	2	2	2
Malfunctioning Fluorescent	50	80	2	2	2	2	2	2	2	2	2	2
Television	50	60	2	2	2	2	3	3	3	3	3	3
Xenon gas discharge photo-stimulator	3	60	2	2	2	2	2	2	2	2	2	2
1=no, 2=yes, 3=possible												

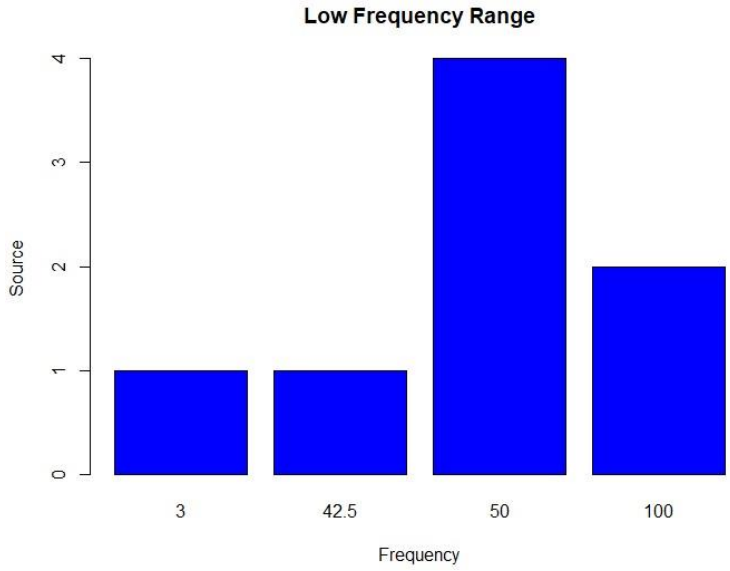
Chart 2: Chart 2 shows the Lighting sources, frequency range, and physiological effects that humans experience [2,5].

To better understand the data that is shown in Chart 2, it is important to understand at what frequency the human body responds negatively to light and at what frequency the human body has no response, or rather is unable to perceive the frequency. Humans perceive frequencies at levels below ~165 Hz and epileptics are at much higher risk of seizures at frequencies between ~3 - ~60 Hz respectively [6]. Looking at Chart 2, it is easily deciphered that the majority of the common lights used in homes and commercial properties fall within that range. However, not everyone suffers negatively from the frequency "flicker factor." On the following pages are statistical calculations showing the probability that, if exposed to the "flicker factor", what lights have the greater possibility of a negative response.

It should be noted that there are certain tests that were run for this study, do not apply because the data type and the testing method do not work. They are included in this study to meet the criteria for this assignment. Those tests are noted.

