ST 518 Project

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Contents

Executive Summary

A one or two paragraph summary that includes a description of the experiment, significant results (including any interesting numerical results), and any conclusions you draw. The reader should be able to glean all the important aspects of your work from the executive summary. Effectively and succinctly convey objectives, summary of experimental design, and results and conclusions drawn from experiment.

Introduction

Explain what you are trying to learn from the experiment – you may borrow heavily from my description. Effectively describe the purpose of the experiment.

The purpose of this experiment is to investigate specific factors and their effect on the amount of time it takes to dissolve a cold medicine tablet in water. The data is from an "Effervescent Experiment" designed to compare dissolving times of two different brands of tablets (name brand and store brand) at three different equally spaced water temperatures (6°C, 23°C, and 40°C). The run order number, as well as whether or not the sample was stirred, were also recorded and are investigated in the analysis portions of this report.

Below, we have a brief look at the first 10 of 48 rows of data in order to begin to gain an understanding of the data set we are working with.

Table 1: First 10 Rows of Effervescence Data

Brand	Temp	Stirred	Order	Time
name	6	yes	8	77.21547
name	23	yes	3	75.37855
name	40	yes	7	68.08492
store	6	yes	1	77.87371
store	23	yes	2	66.38436

Brand	Temp	Stirred	Order	Time
store	40	yes	18	59.82388
name	6	yes	9	75.94293
name	23	yes	4	69.08937
name	40	yes	10	64.45156
store	6	yes	12	77.33947

Experimental Design

Include a description of the experiment and the data that was collected – you may borrow heavily from my description. Effectively describe the experimental design and factors.

The experiment carried out was a complete block design where $b = 2$ blocks (by stirred status) were selected with $n = 4$ observations on each of the treatment combinations in each block. In Block I, the water was stirred using a magnetic stirring plate at 350 revolutions per minute, whereas in Block II, the water was not stirred. The time for the tablet to dissolve was measured from the moment the tablet was dropped into the water to the time the tablet was completely dissolved. Each tablet was dropped from a fixed height into 60mL of water. The observation was taken as an average of the times as measured by four experimenters and was recorded, along with the run order for each observation.

Exploratory Analysis

Summary statistics for each variable can be seen below. For the `Brand`, `Temp`, `Stirred`, and `Order` variables, we can see counts for each level. For the `Time` variable, we can see a five-number summary for the variable.

Table 2: Summary Stats for Variables

Brand	Temp	Stirred	Order	Time
name :24	6 :16	no :24	1 : 1	Min. :58.24
store:24	23:16	yes:24	2 : 1	1st Qu.:66.09
NA	40:16	NA	3 : 1	Median :70.92
NA	NA	NA	4 : 1	Mean :70.77
NA	NA	NA	5 : 1	3rd Qu.:76.93
NA	NA	NA	6 : 1	Max. :80.92
NA	NA	NA	(Other):42	NA

The Summary Stats for Time by Group Table shows a decrease in dissolving time as Temp increases regardless of Brand or Stirred status. There doesn't appear to be a trend between Name and Store Brand. For example, when the water was stirred for the Name Brand at Temp 6, 20 and 40, the mean was 76.2, 72.69, and 65.85, respectively. When the water was stirred for the Store Brand at Temp 6, 20 and 40, the mean was 77.34, 66.12, and 59.13, respectively. Name Brand generally had a higher dissolving time, but occasionally, Store Brand would have a higher dissolve time than Name Brand. The same was for when the water was not Stirred, both instances at the 6 degree Temp. There was also some unusally high standard deviations for Name Brand at the 23 and 40 degree Temps with their standard deviations at 2.64 and 1.6, respectively. Both instances where the water was Stirred. Store Brand at 6 degree Temp, not Stirred had a standard deviation of 1.3. The standard deviations tended to range between 0.2 and 0.77.

