Project: Liquid Displacement Using Mentos

Presented By:

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Experimental Design STAT 5080 / 4080

Description of Data Collection

The goal of this experiment is to observe how mentos react with soda in different situations. For our experiment we decided to do a 3-factor experiment consisting of the number of mentos level (2,4), type of soda (Coca Cola, Diet Coke) and temperature (refrigerated/non-refrigerated). Overall, the data collection process went exactly as planned in our proposal. Each of the 24 tests consisted of picking up a bottle and placing it on the scale with the mentos that will be used in that run. Then we will place the bottle in a plastic tote and put the mentos in the bottle, from there we will wait for the reaction to stop then wiping down the bottle and re-weighing the bottle with the mentos inside. After all the 24 runs were completed, we subtracted the before and after weight of the bottle to come up with the difference and thus how much of the liquid in oz was removed from the bottle.

One of the things that did not go according to plan was the weather. As our experiment was planned to be done outside, it did not need a certain temperature for it to work well. It did need for it to not be raining. Since it did end up raining, we had to move the experiment to a different location which was still outside but was covered so the rain would not affect it. However, in the end, the cover was not needed as a couple of minutes before we started the experiment it quit raining and did not start back up until after we had finished.

Discussion of Analysis

To start off our analysis, we generated the ANOVA table to understand the factors and interactions that are significant and the ones that are not. We went ahead to check necessary assumptions, analyze interaction plots, check the effect of some necessary factors and finally we compared the best set of conditions using the Scheffe Test which gave us some interesting findings.

1. ANOVA Table

	Df	**Sum Sq**	**Mean Sq**	**F value**	**P-value**
A	1	3.721	3.721	35.698	**1.94e-05**
B	1	17.906	17.906	171.783	**5.67e-10**
C	1	18.079	18.079	173.445	**5.29e-10**
A:B	1	0.003	0.003	0.029	0.86659
A:C	1	0.053	0.053	0.510	0.48525
B:C	1	1.576	1.576	15.119	**0.00131**
A:B:C	1	0.000	0.000	0.000	0.99503
Residuals	16	1.668	0.104		

Table 1: ANOVA Table

Using α=0.05, we see that factors A, B and C are significant (if we only consider their p-values). We also see an interaction effect between factors B and C being significant. The other interactions are not significant.

2. Assumptions Checking

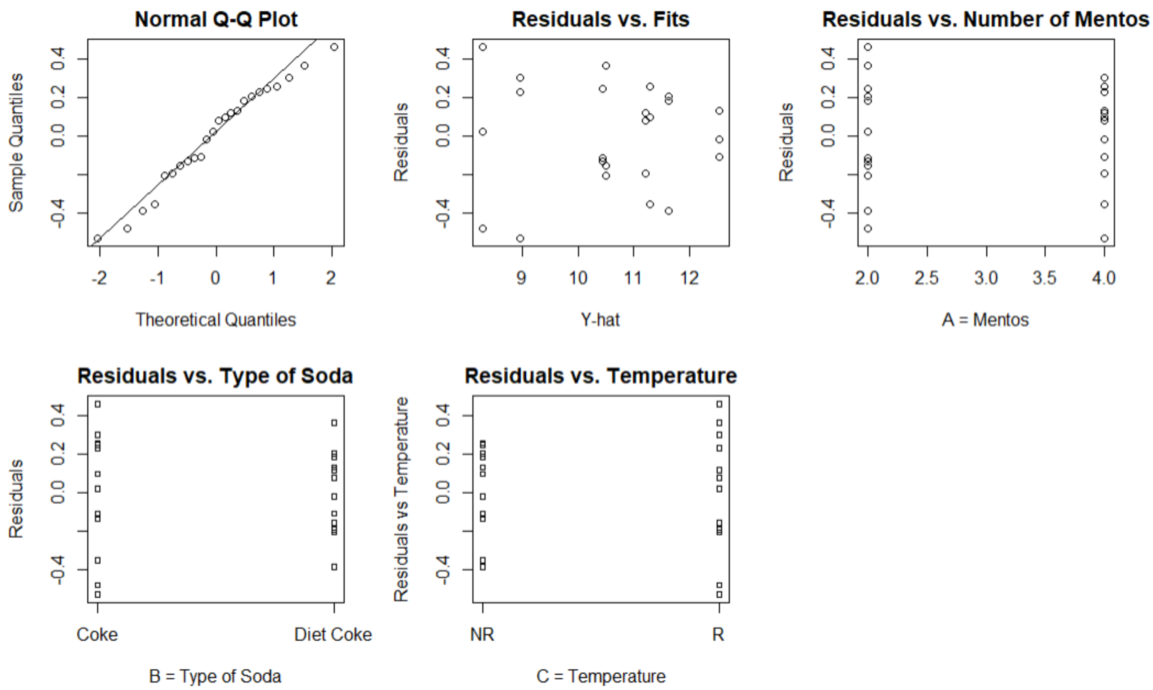

Figure 1: Assumptions Checking

The above Normality plot resembles a straight line with only slight departures. This suggests that the assumption of normality is not violated and looks approximately normal.

