Impact of Caffeinated and Caffeine-Free Beverages on the Problem Solving Skills of A Virtual Population

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Caffeine is the most popular psychoactive substance in the world, particularly due to its widely known stimulating effects. As a stimulant, caffeine has mostly commonly been used to increase mental alertness, which is why the goal of our study is to determine if there is an association between caffeine use and problem solving skills. We collected data using The Islands, a virtual population for conducting experiments. After collecting a sample of 150 virtual participants and splitting them into three age groups, either 250 mL of water, an energy drink, coffee or caffeine-free versions of the latter two were administered to each participant. Using a balanced one-way ANOVA, we found that [summary of key findings]. [brief overview of result implications, improvments needed].

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#TODO: - Fix label references - choose proper model (one way or two way?)

1 Introduction

As the world's most popular psychoactive substance, caffeine's widely known effects have been studied extensively. Despite certain drawbacks like digestion and anxiety issues in some people, due to being a stimulant, it has most commonly been used to temporarily increase mental alertness which improves things like memory and lessens fatigue, thus providing an energy boost.

In this study, we are analyzing whether there is an association between caffeine use and problem solving skills by giving coffee, energy drinks, and caffeine-free versions of both to participants from the The Islands, a virtual population developed by the University of Queensland for learning and teaching in statistics. Our sample was split into three age groups: 18-35, 36-54, and 55+. Considering the effects of caffeine, participants assigned a caffeinated drink would be expected to achieve a higher score that those that are not.

We aim to study the following research questions:

- RQ1: Does beverage type have an impact on problem solving score?
  - Null hypothesis: no association between beverage type and problem solving score.
  - Alternate hypothesis: association between beverage type and problem solving score exists.
- RQ2: Is there an association between the age group the participant belongs to, and the beverage type, on their problem solving scores.
  - Null hypothesis: no association between age group and beverage type on problem solving score.
  - Alternate hypothesis: association between age group and beverage type on problem solving score exists.
- RQ3: Do caffeinated coffee and energy drinks have a higher impact on problem solving scores compared to their caffeine-free counterparts?
  - Null hypothesis: no association between caffeinated drinks and higher score
  - Alternate hypothesis: association between caffeinated drinks and higher score exists.

This paper consist of our methodology, analysis, results, limitations, and a conclusion for our study.

2 Methodology

In February 2025, we conducted an experiment to determine if different caffeinated and caffeine-free drinks effect the problem solving skills of virtual participants on The Islands. Our experiment utilized a balanced one-way ANOVA design. The factor was the drink given to each participant and the response variable was a participant's score on a twenty minute problem solving test.

In an effort to maintain some degree of controlling, we selected all participants from the same town in The Islands called Nidoma. However, because there were not many significant factors that could easily be controlled, we opted to primarily use blocking. The participants were blocked into three age groups, with each age group receiving an equal amount of each treatment. To help account for factors that could not be controlled or blocked, we randomly assigned treatments among the participants using an R script (see appendix).

Our participant sample included 150 participants ($n = 150$), with 50 in each of the following age blocks: 18-35, 36-54, and 55+. Each participant was given one of five 250 millilitre drinks: Water (Control), Energy Drink, Energy Drink Decaffeinated, Coffee, or Coffee Decaffeinated. There were a total of 30 participants per treatment factor, with 10 in each age group, thereby replicating and ensuring a balanced design. After each participant was given their drink, a twenty minute problem solving test was administered with their scores record from 0 to 100. Since each participant was exposed to only one treatment and randomly assigned to a treatment group, this experiment utilized a between-subjects design.

3 Analysis

3.1 Summary Statistics and Checking Assumptions

We began by summarizing statistics of our data, presented in Table 1. The high mean and median indicate that participants generally scored well on the problem solving test. Additionally, the low standard deviation and IQR indicate that the scores were tightly clustered around the mean with little variation. The minimum of 67, which lies well outside of $1.5 \times$ IQR, indicates the presence of outliers, the amount of which would need further inspection to be determined. Since the maximum of 100 lies within $1.5 \times$ IQR, we can determine that any outliers present are on the lower side.