Table 3: Summary Stats for Time by Group

| Brand	Stirred	Temp	Mean	SD	Min	Q1	Median	Q3	Max
name	no	6	78.99	0.64	78.15	78.80	79.04	79.24	79.72
name	no	23	76.36	0.33	76.07	76.20	76.28	76.43	76.83
name	no	40	70.56	0.50	70.00	70.29	70.51	70.78	71.20
name	yes	6	76.20	0.68	75.81	75.83	75.89	76.26	77.22
name	yes	23	72.69	2.64	69.09	71.82	73.15	74.02	75.38
name	yes	40	65.85	1.60	64.45	64.87	65.44	66.42	68.08
store	no	6	79.49	1.30	77.78	79.02	79.63	80.10	80.92
store	no	23	67.52	0.45	67.08	67.14	67.52	67.90	67.93
store	no	40	58.96	0.35	58.54	58.77	58.99	59.19	59.33
store	yes	6	77.34	0.77	76.24	77.07	77.61	77.88	77.89
store	yes	23	66.19	0.20	65.93	66.09	66.23	66.33	66.38
store	yes	40	59.13	0.66	58.24	58.91	59.22	59.43	59.82

The box plot below displays a five-number summary of dissolving time for each brand of tablet. The plot displays Time as a function of Brand and indicates that there is an effect of the brand on time.

Tablet Dissolve Time for Brand
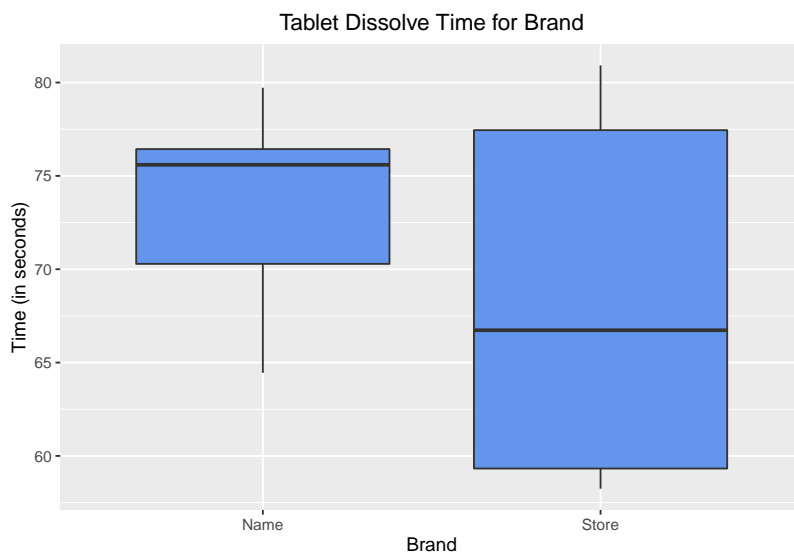
The box plot below displays a five-number summary of dissolving time for each stirred status. The box plot displays Time as a function of Stirred and indicates that there is an effect of the stirred status on time.

Tablet Dissolve Time for Stirred Status

The box plot below displays the dissolving time for different water temperatures. `Time` is displayed as a function of `Temperature`, however, we can also see how the `Brand` and `Stirred` variables affect the dissolving time by observing the color and shape of the points. It is clear that a warmer temperature reduces the dissolving time. It also appears that, as mentioned above, stirring the water reduces the dissolving time and that at the higher temperatures, the store brand dissolves more quickly than the name brand tablets.

Tablet Dissolve Time for Water Temperature
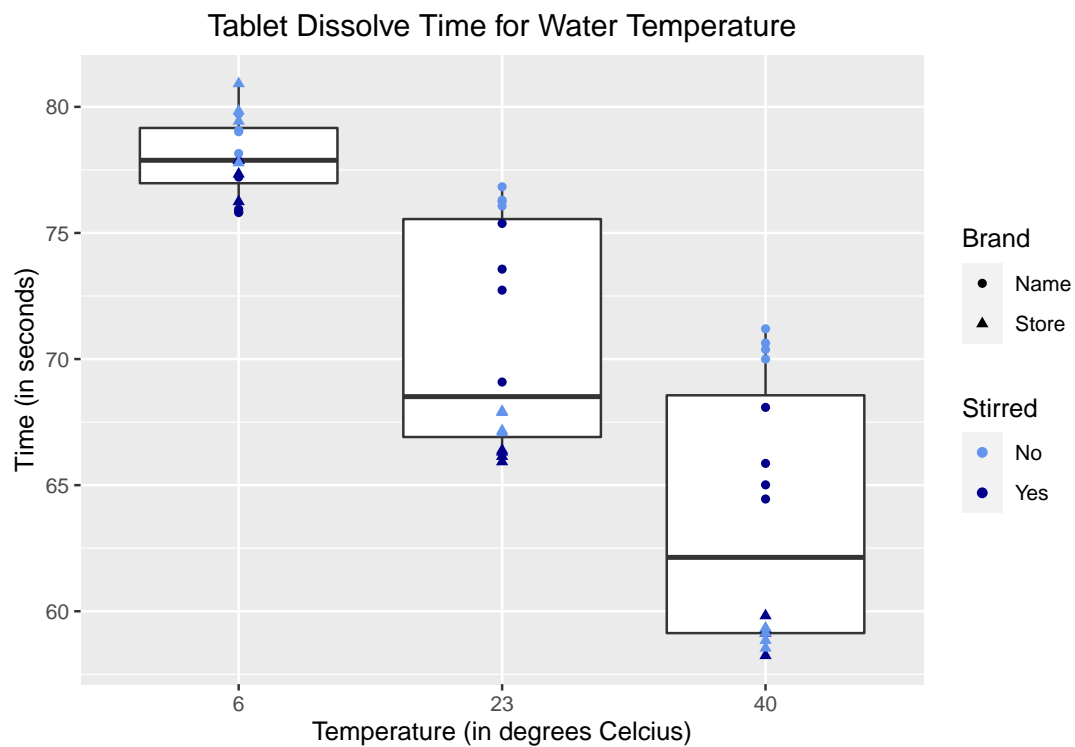
Analysis and Results