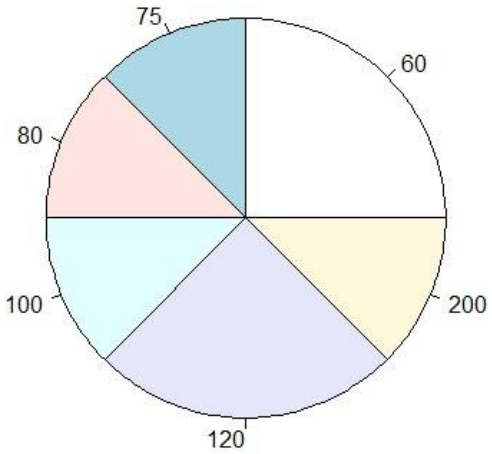
Results and Analysis



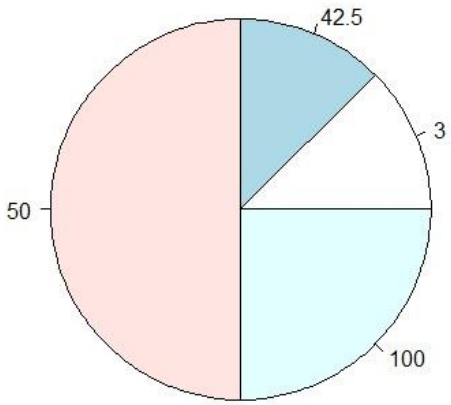


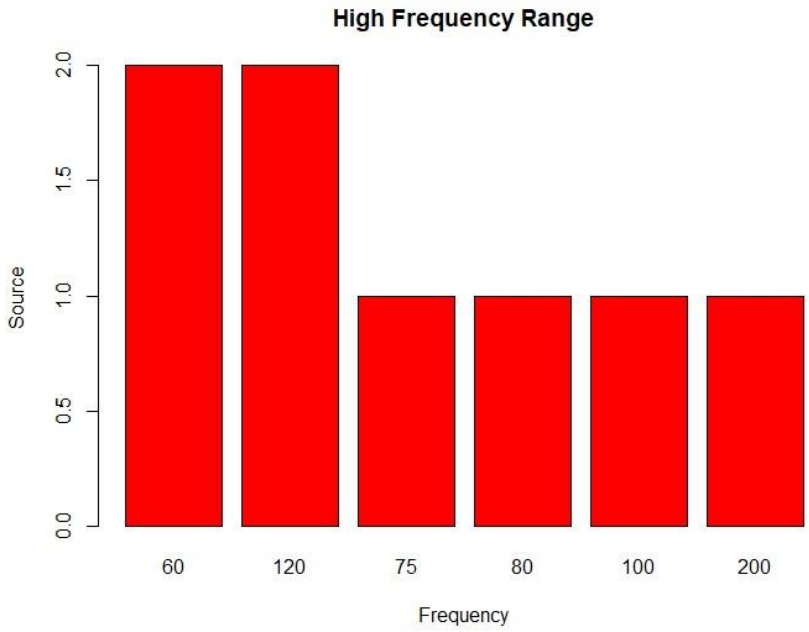
The two boxplots above show the frequency distribution between high and low frequency. The high frequency boxplot shows a fairly uniform distribution, and the low frequency boxplot shows a normal distribution with a left tail. The two pie charts below show the same distributions in a different visual image.