Table 1: Summary of Problem Solving Test Scores

	Min	Max	Mean	Median	SD	IQR
Value	67	100	93.4867	96	6.9618	6.75

Further preliminary information can be gained upon graphing the scores using box plots in Figure 1.

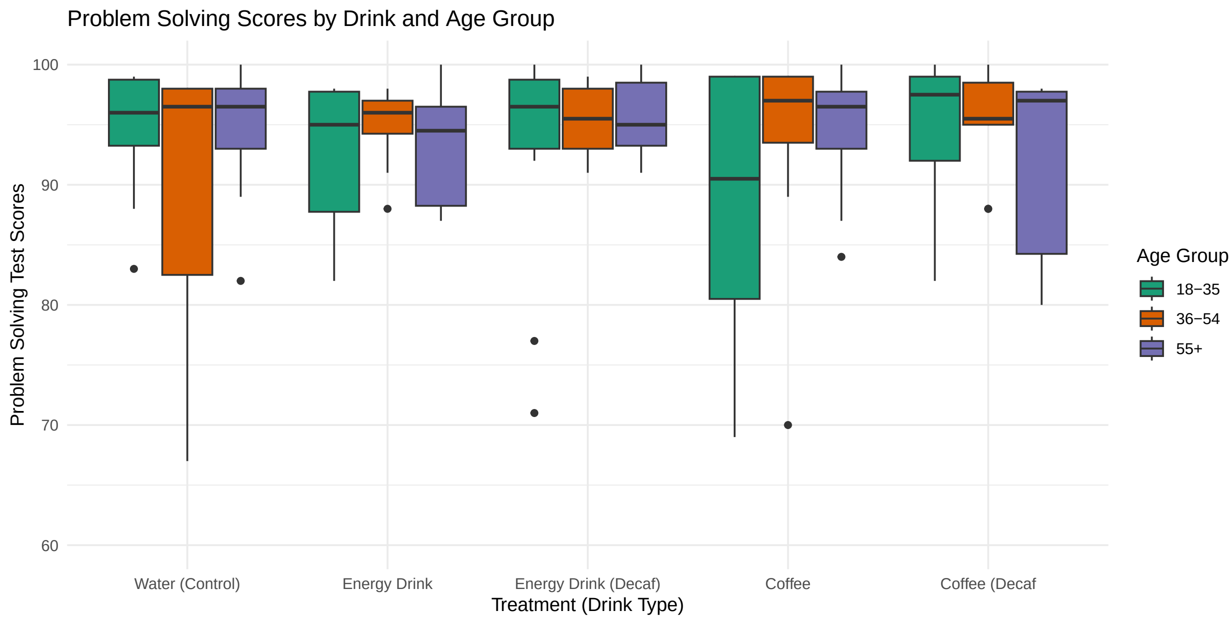

Figure 1: Box Plot Showing Problem Solving Scores by Drink and Age Group

Before proceeding with planning analysis, we must check the three assumptions for a one-way ANOVA: independence, normally distributed, and equal variance.

For our tests we decided to do a one-factor test (with just the treatments as a factor) and a two-factor test (with the blocking factor of age also added as a factor). For both tests, we found that the assumptions of homogeneity of variance and, in particular, normality of residuals were violated.