Fit appropriate models and follow good statistical analysis process to determine the best model to use. Make use of proper diagnostics. Choose the appropriate effects to compare, correctly estimate and test significance of the effects and trends.

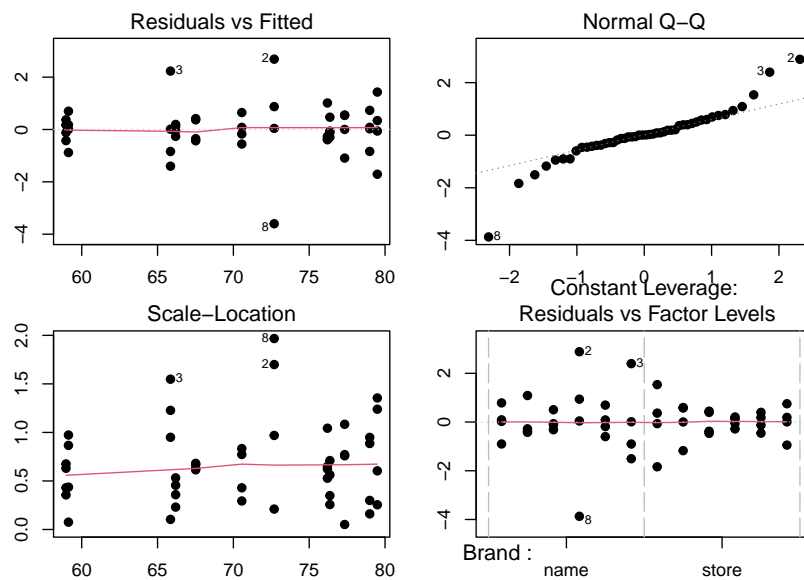**Model 1**
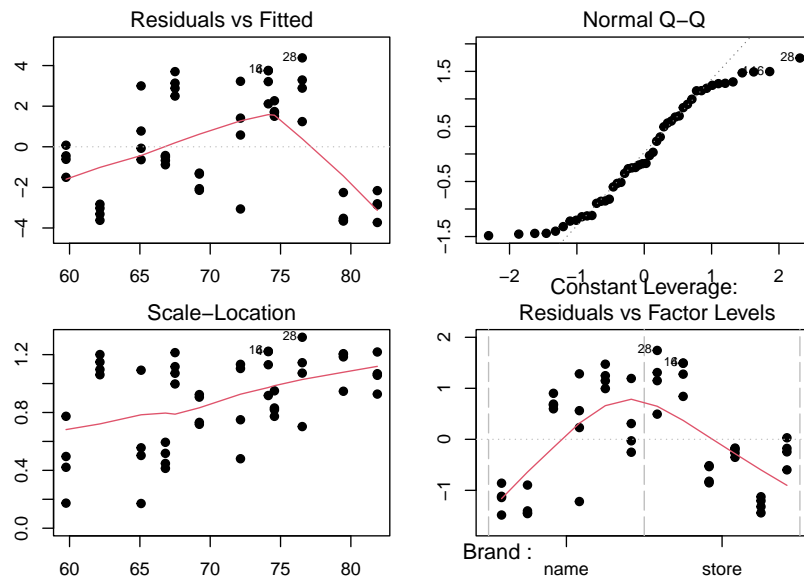

```
##            Df Sum Sq Mean Sq F value   Pr(>F)
## Brand       1  342.0   342.0  48.514 1.44e-08 ***
## Temp        2 1654.7   827.4 117.364 < 2e-16  ***
## Stirred     1   69.9    69.9   9.914  0.00298 **
## Residuals  43  303.1     7.0
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Coefficients of Model 1