The residual vs fits plot looks fine supporting the constant variance assumption. For the residual plots against number of mentos, types of soda and temperature, the variances are approximately equal supporting the assumption of homogeneity of variance.

3. Pairwise Comparisons for A (Number of Mentos)

From our ANOVA (Analysis of Variance) table, we found out that B:C interaction was significant. Since A was significant and no significant interaction contained A, we did Tukey for A.

```
##   Tukey multiple comparisons of means
 ##     95% family-wise confidence level
## Fit: aov(formula = resp ~ A * B * C, data = threeway)
## $A
 ##       diff       lwr      upr    p adj
 ## 4-2 0.7875 0.5080886 1.066911 1.94e-05
```

We are 95% confident that the mean liquid loss due to four mentos candies is between 0.51 and 1.07 ounces more than that of two mentos candies. Therefore, we can say is it better at displacing liquid.

4. Two-factor Interaction Plots

Since B:C interaction was significant, we analyze the two-factor interaction plots to see whether it is consistent with the conclusion from the ANOVA table.

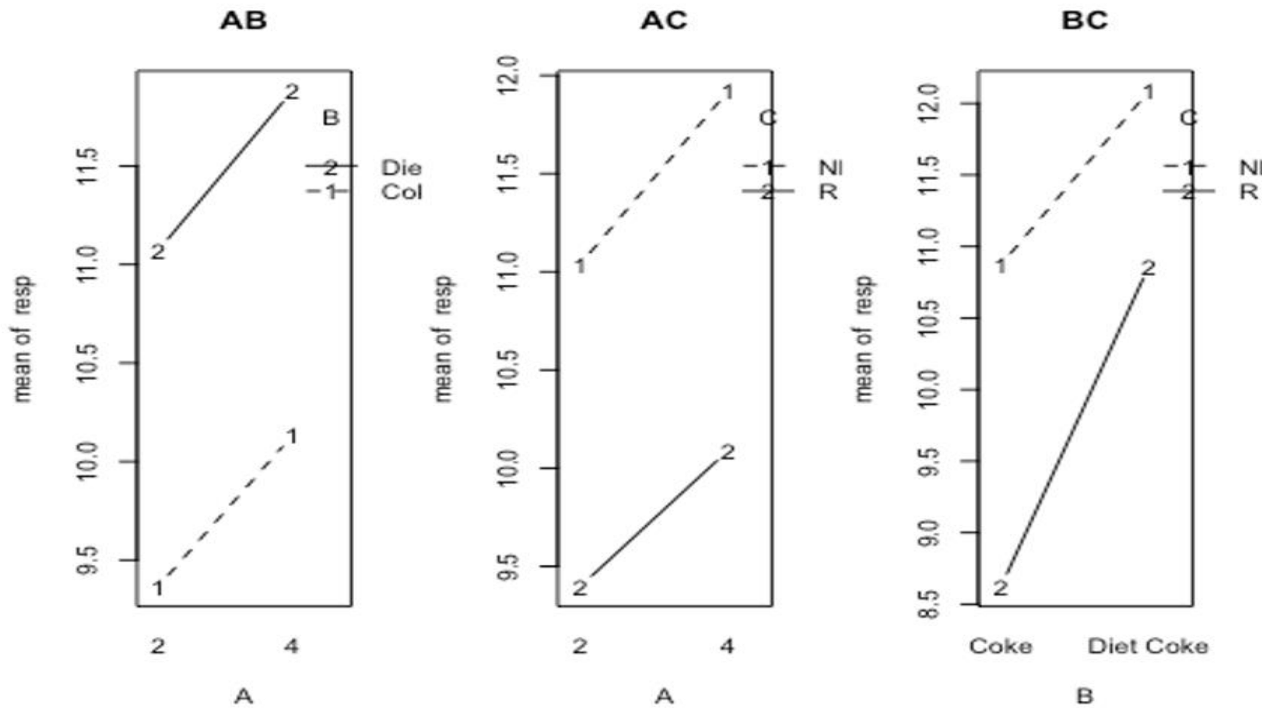

Figure 2: Two factor interaction

From the Interaction plot, we can see that the effect of B changes for different levels of C and vice versa, we also observe that A:B and A:C don't show any interaction effect.

5. Contrasts for B:C Interaction

Flowing from our observation that the B:C interaction is significant, but since each of them have just one degree of freedom so we'll just do one contrast. We'd like to maintain a 95% family-wise error rate.