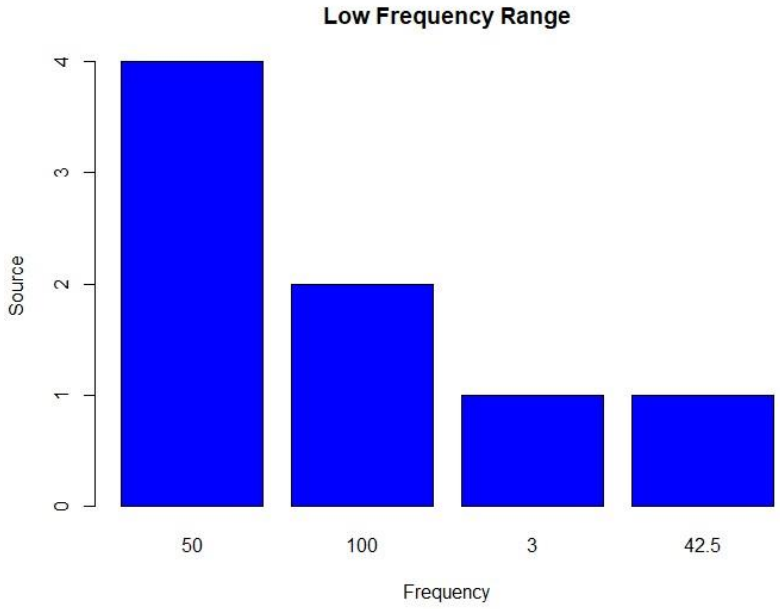
High Frequency Range



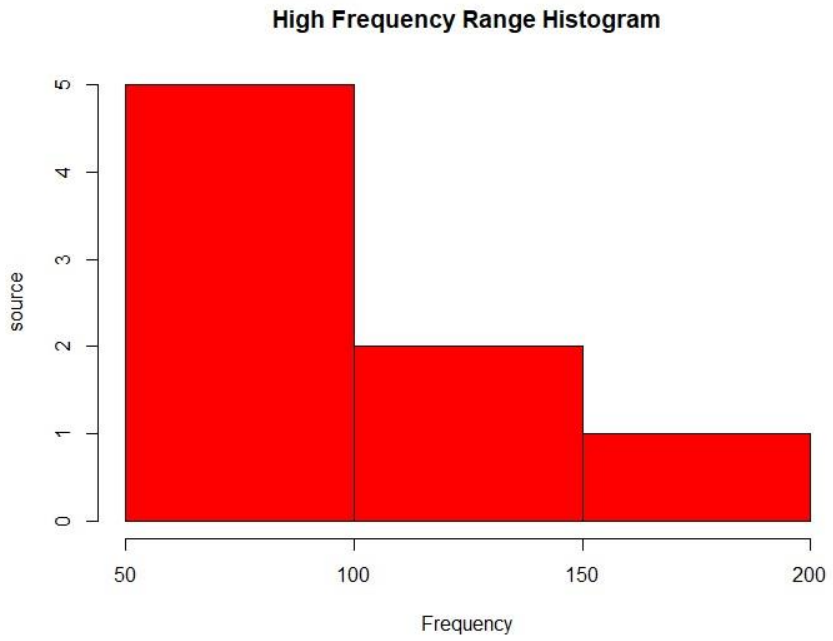
Low Frequency Range

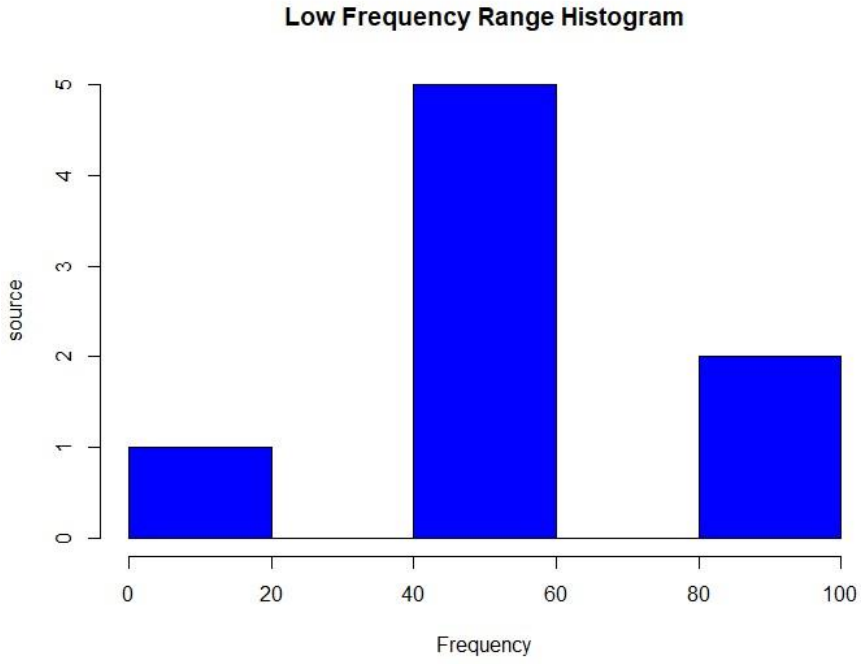




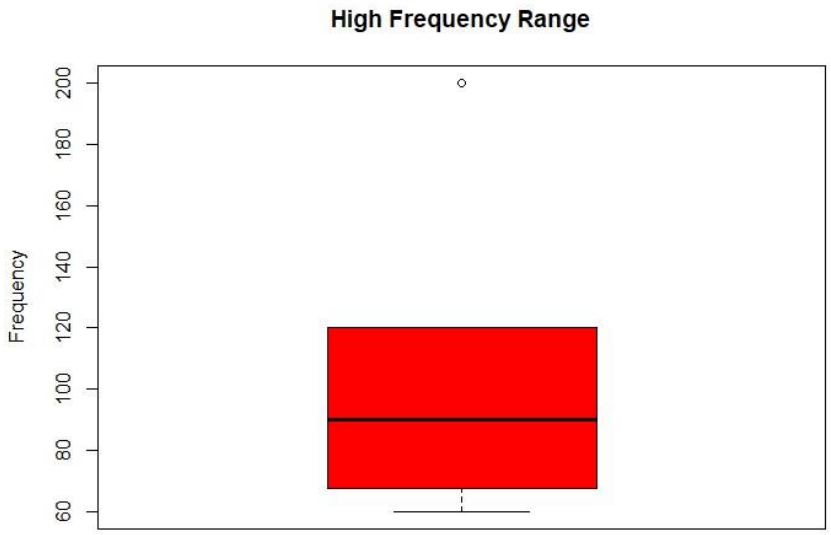


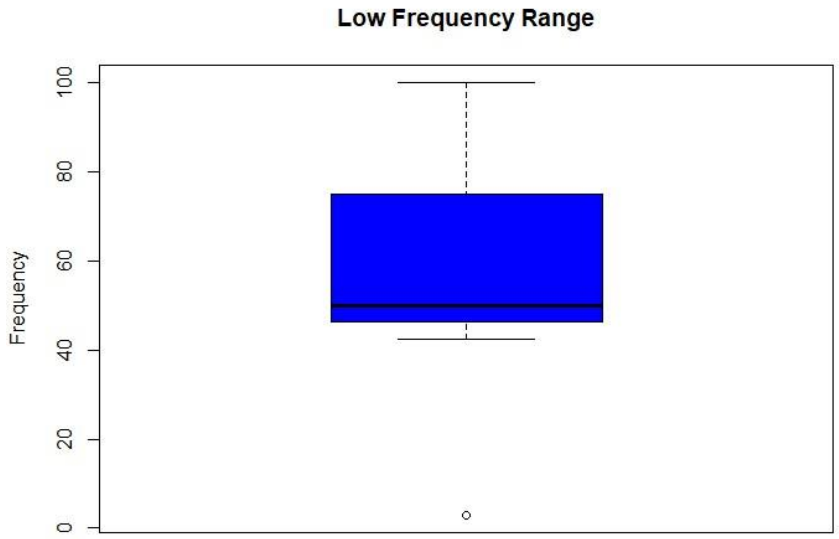
As we can already start to see in the plots above the 50 -120 Hz frequency is showing much more prevalence. This is the frequency that is critical in negative human effects.