```
## (Intercept)  Brandstore       Temp23       Temp40   Stirredyes
##   81.881558   -5.338595    -7.315177   -14.381286    -2.413294
```

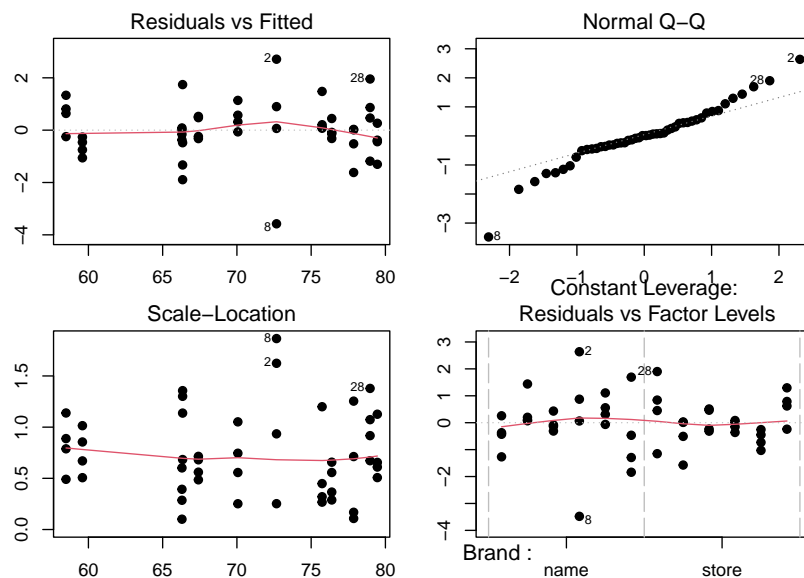**Model 2**


```
##            Df Sum Sq Mean Sq F value  Pr(>F)
## Brand       1  342.0   342.0 296.041 < 2e-16 ***
## Temp        2 1654.7   827.4 716.169 < 2e-16 ***
```

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```
## Stirred               1    69.9    69.9  60.495 3.22e-09 ***
## Brand:Temp            2   231.9   115.9 100.345 1.90e-15 ***
## Brand:Stirred         1    20.5    20.5  17.753 0.000161 ***
## Temp:Stirred          2     0.1     0.1   0.054 0.947535
## Brand:Temp:Stirred    2     9.1     4.5   3.919 0.028838 *
## Residuals            36    41.6     1.2
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Coefficients of Model 2

```
##                 (Intercept)                     Brandstore
##                  78.9906136                      0.5017854
##                      Temp23                         Temp40
##                  -2.6271025                     -8.4355000
##                   Stirredyes                Brandstore:Temp23
##                  -2.7882004                     -9.3497720
##           Brandstore:Temp40             Brandstore:Stirredyes
##                 -12.0934259                      0.6328276
##           Temp23:Stirredyes              Temp40:Stirredyes
##                  -0.8838592                     -1.9134790
## Brandstore:Temp23:Stirredyes Brandstore:Temp40:Stirredyes
##                   1.7149658                      4.2306652
```

Model 3


```
##               Df  Sum Sq Mean Sq F value   Pr(>F)
## Brand          1   342.0   342.0  269.45  < 2e-16 ***
## Temp           2  1654.7   827.4  651.85  < 2e-16 ***
## Stirred        1    69.9    69.9   55.06 4.90e-09 ***
## Brand:Temp     2   231.9   115.9   91.33 1.22e-15 ***
## Brand:Stirred  1    20.5    20.5   16.16  0.00025 ***
## Residuals     40    50.8     1.3
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Coefficients of Model 3

```
##          (Intercept)             Brandstore                  Temp23
```

