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Liquid Type and Submersion Time on Nails

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Abstract

This study was designed to investigate the effect of different liquids and submersion time on the weight of a nail. Four different liquids (water, Coke, Diet Coke, and 2% milk) were poured in a total of 36 red solo cups (nine cups for each liquid), and one nail was placed in each cup. The study did not yield significant evidence that changing the type of liquid or the submersion time of the nails has an effect on the weight of the nails at the 5% significance level.

1. Introduction

Nails are a widely used construction material. Whether it is used to connect pieces of wood, or simply hanging a painting on the wall, it is important to know the durability of this particular tool. We were motivated to investigate the durability of nails, to see how well they would hold up against a rainy day outside or a sudden spill of Diet Coke; and since nails are commonly used, these results can be helpful for anyone. Maybe you are in the process of building a birdhouse and want to know if the use of nails is appropriate because you are unsure whether they will rust in the rain? Or perhaps you're curious whether the time some milk spilled on your table affected the nails holding it together. Look no further, because in this experiment, we will be investigating the effect of different liquids (Water, Coke, Diet Coke, and 2% milk) and submersion time (12 hours, 24 hours, and 36 hours) on the weight of a nail.

A similar paper can be seen in the article "What Household Liquids Make Steel Nails Rust?" written by Shannon Johnson. This article focused on why different liquids cause rusting, while we focused on the change of weight of the nail. In the article, water and carbonated beverages were discussed, which made up three of our four types of liquid. However, they also discussed the difference between types of nail, stainless steel and steel. Another article that relates to our study is "What Chemicals Rust Metal Rapidly?" by John Papiewski. This article also focused on rusting, more specifically what substances cause metal to rust, and tested different substances. For example, in addition to water they also tested the effects of salt, bleach, and vinegar.
Unlike these articles, we were interested in finding which treatment combination of liquid and submersion time would change the weight of the nail the most. We expected that the longer nails were submerged in any of the liquids, the more the weight would change since it gives the nail a longer time to soak and rust. In terms of which liquid would change the weight of the nails the most, we hypothesized that either Diet Coke or Coke would change the weight of the nail the most due to their acidity. We knew that if the nail spent long enough in water, it would start to rust and change in weight, but we did not know how long. So ultimately, we expected either Diet Coke or Coke, both spending 36 hours submerged would have the greatest difference in weight.

2. Materials and Methods

The equipment and materials used in this experiment were 36 Red Solo Cups, 36 nails (from Target), water, Diet Coke, Coke, 2% milk, a tablespoon measuring spoon, a scale (from Amazon), and paper towels. Some potential measurement issues are the accuracy of the scale we used and how well the nails were dried before measuring. The experiment process was broken up into four main steps. Step one consisted of labeling each cup with numbers ranging from one to thirty-six. Step two was randomly assigning each nail to a unique cup; we first weighed the nail and then placed it into its corresponding cup. Step three was randomly assigning each cup a liquid and submersion time, then pouring two tablespoons of said liquid into the cup. The fourth and final step was drying off the nail with a paper towel and then weighing the nail after its submersion time was up. We started our experiment on February 4, 2022 at 9:00 PM. The 12-hour measurement was taken at 9:00 AM on February 5, 2022. The 24-hour measurement was taken at 9:00 PM on February 5, 2022. The 36-hour measurement was taken at 9:00 AM on February 6, 2022. The data collection process was smooth and we did not run into any issues.

2.1 Treatment Structure

The treatment structure is a 4x3 factorial, with 12 treatments. Our factors of interest are type of liquid with 4 levels (water, 2% milk, Coke, Diet Coke) and submersion time with 3 levels (12 hours, 24 hours, 36 hours). The 12 treatments are water with a 12 hour submersion time, water with a 24 hour submersion time, water with a 36 hour submersion time, 2% milk with a 12 hour submersion time, 2% milk with a 24 hour submersion time, 2% milk with a 36 hour submersion time, Coke with a 12 hour submersion time, Coke with a 24 hour submersion time, Coke with a 36 hour submersion time, Diet Coke with a 12 hour submersion time, Diet Coke with a 24 hour submersion time, and Diet Coke with a 36 hour submersion time. We chose these specific levels of factor for submersion time because we wanted to see how fast liquids would start affecting the nails. We chose these specific liquids because they are common drinks that appear in our everyday lives.