Again, in the histograms above, the 40 – 60 Hz and 50 – 100 Hz is the most prevalent.





In the boxplots above, the 50 – 60 Hz and 60 – 120 Hz range has the most occurrences with the mean values between 50 – 90 Hz, respectively.

High Frequency Summary

```
 Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
60.00   71.25   90.00  101.88  120.00  200.00
IQR = 120-71.25
```

Low Frequency Summary

```
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
   3.00   48.12   50.00   55.69   62.50  100.00
> IQR = 62.5-48.12
```

High Frequency Descriptive Statistics

```
     median         mean      SE.mean CI.mean.0.95          var      std.dev     coef.var
 90.0000000  101.8750000   16.3646369   38.6962172 2142.4107143   46.2861828    0.4543429
```

Low Frequency Descriptive Statistics

```
    median         mean      SE.mean CI.mean.0.95          var      std.dev     coef.var
50.0000000   55.6875000   11.1855046   26.4495155 1000.9241071   31.6373846    0.5681236
```

High Frequency Skewedness

```
   vars n   mean    sd median trimmed   mad min max range skew kurtosis    se
X1    1 8 101.88 46.29     90  101.88 44.48  60 200   140 0.98    -0.28 16.36
```

Low Frequency Skewedness

```
   vars n  mean    sd median trimmed  mad min max range skew kurtosis    se
X1    1 8 55.69 31.64     50   55.69 5.56   3 100    97  0.1    -1.07 11.19
```