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```
##          79.4568366          -0.4891531                -3.0690321
##              Temp40           Stirredyes       Brandstore:Temp23
##          -9.3922395          -3.7206465                -8.4922892
##   Brandstore:Temp40 Brandstore:Stirredyes
##          -9.9780933           2.6147046
```

**Model selection by AIC criterion**

```
##
## Model selection based on AICc:
##
##          K   AICc Delta_AICc AICcWt Cum.Wt      LL
## Model 3  9 161.65       0.00    0.9    0.9  -69.46
## Model 2 13 166.04       4.39    0.1    1.0  -64.67
## Model 1  6 238.73      77.08    0.0    1.0 -112.34
```

Tukey's

```
##   Tukey multiple comparisons of means
##     95% family-wise confidence level
##
## Fit: aov(formula = Time ~ Brand + Temp, data = data)
##
## $Brand
##                 diff       lwr       upr p adj
## store-name -5.338595 -7.032557 -3.644633 1e-07
##
## $Temp
##              diff        lwr        upr p adj
## 23-6    -7.315177  -9.812030  -4.818324 0e+00
## 40-6   -14.381286 -16.878139 -11.884433 0e+00
## 40-23   -7.066109  -9.562963  -4.569256 1e-07
```

Using Order as a covariate with Time

When we graph the Order variable with respect to Time and group it by Stirred, there appears to be a linear association between the two blocks, albeit weak, but when we look at the two blocks separately, we can see the potential of using Order as a covariate to assist us in determining if there is a difference in dissolving times between the two blocks.
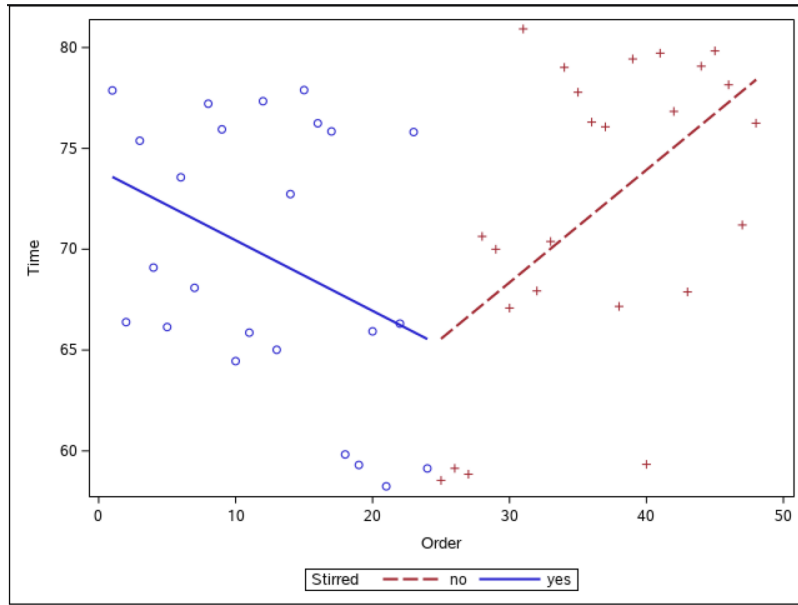
For Block 1, where the liquid was stirred, there appears to be a downward linear trend in the dissolving time of the cold medicine tablets. For Block 2, where the liquid was not stirred, there appears to be an upward linear trend in the dissolving time of the cold medicine tablets. Since the Order variable directly matches the Stirred variable, meaning the first 24 values of Order coincide with Block 1 and the second 24 values of Order coincide with Block 2 and the slopes for the two Blocks are not moving in the same direction as we can observe looking at our initial graph, we can write our model as follows:

Time = Mean + Brand + Temp + Brand*Temp + Error

When we look at our model for Block 1 and Block 2, we see that our regression slopes are not all equal to 0 given the p-values (<0.001) for both models are less than our significance level of 0.05 and that there is a significant interaction effect. Since we have different slopes we can look at the differences between Brand and Temp at the different levels. For both Blocks, we can see that there was not a significant difference between the Brands at 6 degrees Celsius.

Output for Stirred=No.

Least Squares Means							
Effect	Brand	Temp	Estimate	Standard Error	DF	t Value	Pr > |t|
Brand*Temp	name	6	78.9906	0.3414	18	231.37	<.0001