2.2 Response Variable(s)

The response variable is the change in weight (grams) of the nail (before submersion - after submersion). We will be measuring this using a scale we bought from Amazon. We want to see high values because we want to see a large change in the weight of the nail.

2.3 Experimental Unit

Our experimental unit is each nail, acquired from Target. We used 36 nails, for 3 replications per treatment.

2.4 Design Structure

The design structure of our experiment was a Completely Randomized Design (CRD). To randomly assign treatments to experimental units, we did this in three steps. Step one consisted of labeling each cup with numbers ranging from one to thirty-six. Step two was randomly assigning each nail to a unique cup; we first weighed the nail and then placed it into its corresponding cup. Step three was randomly assigning each cup a liquid and submersion time and then pouring two tablespoons of said liquid into the cup. There were 3 replications per treatment, so with 12 treatment combinations, 36 total replications. We did not use blocking in our experiment.

2.5 Dealing with other sources of variation

To minimize extraneous variables, we kept all the cups (with the liquid and nails) in the same room, had the same person use the same machine to weigh the nails before and after submersion, had the same person measure the liquid before pouring it, used the same type of cup for every nail, removed the nail the same way (have the same person remove each nail) and used the same type of nail for each treatment. We randomized the run order by first randomizing which order the liquids were poured into a cup (random number generator, assigning each liquid a number). This addresses the difference in length of time after liquid is poured, but before the nail is placed into the cup. Then, we randomly assigned each nail to a cup (same process as the liquids, but assigning each nail a number). We also randomly assigned each cup a submersion time. One measurement issue we suspect we ran into was the accuracy of the scale we used to measure the weight of the nails. Since our scale was not the highest quality, slight differences in position of the nail on the scale would affect the weight of the nail. We attempted to place the nail the same way on the scale each time, but the exact same placement is not possible.

2.6 Statistical model and data analysis

The Effects model for our experiment is: $y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$ where y_{ijk} is the change in weight in the i^{th} liquid type and j^{th} submersion time for the k^{th} nail. μ is the overall mean response of change in weight. α_i is the effect of liquid type, and this is a fixed effect. β_j is the effect of submersion time, and this is a fixed effect. $(\alpha\beta)_{ij}$ is the interaction effect of liquid type and submersion time, and this is also a fixed effect. ε_{ijk} is the random error, which is a random effect. The values that the difference subscripts can take are: i can range from 1, 2, 3, and 4, j can range from 1, 2, and 3, and k can range from 1, 2, and 3. Since liquid type, submersion time, and the interaction effect of liquid and submersion time are all fixed effects, the assumptions we made by the model are that the effects sum to zero. So, α_i sums to zero, β_j sums to zero, and $(\alpha\beta)_{ij}$ sums to zero. For ε_{ijk}, we assume that ε_{ijk}~iidN(0, σ^2 error). The software used to analyze the data was JMP Pro 16.0.0 and the statistical model used was ANOVA with a FWER of 0.05.

3. Analysis and Results

3.1 Descriptive statistics

Preliminary results, on average, show an increase in nail weight across submersion time for all liquid types. As can be seen in Figure 3.1, Coca-cola exhibited a moderate, positive, linear relationship, meanwhile 2% Milk, Diet Coca-cola, and Water present strong, non-linear, relationships. There is one possible high outlier in Diet Coca-cola at 24 hours, and one possible low outlier in both Water at 24 hours and Coca-cola at 36 hours. Looking at Figure 3.2, there is evidence of a main effect of liquid type and submersion time, and since at least one of the lines are not parallel there is evidence of an interaction between liquid type and submersion time. In other words, it is possible the effect of liquid type on weight change depends on the submersion time.