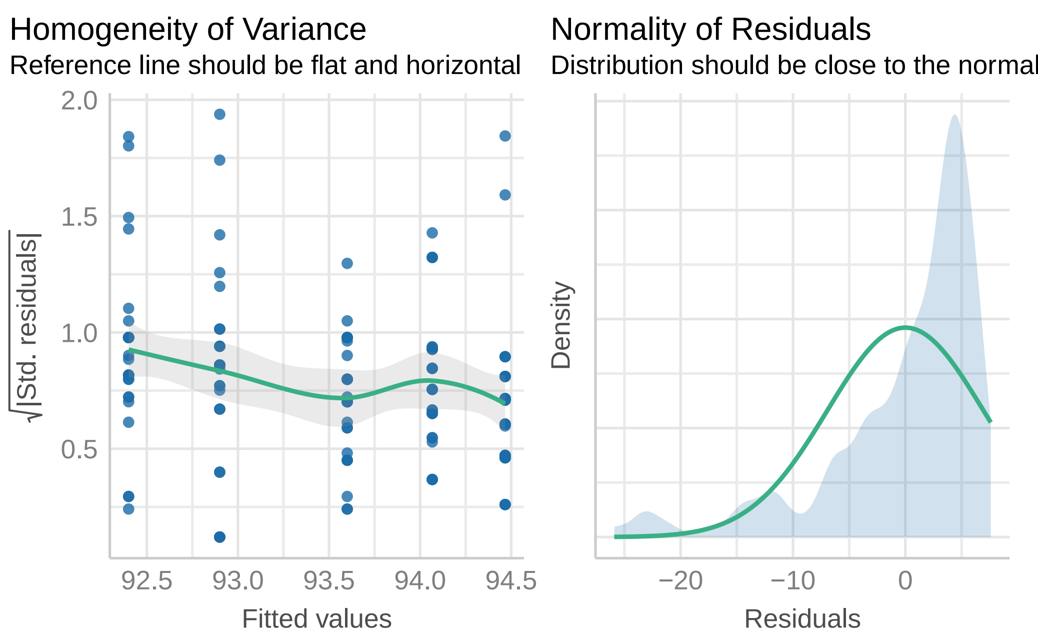

Figure 2

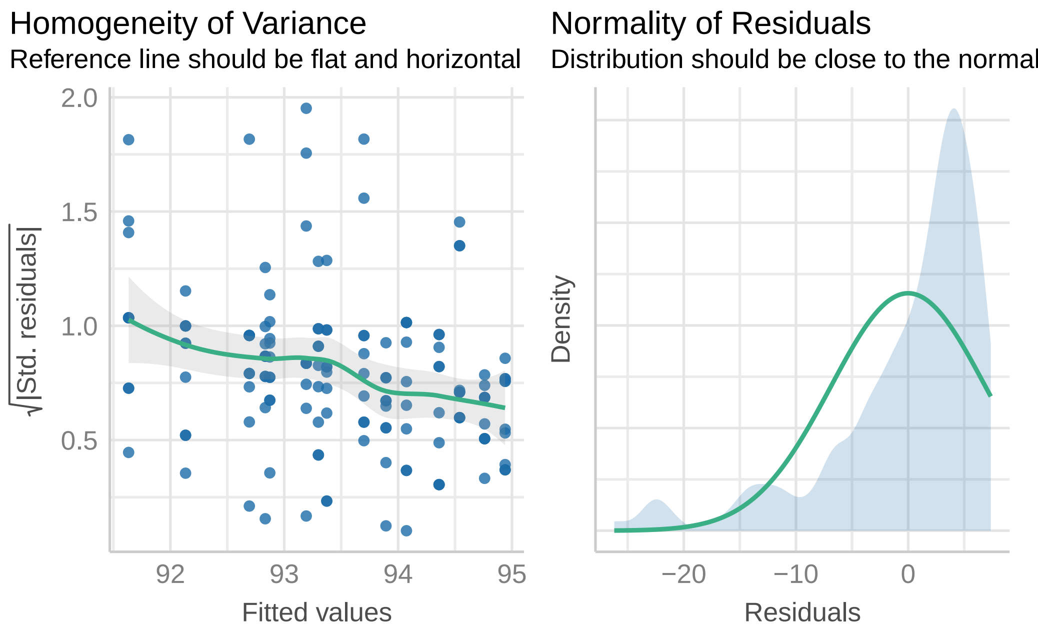

Figure 3

3.2 Statistical Tests

Due to the violations of the normality and equal variance assumptions, we use a non-parametric one-way ANOVA method.