Brand*Temp	name	23	76.3635	0.3414	18	223.67	<.0001
Brand*Temp	name	40	70.5551	0.3414	18	206.66	<.0001
Brand*Temp	store	6	79.4924	0.3414	18	232.84	<.0001
Brand*Temp	store	23	67.5155	0.3414	18	197.76	<.0001
Brand*Temp	store	40	58.9635	0.3414	18	172.71	<.0001

Differences of Least Squares Means									
Effect	Brand	Temp	_Brand	_Temp	Estimate	Standard Error	DF	t Value	Pr > |t|
Brand*Temp	name	6	name	23	2.6271	0.4828	18	5.44	<.0001
Brand*Temp	name	6	name	40	8.4355	0.4828	18	17.47	<.0001
Brand*Temp	name	6	store	6	-0.5018	0.4828	18	-1.04	0.3124
Brand*Temp	name	6	store	23	11.4751	0.4828	18	23.77	<.0001
Brand*Temp	name	6	store	40	20.0271	0.4828	18	41.48	<.0001
Brand*Temp	name	23	name	40	5.8084	0.4828	18	12.03	<.0001
Brand*Temp	name	23	store	6	-3.1289	0.4828	18	-6.48	<.0001
Brand*Temp	name	23	store	23	8.8480	0.4828	18	18.33	<.0001
Brand*Temp	name	23	store	40	17.4000	0.4828	18	36.04	<.0001
Brand*Temp	name	40	store	6	-8.9373	0.4828	18	-18.51	<.0001
Brand*Temp	name	40	store	23	3.0396	0.4828	18	6.30	<.0001
Brand*Temp	name	40	store	40	11.5916	0.4828	18	24.01	<.0001
Brand*Temp	store	6	store	23	11.9769	0.4828	18	24.81	<.0001
Brand*Temp	store	6	store	40	20.5289	0.4828	18	42.52	<.0001
Brand*Temp	store	23	store	40	8.5521	0.4828	18	17.71	<.0001

Output for Stirred=Yes.

Least Squares Means							
Effect	Brand	Temp	Estimate	Standard Error	DF	t Value	Pr > |t|
Brand*Temp	name	6	76.2024	0.6790	18	112.22	<.0001
Brand*Temp	name	23	72.6915	0.6790	18	107.05	<.0001
Brand*Temp	name	40	65.8534	0.6790	18	96.98	<.0001
Brand*Temp	store	6	77.3370	0.6790	18	113.89	<.0001
Brand*Temp	store	23	66.1913	0.6790	18	97.48	<.0001
Brand*Temp	store	40	59.1253	0.6790	18	87.07	<.0001

Differences of Least Squares Means									
Effect	Brand	Temp	_Brand	_Temp	Estimate	Standard Error	DF	t Value	Pr > |t|
Brand*Temp	name	6	name	23	3.5110	0.9603	18	3.66	0.0018
Brand*Temp	name	6	name	40	10.3490	0.9603	18	10.78	<.0001
Brand*Temp	name	6	store	6	-1.1346	0.9603	18	-1.18	0.2528
Brand*Temp	name	6	store	23	10.0112	0.9603	18	10.43	<.0001
Brand*Temp	name	6	store	40	17.0771	0.9603	18	17.78	<.0001
Brand*Temp	name	23	name	40	6.8380	0.9603	18	7.12	<.0001
Brand*Temp	name	23	store	6	-4.6456	0.9603	18	-4.84	0.0001
Brand*Temp	name	23	store	23	6.5002	0.9603	18	6.77	<.0001
Brand*Temp	name	23	store	40	13.5662	0.9603	18	14.13	<.0001
Brand*Temp	name	40	store	6	-11.4836	0.9603	18	-11.96	<.0001
Brand*Temp	name	40	store	23	-0.3378	0.9603	18	-0.35	0.7291
Brand*Temp	name	40	store	40	6.7281	0.9603	18	7.01	<.0001
Brand*Temp	store	6	store	23	11.1458	0.9603	18	11.61	<.0001
Brand*Temp	store	6	store	40	18.2117	0.9603	18	18.96	<.0001
Brand*Temp	store	23	store	40	7.0660	0.9603	18	7.36	<.0001

Conclusion

Effectively describe conclusions and reasons for recommendation, analysis limitations, and future work. Address the proper role of the Stirred variable in this analysis.