Figure 3.1: Scatter plots showing how weight change changed with changes in submersion time depending on liquid type

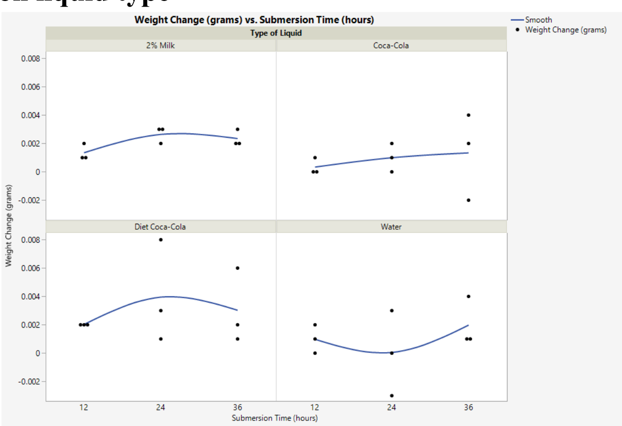
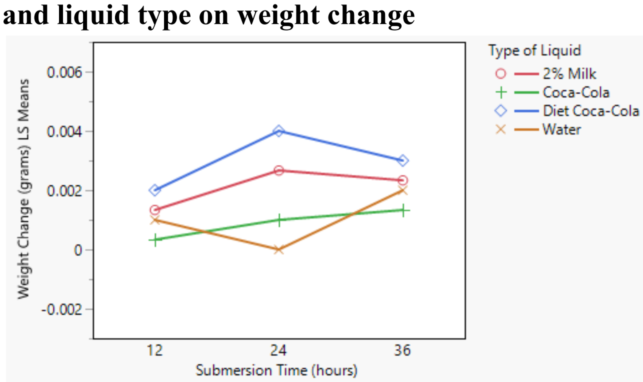


Figure 3.2: Interaction Plot between submersion time and liquid type on weight change



3.2 Inferential findings

Independence was met due to randomization of each nail to treatment and randomization of run order. Normality does not appear to be violated since the normal quantile plot is fairly linear, and the Shapior-Wilk test resulted in a large p-value (P=0.0501). Likewise, the equal variance assumption does not appear to be violated because the residuals by predicted plot did not show any fanning, and the heights of each stack of residuals were about the same. Since these three assumptions were met, we proceeded with an analysis of variance (ANOVA).

At a 5% level of significance, the whole model F-test was not statistically significant, with a large p-value (P=0.4298). Consequently, neither the interaction between liquid type and submersion time (P=0.8411) nor either main effect (P=0.0913 for LT, P=0.4305 for ST) was statistically significant. Since we did not find any significant results, we are unable to do a post-hoc analysis as the result will be that we fail to reject the null hypothesis.

Table 3.1: Mean (± SE) weight change (grams) for Submersion Time

	Mean	SE
12 hours	0.0012	0.0006
24 hours	0.0019	0.0006
36 hours	0.0022	0.0006

Table 3.2: Mean (± SE) weight change (grams) for Liquid Type

	Mean	SE
2% Milk	0.0021	0.0006
Coca-cola	0.0009	0.0006
Diet Coca-cola	0.0030	0.0006
Water	0.0010	0.0006

Table 3.3: Mean (± SE) weight change (grams) for Liquid Type * Submersion Time combinations

Liquid Type	Submersion Time (hr)	Mean	SE
2% Milk	12	0.0013	0.0011
2% Milk	24	0.0027	0.0011
2% Milk	36	0.0023	0.0011
Coca-cola	12	0.0003	0.0011
Coca-cola	24	0.0010	0.0011
Coca-cola	36	0.0013	0.0011
Diet Coca-cola	12	0.0020	0.0011
Diet Coca-cola	24	0.0040	0.0011
Diet Coca-cola	36	0.0030	0.0011
Water	12	0.0010	0.0011
Water	24	0	0.0011
Water	36	0.0020	0.0011

4. Conclusion

While there was evidence that nails weighed more on average after being submerged in liquid, there was not convincing evidence at the 5% significance level that either the type of liquid or the submersion time had an effect on the change in weight of the nails. However, while neither of the main effects were significant, the effect test for the type of liquid did have a much smaller p-value than that of submersion time. Therefore, although the type of liquid did not show convincing evidence of an effect on the weight of the nails, it did show much stronger evidence of an effect than that of submersion time. This means that a better experiment design could possibly lead to significant results, especially for the effect of type of liquid on the weight of the nails.