 # The effect of B when C=R minus the effect of B when C=NR

[1] 0.4119246 1.0250000 1.6380754

We are 95% confident (at a family level) that the mean liquid loss of Soda-type (B) when it is refrigerated is between 0.41 and 1.64 ounces more than when it is not refrigerated. Therefore, we can say it is better at displacing liquid.

6. The Best Set of Conditions

	B=Diet Coke, C=R	**B=Coca-Cola, C=R**	**B=Diet Coke, C=NR**	**B=Coca-Cola, C=NR**
A=2	10.50667	8.29	11.63667	10.44333
A=4	11.22333	8.96	12.54000	11.30333

Table 2: Mean Matrix

Observing the mean matrix (data snooping) we can see that the best set of conditions are when A=4, B=Diet Coke, C=NR which gives a value of 12.54 ounces. The next best set of conditions are A=2, B=Diet Coke, C=NR which gives a value of 11.64 ounces.

Since we have performed data snooping, we use the Scheffe test to check if the best (A=4, B=Diet Coke, C=NR) is significantly better than the second best (A=2, B=Diet Coke, C=NR).

c(pe-sch*se, pe, pe+sch*se)

[1] -0.2322837 0.9033333 2.0389504

We are 95% confident that the mean liquid loss from 4 mentos in a non-refrigerated Diet Coke is between 0.23 ounces less than and 0.9 ounces more than that of 4 mentos in a non-refrigerated Diet Coke. Therefore, we can't say it is better at displacing liquid.

Conclusions and Summary

In conclusion, we found that A (number of mentos), B (Soda type) and C (Soda Temperature) are all significant (when we consider only p-values) as well as the B:C interaction from the interaction plot is also significant in our experiment. This meant we must perform a Tukey analysis on A, as well as a contrast comparison for the B:C interaction. We found that the combination of A = 4 Mentos, B = Diet Coke and C = non-refrigerated seemed to be the best combination with A =2 Mentos, B = Diet Coke and C = non-refrigerated followed closely behind. We determined that there was not a significantly greater amount of soda lost between the first combination and the second. Overall, we did find that diet coke and non-refrigerated seemed to produce more overflowing of the soda along with 4 Mentos instead of 2 even though it may have not been a significant difference. These findings are not as we expected because we hypothesized that regular Coca Cola would have a greater displacement of soda because the sugar levels in regular Coca Cola are higher than that of Diet Coke. The 4 Mentos being better at displacing the soda than 2 Mentos is what we expected as we thought the more Mentos present, the more reaction it would have with the soda. For non-refrigerated compared to refrigerated we did not know what to expect but were pleasantly surprised to see that there was a difference and non-refrigerated seemed to displace more soda than refrigerated.

If we were to do this experiment again, we would most likely use more Mentos and larger bottles of Diet Coke and regular Coca Cola. We would do this because we know more Mentos could increase the displacement of soda which would cause a bigger chemical reaction. This is also why we would need bigger bottles of soda in order to see the displacement better. We would check if doing more replications would also give us a better understanding of which factor combinations are the best significantly. If we were to do this experiment again, we would also add different types of soda. Increasing the temperature of the soda would also be interesting since the non-refrigerated displaced soda more. Another good idea we thought of if we ran this experiment again is to have an automatic system that drops the Mentos in the bottle to eliminate any human error in dropping the Mentos.

Statement on the best experience of our lives.

This was the best experience of our lives because we were able to observe the amazing chemical reaction between Mentos and Coke. We also then were able to collect data and perform the most intriguing analysis we have ever done. Some of this analysis was using R-studio and using Tukey analysis in order to find the best combination of Mentos and soda to displace the most soda. This was hands down the best data collection and analysis we have ever done.

Proposals

Stat 5080 Group 3 Initial Proposal

Liquid Displacement Using Mentos

Names: Nzubechukwu Ohalete, Jacob Haussler, Pragya Khanal, James Hawkins

Goal or objective:

To see how much liquid is displaced when different quantities of mentos are placed within different kinds of soda at different temperatures.

Response: how much liquid is lost from the reaction.

Factor	Levels
Position A = # of Mentos	2 (2,5)
Position B = Type of soda	2 (Coca-Cola=1, Fanta=2)
Position C = Temperature	2 (Refrigerated=1, Room temperature=2)

Narrative:

We will measure how much liquid is removed from the bottle by taking the weight of the bottle plus the mentos weight and then weighing the bottle to see how much weight the bottle has lost. The difference between these two values will be the response variable. The response variable is continuous as any amount of liquid can come out of the bottle. We decided on a total of 16 experimental runs which is two runs for each set up. We have proposed to include 3 factors in this experiment i.e., number of mentos candies, types of soda and the temperature at which we will be doing the experiment. As we do not believe there will be much variation between identical tests since the starting set up would be the same and it simply comes down to a chemical reaction. We currently suspect that the amount of liquid removed will increase dramatically with the number of mentos as the more mentos in the soda the more of the chemical reaction can take place. As for the different soda flavors, we currently don't believe there will be much of a difference since the mentos are reacting with the carbonation and not the flavoring. As for the temperature, we are not sure how it will affect the response variable.