4 Results

5 Limitations

- Talk about how administering problem solving right after treatment could affect results?

Despite the depth provided by The Islands for conducting an experiment, using a virtual population is a major limitation in assessing the impact of caffeine on the problem solving skills of real people. This is because it does not take all of the countless real life factors that impact caffeine into account. Meaning, our experiment may not be incredibly relevant to the real world. Furthermore, we did not wait after giving each participant their beverage. Waiting would have allowed for more absorption of caffeine and therefore a better look into its impact.

6 Conclusion

This study aimed to examine the potential association between caffeine consumption through various beverages and problem-solving performance scores among virtual participants in The Islands. Analysis from a sample of 150 participants showed [include key findings.]

7 Appendix

```r
# Install necessary libraries
packages <- c("tidyverse", "patchwork", "performance", "knitr")
for(pkg in packages) {
  if (!requireNamespace(pkg, quietly = TRUE)) {
    install.packages(pkg)
  }
}

# Load libraries
library(tidyverse)
library(patchwork)
library(performance)
library(knitr)

# Load data, cleaned_data.csv
# data <- read.csv("cleaned_data.csv", header = TRUE)
data <-read.csv(file.choose())

# Set factor levels to display in desired order
data$age_group <- factor(data$age_group,
                         levels = c("Y", "M", "O"),
                         labels = c("18-35", "36-54", "55+"))
data$treatment <- factor(data$treatment,
                         levels = c("W", "E", "ED", "C", "CD"),
                         labels = c("Water (Control)", "Energy Drink",
                                    "Energy Drink (Decaf)", "Coffee",
                                    "Coffee (Decaf)"))
attach(data)

# Table 1: Summary of Problem Solving Test Scores
sum_data <- data.frame(Value = c(min(score), max(score), round(mean(score), 4),
                                 median(score), round(sd(score), 4), IQR(score)))
labs <- c("Min", "Max", "Mean", "Median", "SD", "IQR")
kable(t(sum_data), col.names = labs, align = "c",
      caption = "Summary of Problem Solving Test Scores")

# Figure 1: Problem Solving By Drink and Age Group
tr <- c("Water (Control)", "Energy Drink", "Energy Drink (Decaf)", "Coffee",
        "Coffee (Decaf")
age <- c("18-35", "36-54", "55+")
ggplot(data, aes(x = treatment, y = score, fill = age_group)) +
  geom_boxplot(position = position_dodge(width = 0.8)) +
  scale_x_discrete(labels = tr) +
  scale_y_continuous(limits = c(60, 100)) +
  labs(title = "Problem Solving Scores by Drink and Age Group",
       x = "Treatment (Drink Type)", y = "Problem Solving Test Scores",
       fill = "Age Group") +
```

```
  scale_fill_brewer(palette = "Dark2", breaks = age, labels = age) +
  theme_minimal()

# Figure 2, 3: Normality and Variance Homogeneity Graphs
# for one and two factor ANOVA
one_factor_model <- aov(score ~ data$treatment, data = data)
check_model(one_factor_model, check = c("normality", "homogeneity"))

two_factor_model <- aov(score ~ data$treatment + data$age_group, data = data)
check_model(two_factor_model, check = c("normality", "homogeneity"))

# Print results of assumption checks:
# 1. Check normality of residuals for the one-factor model
normality_results1 <- check_normality(one_factor_model)
print(normality_results1)

# 2. Check homogeneity of variances for the one-factor model
hetero_results1 <- check_heteroscedasticity(one_factor_model)
print(hetero_results1)

# 1. Check normality of residuals for the one-factor model again
normality_results2 <- check_normality(one_factor_model)
print(normality_results2)

# 2. Check homogeneity of variances for the two-factor model
hetero_results2 <- check_heteroscedasticity(two_factor_model)
print(hetero_results2)
```