5. Next steps

One major issue of this experiment was the inaccuracy of the scale that was used for weighing the nails. The scale, which is primarily designed for baking measurements, displayed different weights based on what location the nail was resting on the scale. This was accounted for as best as possible by placing the nails in a similar location on the scale each time they were weighed, both before and after they were submerged in liquid. Another issue with this experiment was potential liquid residue on the nails when they were weighed post-submersion. While the nails were carefully dried with a paper towel each time before they were weighed, there is no guarantee that all the liquid was completely removed from every nail. These are likely sources of random error that were not accounted for in the analysis.

Although the results of this experiment were not significant, there was some evidence of a weak effect of liquid type on the nails' weight change. This is further supported by visual examination of the nails, since the nails submerged in Diet Coke and Coke had visible rust while those in water and 2% milk did not. Perhaps a better experiment would include longer submersion times that are greater lengths apart. This would likely increase the effect size and consequently the power of the significance tests, and strengthen the effect of the type of liquid on the change of weight of the nails. The same experiment with longer submersion times could also provide some evidence of an effect of submersion time on the change of weight, as well as a significant interaction effect between liquid type and submersion time.

An interesting follow-up experiment could use larger objects made out of a similar material as the nails, such as metal rods. An experiment such as this with a larger scale would be much more likely to provide significant results because the effect size would presumably be larger, which would increase the power of our significance tests. This could be important in the construction industry, where parts of the exteriors of some buildings are underwater, and the materials that are used need to last for decades.

References

- Johnson, Shannon. "What Household Liquids Make Steel Nails Rust?" *HomeSteady*, 17 July 2017, https://homesteady.com/13416243/what-household-liquids-make-steel-nails-rust. Accessed 4 February 2022.

- Papiewski, John. "What Chemicals Rust Metal Rapidly?" Sciencing, 29 Apr. 2019, https://sciencing.com/what-chemicals-rust-metal-rapidly-12731440.html. Accessed 24 February 2022.

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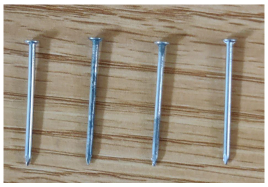
Appendix