Currently we are planning on using 80 minutes to do this experiment. We calculated this by assuming it would take approximately 5 minutes for each run of the 16 reactions. We plan on doing all 16 trials within one session. We will start by cooling the 9 refrigerated soda bottles beforehand and placing them in a cooler, so they stay cold while we go to a location outside. We have used an R code to randomize the order of the experiment. Each test will consist of picking up a bottle and placing it on the scale with the mentos that will be using in that run. Then we will place the bottle on the ground and put the mentos in the bottle, from there we will wait for the reaction to stop and re-weigh the bottle. After all that is done, we will minus the second weight from the first weight to determine how much liquid in grams was lost.

The above reasoning ensures we have put enough time and effort into the data collection in terms of time. Now we will see if this will be an adequate amount of data to achieve desired power. We would like to be able to detect a difference of 1.5 standard deviations () between two levels of each of the factors: A, B and C with a reasonably high probability of .70. With 2 replications, D = 1.5σ , the non-centrality parameter will be $\lambda = \left((2)(2)(2)(1.5\sigma)^2\right)/2(\sigma^2) = 9$. The R code below shows that the critical value for the 3 hypothesis tests of interest is F = 5.32 from the distribution leading to a power of about 0.75. Thus, it appears we will have an adequate amount of data.

We plan to perform the experiment on a single day. Assuming we get this proposal approved on April 4, we plan to perform the experiment on April 6th.

R code used to randomize the experiment and calculate power

```
mentos=rep(NA,16)
soda=rep(NA,16)
temperature=rep(NA,16)
set.seed(0)
randomsoda=sample(c(rep("Coke",8),rep("Fanta",8)))
randomtemp=sample(c(rep("Refrigerated",8),rep("Room Temperature",8)))
count=0
for(i in (2*(1:8)-1)) {
  count=(i+1)/2
  mentos[i:(i+1)]=sample(c(2,5))
  soda[i:(i+1)]=rep(randomsoda[count],2)
  temperature[i:(i+1)]=rep(randomtemp[count],2)
}
cbind(mentos,soda,temperature)

alpha=.05
a=2     #number of levels of A
b=2     #number of levels of B
c=2     #number of levels of C
sigsq=1 #our estimate of sigma^2

nA=2:10                  #sample size for A comparisons
DA=1.5            #desired diff in means to detect with prob 1-beta
```

```
Fcrit=qf(1-alpha,a-1,a*b*c*(nA-1))     #value at which we reject H0
lam=nA*b*c*(DA^2)/(2*sigsq)           #non-centrality paramter (ncp)
beta=pf(Fcrit,a-1,a*b*c*(nA-1),ncp=lam)
power=1-beta
nforA=cbind(nA,Fcrit,beta,power)      #output for A

nB=2:10                     #sample size for B comparisons
DB=1.5          #desired diff in means to detect with prob 1-beta
Fcrit=qf(1-alpha,b-1,a*b*c*(nB-1))     #value at which we reject H0
lam=nB*a*c*(DB^2)/(2*sigsq)           #non-centrality paramter (ncp)
beta=pf(Fcrit,b-1,a*b*c*(nB-1),ncp=lam)
power=1-beta
nforB=cbind(nB,Fcrit,beta,power)      #output for B


nC=2:10                     #sample size for C comparisons
DC=1.5          #desired diff in means to detect with prob 1-beta
Fcrit=qf(1-alpha,b-1,a*b*c*(nC-1))     #value at which we reject H0
lam=nC*a*b*(DC^2)/(2*sigsq)          #non-centrality paramter (ncp)
beta=pf(Fcrit,c-1,a*b*c*(nC-1),ncp=lam)
power=1-beta
nforC=cbind(nC,Fcrit,beta,power)      #output for C

nforA
nforB
nforC

> nforA
      nA    Fcrit         beta     power
 [1,]  2 5.317655 2.519829e-01 0.7480171
```

```
 [2,]  3 4.493998 6.862017e-02 0.9313798
 [3,]  4 4.259677 1.753632e-02 0.9824637
 [4,]  5 4.149097 4.183129e-03 0.9958169
 [5,]  6 4.084746 9.417329e-04 0.9990583
 [6,]  7 4.042652 2.020925e-04 0.9997979
 [7,]  8 4.012973 4.166305e-05 0.9999583
 [8,]  9 3.990924 8.301195e-06 0.9999917
 [9,] 10 3.973897 1.606045e-06 0.9999984

> nforB
      nB    Fcrit         beta     power
 [1,]  2 5.317655 2.519829e-01 0.7480171
 [2,]  3 4.493998 6.862017e-02 0.9313798
 [3,]  4 4.259677 1.753632e-02 0.9824637
 [4,]  5 4.149097 4.183129e-03 0.9958169
 [5,]  6 4.084746 9.417329e-04 0.9990583
 [6,]  7 4.042652 2.020925e-04 0.9997979
 [7,]  8 4.012973 4.166305e-05 0.9999583
 [8,]  9 3.990924 8.301195e-06 0.9999917
 [9,] 10 3.973897 1.606045e-06 0.9999984

> nforC
      nC    Fcrit         beta     power
 [1,]  2 5.317655 2.519829e-01 0.7480171
 [2,]  3 4.493998 6.862017e-02 0.9313798
 [3,]  4 4.259677 1.753632e-02 0.9824637
 [4,]  5 4.149097 4.183129e-03 0.9958169
 [5,]  6 4.084746 9.417329e-04 0.9990583
 [6,]  7 4.042652 2.020925e-04 0.9997979
 [7,]  8 4.012973 4.166305e-05 0.9999583
```