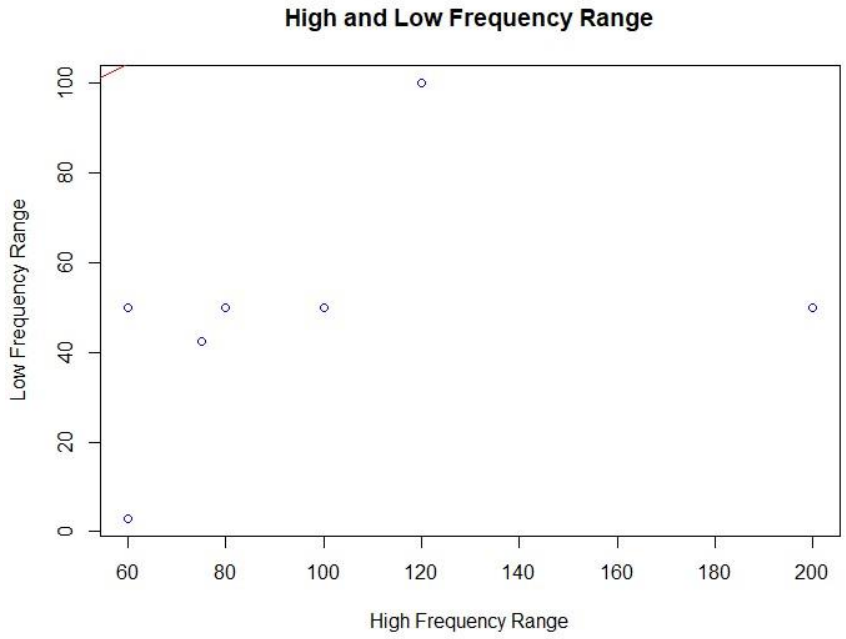
High Frequency Z - Score

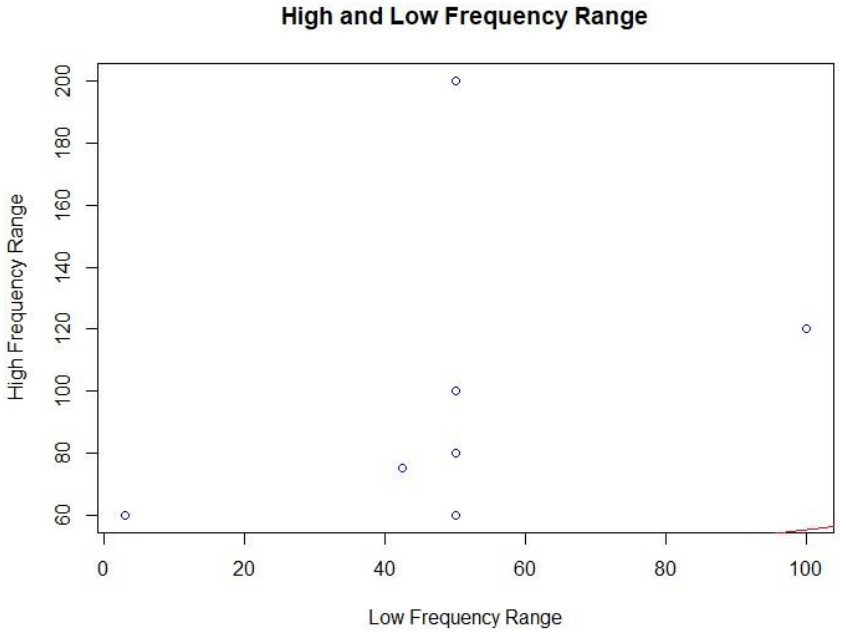
```
            [,1]
[1,] -0.04050885
[2,] -0.58062684
[3,]  0.39158554
[4,]  0.39158554
[5,]  2.11996311
[6,] -0.47260324
[7,] -0.90469763
[8,] -0.90469763
attr(,"scaled:center")
[1] 101.875
attr(,"scaled:scale")
[1] 46.28618
```

Low Frequency Z – Score

```
            [,1]
[1,] -0.1797715
[2,] -0.4168328
[3,]  1.4006373
[4,]  1.4006373
[5,] -0.1797715
[6,] -0.1797715
[7,] -0.1797715
[8,] -1.6653557
attr(,"scaled:center")
[1] 55.6875
attr(,"scaled:scale")
[1] 31.63738
```

Linear Regression Plotting





The linear regression models were shown with the x:y values reversed intentionally. The trend line in the first test was located in the bottom right corner and it was thought the test was incorrect. However, when run the opposite, the trend line moved to the top left corner. Linear regression may not be the best test for this information.

Correlation Matrix

```
        Pearson's product-moment correlation

data:  Lighting_file$Low_Frequency_Range and Lighting_file$High_Frequency_Range
t = 1.0327, df = 6, p-value = 0.3416
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 -0.4353757  0.8582162
sample estimates:
      cor
0.3884827
```

The correlation matrix above clearly shows that we accept the Null Hypothesis The frequency ranges are not random. When analyzing Pearson's, the P – value is the critical number. The P – Value, or Probability value, is the percent probability that the all the numbers tested fall with in the confidence interval (CI).

Linear Regression Modeling

```
$sigma
       1        2        3        4        5        6        7        8
34.40428 34.36502 28.70596 28.70596 18.02140 34.49360 34.38064 27.09136

$wt.res
         1          2          3          4          5          6          7          8
 -5.1896228  -6.0512607  39.4996874  39.4996874 -31.7430715   0.1210669   5.4317566 -41.5682434
```

	dfb.1_	dfb.H_F_	dffit	cov.r	cook.d	hat	inf
1	-0.02628	0.002640	-0.06102	1.629	2.22e-03	0.125	
2	-0.07246	0.046737	-0.08862	1.716	4.68e-03	0.173	
3	0.00335	0.238727	0.61822	0.810	1.59e-01	0.147	
4	0.00335	0.238727	0.61822	0.810	1.59e-01	0.147	
5	4.53004	-6.058271	-6.62181	0.461	7.18e+00	0.767	*
6	0.00126	-0.000744	0.00165	1.708	1.63e-06	0.157	
7	0.09441	-0.071264	0.10251	1.875	6.26e-03	0.242	
8	-0.91687	0.692107	-0.99554	0.723	3.67e-01	0.242	

```
> |
```

Hypothesis Testing

High Frequency Range

```
        One Sample t-test

data:  Lighting_file$High_Frequency_Range
t = 1.9478, df = 7, p-value = 0.9538
alternative hypothesis: true mean is less than 70
95 percent confidence interval:
     -Inf 132.8791
sample estimates:
mean of x
  101.875
```

Low Frequency Range

```
        One Sample t-test

data:  Lighting_file$Low_Frequency_Range
t = -1.2796, df = 7, p-value = 0.1207
alternative hypothesis: true mean is less than 70
95 percent confidence interval:
     -Inf 76.87932
sample estimates:
mean of x
  55.6875
```

In the T Tests above the P – values are above the 0.05 range and we accept the Null Hypothesis.

The values are not random.