- Milk, Coke, DietCoke, Water | 12hr

- Milk, Coke, DietCoke, Water | 24hr

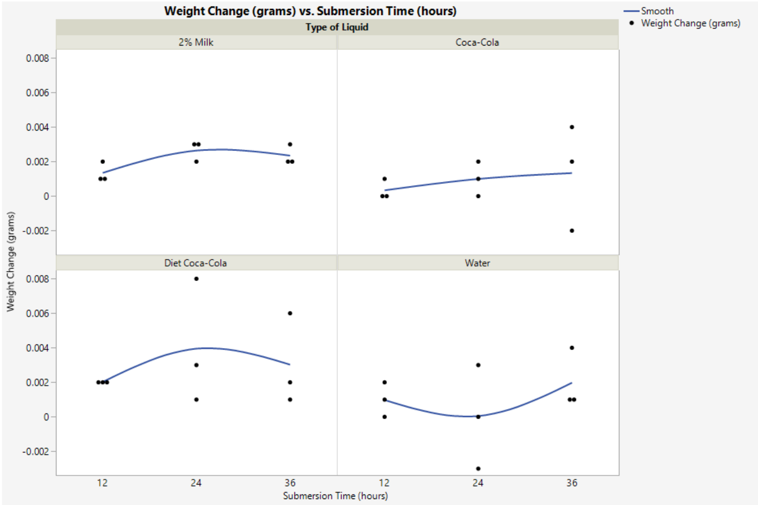


- Milk, Coke, DietCoke, Water | 36hr

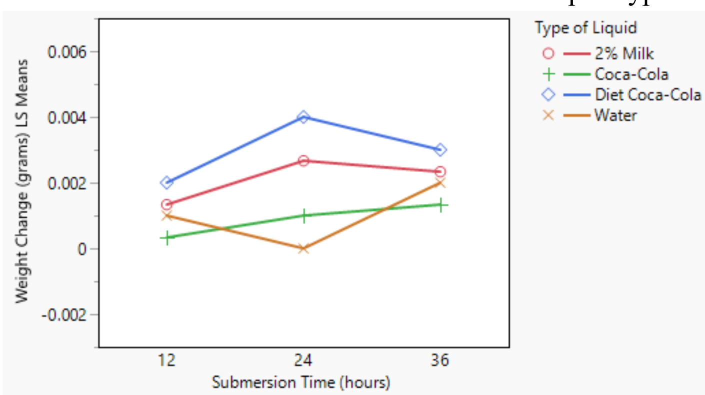
- Randomization Scheme

4/0 Cols 36/0	Pattern	Type of Liquid	Submersion Time	Change in Weight (g)
1	32	Coke	24 hr	•
2	42	Diet Coke	24 hr	•
3	23	2% Milk	48 hr	•
4	13	Water	48 hr	•
5	33	Coke	48 hr	•
6	22	2% Milk	24 hr	•
7	11	Water	12 hr	•
8	22	2% Milk	24 hr	•
9	23	2% Milk	48 hr	•
10	33	Coke	48 hr	•
11	12	Water	24 hr	•
12	42	Diet Coke	24 hr	•
13	13	Water	48 hr	•
14	21	2% Milk	12 hr	•
15	12	Water	24 hr	•
16	41	Diet Coke	12 hr	•
17	33	Coke	48 hr	•
18	22	2% Milk	24 hr	•
19	11	Water	12 hr	•
20	13	Water	48 hr	•
21	31	Coke	12 hr	•
22	41	Diet Coke	12 hr	•
23	42	Diet Coke	24 hr	•
24	41	Diet Coke	12 hr	•
25	31	Coke	12 hr	•
26	31	Coke	12 hr	•
27	43	Diet Coke	48 hr	•
28	21	2% Milk	12 hr	•
29	32	Coke	24 hr	•
30	12	Water	24 hr	•
31	43	Diet Coke	48 hr	•
32	23	2% Milk	48 hr	•
33	32	Coke	24 hr	•
34	11	Water	12 hr	•
35	21	2% Milk	12 hr	•
36	43	Diet Coke	48 hr	•

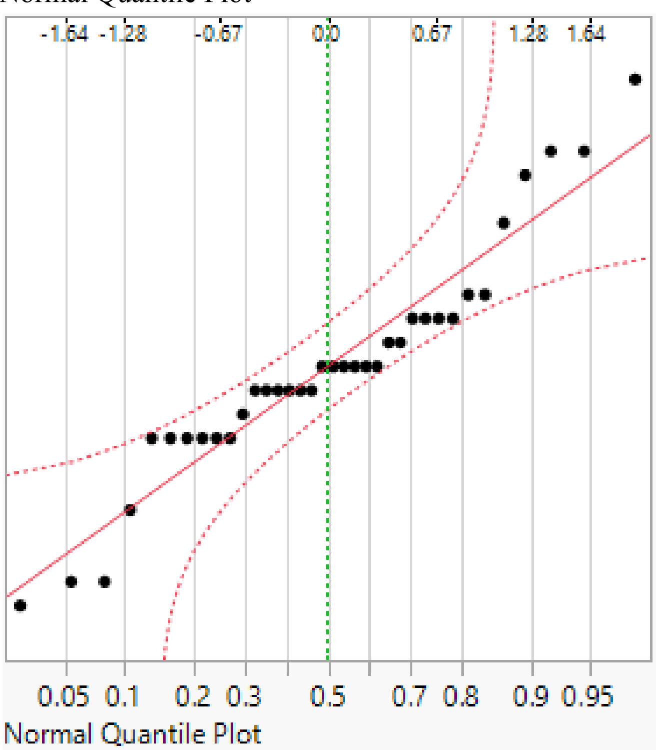
- Scatter plots showing how weight change changed with changes in submersion time depending on liquid type