[8,] 9 3.990924 8.301195e-06 0.9999917

[9,] 10 3.973897 1.606045e-06 0.9999984

Data table

# of Mentos used	Type of Soda	Temperature	Liquid removed
5	Fanta	Refrigerated	
2	Fanta	Refrigerated	
2	Coca-Cola	Room temperature	
5	Coca-Cola	Room temperature	
5	Coca-Cola	Room temperature	
2	Coca-Cola	Room temperature	
2	Coca-Cola	Refrigerated	
5	Coca-Cola	Refrigerated	
2	Fanta	Room temperature	
5	Fanta	Room temperature	
5	Coca-Cola	Room temperature	
2	Coca-Cola	Room temperature	
5	Fanta	Refrigerated	
2	Fanta	Refrigerated	
5	Fanta	Refrigerated	
2	Fanta	Refrigerated	

Stat 5080 Group 3 Resubmission Proposal

Liquid Displacement Using Mentos

Names: Nzubechukwu Ohalete, Jacob Haussler, Pragya Khanal, James Hawkins

Goal or objective:

To see how much liquid is displaced when different quantities of mentos are placed within different kinds of soda at different temperatures.

Response: how much liquid is lost from the reaction.

Factor	Levels
Position A = # of Mentos	2 (2,4)
Position B = Type of soda	2 (Coca-Cola=1, Diet Coke=2)
Position C = Temperature	2 (Refrigerated=1, Non-Refrigerated=2)

Narrative:

For our experiment, we will be using 16-ounce plastic bottles. We plan to measure the amount of liquid removed after the reaction. We are using a digital scale for weighing purposes. We are measuring how much liquid is removed from the bottle by taking the weight of the bottle plus the mentos weight and then weighing the bottle to see how much weight the bottle has lost. To ensure that we are weighing only the remaining liquid, we are wiping the bottle clean before placing it on the scale and also wiping the scale clean after each measurement. The difference between these two values will be the response variable. The response variable is continuous as any amount of liquid can come out of the bottle. We decided on a total of 24 experimental runs which is three runs for each set up. We have proposed to include 3 factors in this experiment i.e., number of mentos candies, types of soda and the temperature at which we will be doing the experiment. We picked the number of mentos candies as 2 and 4 because we think that the difference of 1 mentos might not reflect a notable change in the amount of liquid displaced. So, we decided to increase the difference by 2. As we do not believe there will be much variation between identical tests since the starting set up would be the same and it simply comes down to a chemical reaction. We currently suspect that the amount of liquid removed will increase dramatically with the number of mentos as the more mentos in the soda the more of the chemical reaction can take place. While considering the variation in sugar levels, we have chosen Coca-cola and Diet Coke to perform this experiment. As for the temperature, we are not sure how it will affect the response variable.