Eye Strain to Headache Chi Square

```
        Chi-squared test for given probabilities

data:  ltab
X-squared = 4.5, df = 1, p-value = 0.03389
```

In the Chi Square test above, the P value is below the 0.05 range and we must reject the Null

Hypothesis. There is no relationship and the variables are dependent

Nauseousness to Blurred Vision Chi Square

```
        Chi-squared test for given probabilities

data:  ltab5
X-squared = 0.5, df = 1, p-value = 0.4795
```

In the Chi Square test above, we fail to reject the Null Hypothesis because the P value is above 0.05. The variables are independent and there is no relationship.

Nauseousness to Malaise Chi Square

```
        Pearson's Chi-squared test with Yates' continuity correction

data:  ltab6
X-squared = 4.3022, df = 1, p-value = 0.03806
```

In the Chi Square test above, we reject the Null Hypothesis because the P value is below 0.05. The variables are dependent and there is a relationship.

Numbness in Extremities to Blurred Vison Chi Square

```
        Chi-squared test for given probabilities

data:  ltab4
X-squared = 1.75, df = 2, p-value = 0.4169
```

In the Chi Square test above, we fail to reject the Null Hypothesis because the P value is above the 0.05. The variables are independent and there is no relationship.

Numbness in Extremities to Simple Partial Seizures Chi Square

```
        Pearson's Chi-squared test

data:  ltab2
X-squared = 9.3333, df = 4, p-value = 0.05329
```

In the Chi Square test above, we fail to reject the Null Hypothesis because the P value is above 0.05. The variables are independent and there is no relationship.

Numbness in Extremities to Tonic-Clonic Seizures Chi Square

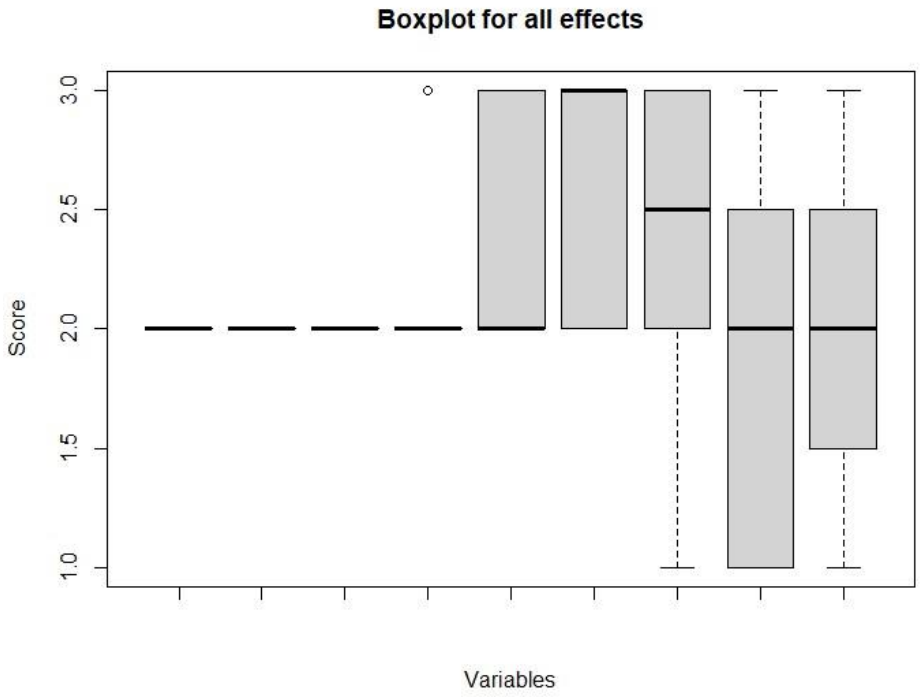
```
        Pearson's Chi-squared test

data:  ltab3
X-squared = 8, df = 4, p-value = 0.09158
```

In the Chi Square test above, we accept the Null Hypothesis because the P value is above 0.05.

The variables are independent and there is no relationship.

ANOVA Testing



```
Terms:
                Numbness_in_Extremities    Residuals
Sum of Squares             1.590445e-31 1.221462e-30
Deg. of Freedom                       1            6

Residual standard error: 4.511951e-16
Estimated effects may be unbalanced
```