- Interaction Plot between submersion time and liquid type on weight change



- Normal Quantile Plot

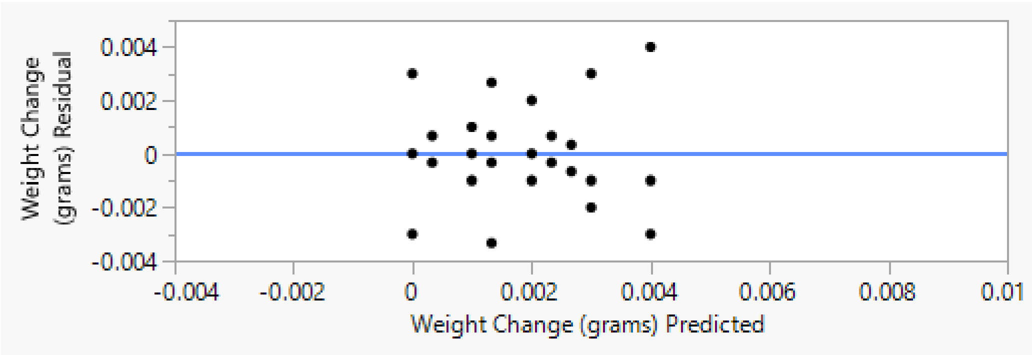


- Shapiro-Wilk Test

Goodness-of-Fit Test

	W	Prob<W
Shapiro-Wilk	0.9398022	0.0501

- Residuals by Predicted Plot



- ANOVA Table

Summary of Fit

RSquare	0.327056
RSquare Adj	0.018623
Root Mean Square Error	0.001929
Mean of Response	0.00175
Observations (or Sum Wgts)	36

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	11	0.00004342	3.947e-6	1.0604
Error	24	0.00008933	3.7222e-6	**Prob > F**
C. Total	35	0.00013275		0.4298

Parameter Estimates

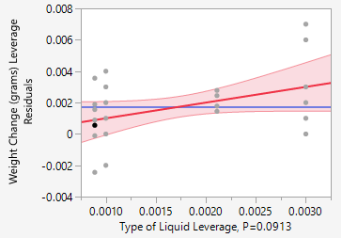
Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Type of Liquid	3	3	0.00002697	2.4154	0.0913
Submersion Time (hours)	2	2	0.00000650	0.8731	0.4305
Type of Liquid*Submersion Time (hours)	6	6	0.00000994	0.4453	0.8411

- Means and SE

Type of Liquid

Leverage Plot

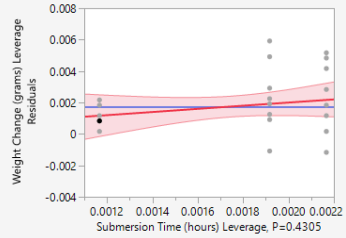


Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%	Mean
2% Milk	0.00211111	0.00064310	0.0007838	0.00343841	0.002111
Coca-Cola	0.00088889	0.00064310	-0.0004384	0.00221619	0.000889
Diet Coca-Cola	0.00300000	0.00064310	0.0016727	0.00432730	0.003000
Water	0.00100000	0.00064310	-0.0003273	0.00232730	0.001000

Submersion Time (hours)

Leverage Plot

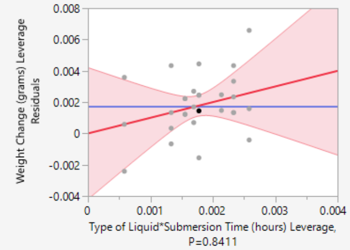


Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%	Mean
12	0.00116667	0.00055694	0.00001719	0.00231614	0.001167
24	0.00191667	0.00055694	0.00076719	0.00306614	0.001917
36	0.00216667	0.00055694	0.00101719	0.00331614	0.002167

Type of Liquid*Submersion Time (hours)

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Lower 95%	Upper 95%
2% Milk,12	0.0013333	0.00111389	-0.0009656	0.00363228
2% Milk,24	0.0026667	0.00111389	0.0003677	0.00496561
2% Milk,36	0.0023333	0.00111389	0.0000344	0.00463228
Coca-Cola,12	0.0003333	0.00111389	-0.0019656	0.00263228
Coca-Cola,24	0.0010000	0.00111389	-0.0012989	0.00329895
Coca-Cola,36	0.0013333	0.00111389	-0.0009656	0.00363228
Diet Coca-Cola,12	0.0020000	0.00111389	-0.0002989	0.00429895
Diet Coca-Cola,24	0.0040000	0.00111389	0.0017011	0.00629895
Diet Coca-Cola,36	0.0030000	0.00111389	0.0007011	0.00529895
Water,12	0.0010000	0.00111389	-0.0012989	0.00329895
Water,24	-2.168e-19	0.00111389	-0.0022989	0.00229895
Water,36	0.0020000	0.00111389	-0.0002989	0.00429895