Currently we are planning on using 120 minutes to do this experiment. We calculated this by assuming it would take approximately 5 minutes for each run of the 24 reactions. We plan on doing all 24 trials within one session. We will start by cooling the 12 refrigerated soda bottles beforehand and placing them in a cooler, so they stay cold while we go to a location outside. We have used an R code to randomize the order of the experiment. Each test will consist of picking up a bottle and placing it on the scale with the mentos that will be used in that run. Then we will place the bottle in a plastic tote and put the mentos in the bottle, from there we will wait for the reaction to stop and re-weigh the bottle. We will clean the plastic tote every time we do the trial. Using a plastic tote will make our work less messy and we can dump the liquid into a sewer. The tote would be placed on a level ground. The mentos candies will be stacked together and dropped at once. After all that is done, we will minus the second weight from the first weight to determine how much liquid in ounces was lost. Only one person will be dropping the candies in each trial. We have also assigned roles to our group members for the experiment. James will be dropping the candies into the bottle. Pragya will be weighing the bottles and candies. She will also take care of wiping after each experiment. Nzube will be recording the values of the weights. We will be wearing safety goggles.

The above reasoning ensures we have put enough time and effort into the data collection in terms of time. Now we will see if this will be an adequate amount of data to achieve the desired power. We would like to be able to detect a difference of 1.5 standard deviations () between two levels of each of the factors: A, B and C with a reasonably high probability of .90. With 3 replications, D =1.5σ , the non-centrality parameter will be $\lambda = \left((3)(2)(2)(1.5\sigma)^2\right)/2(\sigma^2) = 13.5$. The R code below shows that the critical value for the 3 hypothesis tests of interest is F = 5.32 from the distribution leading to a power of about 0.93. Thus, it appears we will have an adequate amount of data.

We plan to perform the experiment on a single day. Assuming we get this proposal resubmission approved on April 7, we plan to perform the experiment on April 8th. The location of the experiment is the grass field in front of the Jerome Library.

R code used to randomize the experiment and calculate power

```
mentos=rep(NA,24)

soda=rep(NA,24)

temperature=rep(NA,24)

set.seed(4)

soda=sample(c(rep("Coca-Cola",12), rep("Diet Coke",12)))

temperature=sample(c(rep("Refrigerated",12), rep("Non-Refrigerated",12)))

mentos=sample(rep(c(2,4),12))

cbind(mentos,soda,temperature)


alpha=.05

a=2    #number of levels of A

b=2    #number of levels of B

c=2    #number of levels of C

sigsq=1 #our estimate of sigma^2


nA=2:10                #sample size for A comparisons
```

DA=1.5 #desired diff in means to detect with prob 1-beta

Fcrit=qf(1-alpha,a-1,a*b*c*(nA-1)) #value at which we reject H0

lam=nA*b*c*(DA^2)/(2*sigsq) #non-centrality paramter (ncp)

beta=pf(Fcrit,a-1,a*b*c*(nA-1),ncp=lam)

power=1-beta

nforA=cbind(nA,Fcrit,beta,power) #output for A

nB=2:10 #sample size for B comparisons

DB=1.5 #desired diff in means to detect with prob 1-beta

Fcrit=qf(1-alpha,b-1,a*b*c*(nB-1)) #value at which we reject H0

lam=nB*a*c*(DB^2)/(2*sigsq) #non-centrality paramter (ncp)

beta=pf(Fcrit,b-1,a*b*c*(nB-1),ncp=lam)

power=1-beta

nforB=cbind(nB,Fcrit,beta,power) #output for B

nC=2:10 #sample size for C comparisons

DC=1.5 #desired diff in means to detect with prob 1-beta

Fcrit=qf(1-alpha,b-1,a*b*c*(nC-1)) #value at which we reject H0

lam=nC*a*b*(DC^2)/(2*sigsq) #non-centrality paramter (ncp)

beta=pf(Fcrit,c-1,a*b*c*(nC-1),ncp=lam)

power=1-beta

nforC=cbind(nC,Fcrit,beta,power) #output for C

nforA

nforB

nforC

```
> nforA
     nA    Fcrit       beta     power
```

```
 [1,]  2 5.317655 2.519829e-01 0.7480171
 [2,]  3 4.493998 6.862017e-02 0.9313798
 [3,]  4 4.259677 1.753632e-02 0.9824637
 [4,]  5 4.149097 4.183129e-03 0.9958169
 [5,]  6 4.084746 9.417329e-04 0.9990583
 [6,]  7 4.042652 2.020925e-04 0.9997979
 [7,]  8 4.012973 4.166305e-05 0.9999583
 [8,]  9 3.990924 8.301195e-06 0.9999917
 [9,] 10 3.973897 1.606045e-06 0.9999984

> nforB
      nB    Fcrit         beta     power
 [1,]  2 5.317655 2.519829e-01 0.7480171
 [2,]  3 4.493998 6.862017e-02 0.9313798
 [3,]  4 4.259677 1.753632e-02 0.9824637
 [4,]  5 4.149097 4.183129e-03 0.9958169
 [5,]  6 4.084746 9.417329e-04 0.9990583
 [6,]  7 4.042652 2.020925e-04 0.9997979
 [7,]  8 4.012973 4.166305e-05 0.9999583
 [8,]  9 3.990924 8.301195e-06 0.9999917
 [9,] 10 3.973897 1.606045e-06 0.9999984

> nforC
      nC    Fcrit         beta     power
 [1,]  2 5.317655 2.519829e-01 0.7480171
 [2,]  3 4.493998 6.862017e-02 0.9313798
 [3,]  4 4.259677 1.753632e-02 0.9824637
 [4,]  5 4.149097 4.183129e-03 0.9958169
 [5,]  6 4.084746 9.417329e-04 0.9990583
 [6,]  7 4.042652 2.020925e-04 0.9997979
```