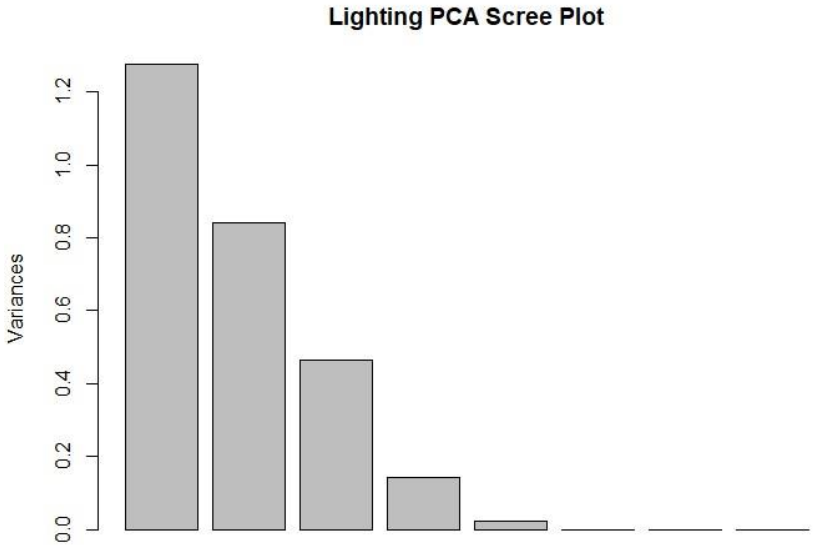
```
                         Df    Sum Sq   Mean Sq F value Pr(>F)
Numbness_in_Extremities   1 1.590e-31 1.590e-31   0.781  0.411
Residuals                 6 1.222e-30 2.036e-31
```

The ANOVA testing is null and void because the data set being used for this analysis uses only two quantitative variables. However, this test was performed to show the explanation. Had this test been a valid test on quantitative data then we would fail to reject the Null Hypothesis because the F value is above 0.05.

Multiple Regression Modeling

In the Multiple Regression results above, the F value is above the required 0.05 and therefore, we again fail to reject the Null Hypothesis and reject the Alternative Hypothesis.

Principal Components Analysis

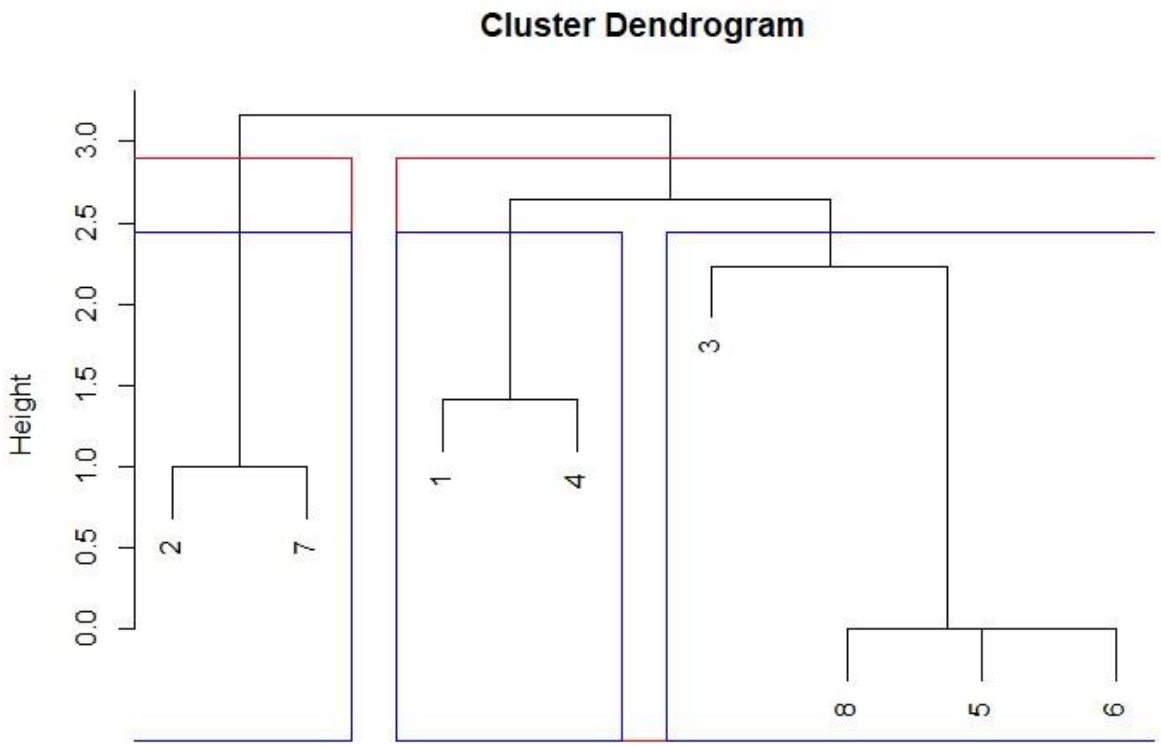


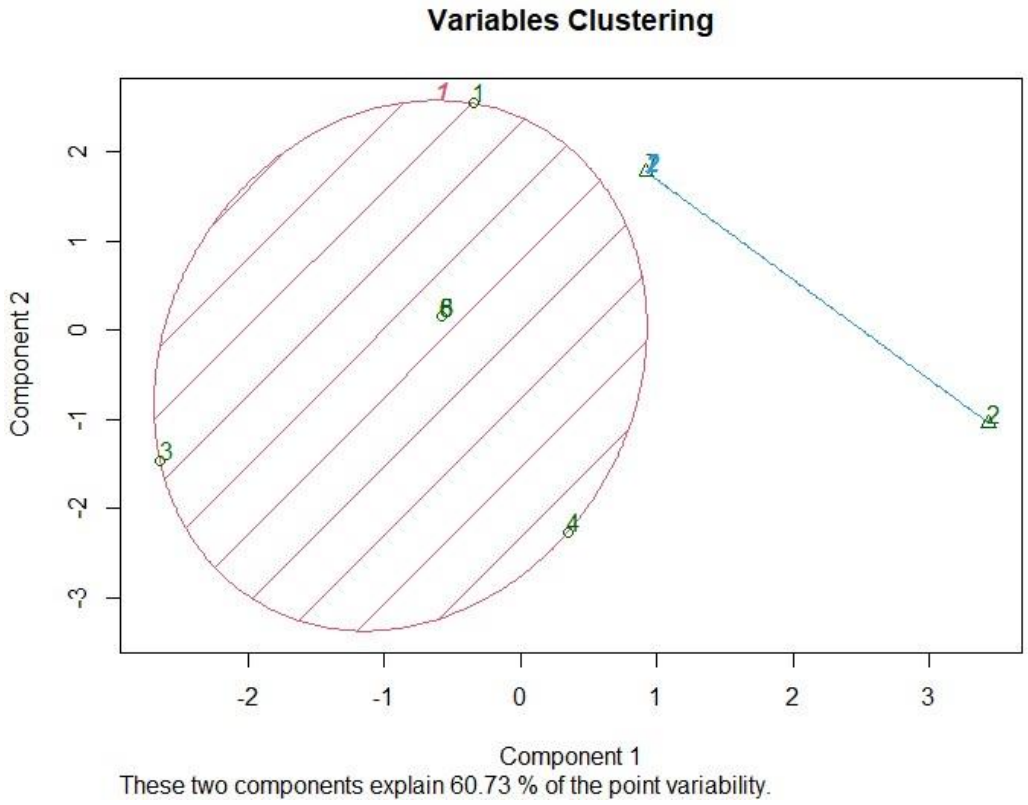

```
K-means clustering with 2 clusters of sizes 6, 2

Cluster means:
        PC1        PC2         PC3         PC4          PC5           PC6           PC7           PC8
1 -0.507958 -0.2625113  0.05212867 -0.01434206 -0.002134028 -1.272131e-17 -6.938894e-17  4.972874e-17
2  1.523874  0.7875339 -0.15638600  0.04302619  0.006402085  2.775558e-17  1.665335e-16 -1.526557e-16

Clustering vector:
[1] 1 2 1 1 1 1 2 1

within cluster sum of squares by cluster:
[1] 10.83333  0.50000
 (between_SS / total_SS =  41.1 %)
```


Cluster Dendrogram
Height
0.0
0.5
1.0
1.5
2.0
2.5
3.0
2
7
1
4
3
8
5
6


Variables Clustering
Component 2
-3
-2
-1
0
1
2
-2
-1
0
1
2
3
Component 1
These two components explain 60.73 % of the point variability.

Conclusion and Summary

According to the Hypothesis testing for the High Frequency Range and Low Frequency Range we fail to reject our original hypothesis stating there is a correlation between the lighting sources that range from ~3 - ~60 Hz with a mean value of 55. 6875 and 101.6875 and a CI of 95%. This information alone does not tell the entire story. This study needs to be expanded further to include human testing of optical photosensitivity as it is directly impacted by different lighting sources at different Hz ranges. This information would be quantitative in nature and would give a much better picture to the actual Hz value given each lighting source having the greatest probability of causing a negative response. There is a statistically significant relationship between some of the variables used in this study, however, a more in-depth study needs to be completed to quantify the variable data. Using the ranking system used in this study did not work as well as I had expected and needs to be developed further for a better understanding of the relationship of all the variables. We learned that the “flicker factor” Hz ranges are statistically significant and they fit into the response ranges for negative human response. We know the intensity of the blue and violet range on the visible spectrum is significantly higher and given that intensity, the Hz ranges tested in this study combined, optical photosensitivity would have a more likely negative response. Given this information, it would be more beneficial for homes and commercial properties to choose a different color on the visible light spectrum.

References

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