[7,] 8 4.012973 4.166305e-05 0.9999583

[8,] 9 3.990924 8.301195e-06 0.9999917

[9,] 10 3.973897 1.606045e-06 0.9999984

Data table

# of Mentos used	Type of Soda	Temperature	Liquid removed
4	Diet Coke	Non-Refrigerated	
2	Coca-Cola	Non-Refrigerated	
2	Coca-Cola	Refrigerated	
4	Coca-Cola	Non-Refrigerated	
4	Diet Coke	Non-Refrigerated	
2	Coca-Cola	Non-Refrigerated	
2	Diet Coke	Non-Refrigerated	
4	Diet Coke	Refrigerated	
2	Diet Coke	Non-Refrigerated	
2	Coca-Cola	Refrigerated	
2	Coca-Cola	Refrigerated	
4	Coca-Cola	Non-Refrigerated	
2	Diet Coke	Refrigerated	
2	Diet Coke	Non-Refrigerated	
4	Diet Coke	Refrigerated	
4	Coca-Cola	Refrigerated	
4	Coca-Cola	Refrigerated	
2	Coca-Cola	Refrigerated	
2	Diet Coke	Non-Refrigerated	
4	Diet Coke	Refrigerated	
4	Coco-Cola	Refrigerated	
4	Diet Coke	Non-Refrigerated	
4	Coco-Cola	Non-Refrigerated	
2	Diet Coke	Refrigerated	

While your sample size calculations are correct, you do have the smallest possible experiment (a=b=c=n=2) and power of only about 0.75. Consider 3 levels of Mentos or n=3.

We will do 3 replications. (i.e. n=3)

There is no mention of who will be putting the Mentos into the bottles. Will this just be one person or will different people just jump in and do it when they feel like it? Or, with n=2 as currently proposed, will you use two different droppers and block?

Only one person will be dropping the candies in each trial. We have also assigned roles to our group members for the experiment. James will be dropping the candies into the bottle. Pragya will be weighing the bottles and candies. She will also take care of wiping. Nzube will be recording the values of the weights. We will be wearing safety goggles.

If the experiment does only take 80 minutes, the following may not be much of an issue. But being outdoors, “room temperature” may be difficult to maintain. Another reason to consider blocking.

We will just use “refrigerated” and “non-refrigerated” bottles because room temperature may be difficult to maintain.

Where are you going to do this? It will be messy so you need someplace you will not get in trouble for spraying soda all over.

The location of the experiment is the grass field in front of the Jerome Library. It is spacious with a sewer nearby. Using a plastic tote will make our work less messy and we can dump the liquid into a sewer.

Wear safety googles!

Thank you, Dr. Herb. We will wear safety goggles.

How did you pick 2 and 5? Why not, say, 2, 3, and 4?

We picked the number of mentos candies as 2 and 4 because we think that the difference of 1 mentos might not reflect a notable change in the amount of liquid displaced. So, we tried to increase the difference to 2.

What size bottle? Glass or plastic?

For our experiment, we will be using 16-ounce plastic bottles.

I need a lot more detail on how these will be weighed. What kind of scale? Will the bottle be wiped clean before being put on the scale? Will the scale be wiped clean after each measurement?

We plan to measure the amount of liquid removed after the reaction. We are using a digital scale for weighing purposes. We are measuring how much liquid is removed from the bottle by taking the weight of the bottle plus the mentos weight and then weighing the bottle to see how much weight the bottle has lost. To ensure that we are weighing only the remaining liquid, we are wiping the bottle clean before placing it on the scale and also wiping the scale clean after each measurement.

How will the mentos be put in the bottle, all at once, one at a time? Will they be dropped, carefully placed?

The mentos candies will be stacked together and dropped at once.

Fanta has different flavors I believe, which will you use? As you say, the flavor probably does not matter but sugar level may. Should you use Coca-cola and a diet soda instead of Fanta?

While considering the variation in sugar levels, we have chosen Coca-cola and diet soda to perform this experiment.

You mentioned a location outside, where? You will need to be careful that the "ground" is level. How will you ensure that?

The location of the experiment is the grass field in front of the Jerome Library. Since we are doing it on the grass field, we are placing the bottles in a plastic tote on the ground. The plastic tote would be placed on level ground.

Appendix

R Codes

Data Entry

```
resp <- c(10.87,7.81,11.25,10.33,
          10.35,8.75,11.84,10.69,
          10.3,8.31,11.82,10.31,
          11.03,8.43,12.67,11.56,
          11.3,9.26,12.52,10.95,
          11.34,9.19,12.43,11.4)
 mentos <- rep(c(2,4),each=12)
 soda <- rep(c("Diet Coke","Coke"),12)
 temp <- rep(c("R","R","NR","NR"),6)
```

Data Frame

```
```{r include=FALSE}

threeway=data.frame(resp=resp,A=factor(mentos),B=factor(soda),C=factor(temp))

attach(threeway)

```
```

Data Matrix

```
datamat=matrix(resp,6,4,byrow=T)
 colnames(datamat)=c("B=Diet Coke, C=R","B=Coca-Cola, C=R",
                    "B=Diet Coke, C=NR","B=Coca-Cola, C=NR")
 rownames(datamat)=c("A=2","","","A=4","","")
 datamat
```

ANOVA Table

```
outthree=aov(resp~A*B*C,threeway)
 summary(outthree)
```

Assumptions Checking

```
fits=outthree$fitted        #same as fitted(junk_out)
 res=outthree$residuals  #same as residuals(junk_out)

#Assumption Checking with Residual Plots
 par(mfrow=c(2,3))   #create 2 rows and two columns in graphics column
```

```
 qqnorm(res)
 qqline(res)
 plot(fits,res,xlab="Y-hat",ylab="Residuals",
     main="Residuals vs. Fits")
 plot(res~mentos,vertical=T,xlab="A = Mentos",ylab="Residuals", main="Residuals vs. Number of
Mentos")

stripchart(res~soda,vertical=T,xlab="B = Type of Soda",ylab="Residuals",
          main="Residuals vs. Type of Soda")
 stripchart(res~temp,vertical=T,xlab="C = Temperature",ylab="Residuals vs Temperature",
          main="Residuals vs. Temperature")
 par(mfrow=c(1,1))
```

Tukey for A

```
TukeyHSD(outthree, "A")
```

Mean Matrix

```
# Store means for explaining the interaction plots
 meanvec=numeric(8)
 count=1
 for(i in c(2,4)) {
        for(k in c("R","NR")) {
           for(j in c("Diet Coke","Coke")) {
           meanvec[count]=  mean(resp[mentos==i & soda==j & temp==k])
          count = count +1
           }
        }
 }
 meanmat=matrix(meanvec,2,4,byrow=T)
 colnames(meanmat)=c("B=Diet Coke, C=R","B=Coca-Cola, C=R",
                    "B=Diet Coke, C=NR","B=Coca-Cola, C=NR")
 rownames(meanmat)=c("A=2","A=4")
 meanmat
```

Interaction Plots

```
#two factor interactions
 par(mfrow=c(1,3))
 interaction.plot(A,B,resp,type="b",main="AB")
 interaction.plot(A,C,resp,type="b",main="AC")
 interaction.plot(B,C,resp,type="b",main="BC")
```

```
par(mfrow=c(1,1))

 b=2
 c=2
 n=3
 alpha=.05
 dfe=16
 mse=0.104
 Tq=qtukey(1-alpha/(b+c),b,dfe)/sqrt(2)
 tuk=numeric(2)
 tuknames=numeric(2)

# Contrast Comparison for B:C

# The effect of B when C=R minus the effect of B when C=NR

bc_ctrst = mean(resp[B=="Diet Coke"&C=="R"]) - mean(resp[B=="Coke"&C=="R"]) -  (
mean(resp[B=="Diet Coke"&C=="NR"]) - mean(resp[B=="Coke"&C=="NR"]) )
se=sqrt(mse*4/6)
mult=qt(1-alpha/3,dfe)
me=mult*se
c(bc_ctrst-me,bc_ctrst,bc_ctrst+me)
```

Which Combo is best?

```
model.tables(outthree,type="means")
```

Scheffe Test

```
 a=2; b=2; c=2; n=3
 sch=sqrt((a*b*c-1)*qf(1-alpha,a*b*c-1,dfe))
a4b2c1=mean(with(threeway,resp[A==4&B=="Diet Coke"&C=="NR"]))
 a2b2c1=mean(with(threeway,resp[A==2&B=="Diet Coke"&C=="NR"]))
 pe=a4b2c1-a2b2c1
 se=sqrt(2*mse/n)
 c(pe-sch*se, pe, pe+sch*se)
```

References

Montgomery, D.C. (2020), Design and Analysis of Experiments, 10th Edition, Wiley