101B Final Project: Optimizing Memory Retention: Evaluating Cognitive Strategies in Humans

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Abstract

This paper investigates the effectiveness of physical exercise and caffeine consumption on human memory retention. We conducted a randomized block experiment with 108 participants randomly recruited from the University of Arcadia, Providence. Each participant's memorization ability was tested using a standardized task both before and after receiving one of the three treatments. To control for confounding variables, participants were grouped by weight and gender, and treatments were randomly assigned within each block, resulting in a three-factor randomized block experiment. A statistical analysis was performed using an analysis of variance (ANOVA) to assess the main effects of each treatment. Additionally, we ran Tukey's HSD test to identify the most effective combinations for improving memory. The results indicate that caffeine has a significant effect on memory retention, of the energy drink was most influential. On the other hand, we found that there is no significant evidence that exercise has a significant effect on memory retention and that there is no significant interaction between caffeine and exercise type. While this research has its limitations, it contributes to the growing body of research on non-medicated approaches to cognitive enhancement and has implications for educational settings, workplaces, and public health interventions.

Introduction

As college students, we often turn to various sources of caffeine and incorporate different forms of exercise in order to maximize our study to improve retention of course material. Therefore, this study aims to identify effective methods for enhancing memory retention. In exploring potential strategies, several studies supported the findings of Sherman, Buckley, Baena, and Ryan (2016), who reported that caffeine enhances memory performance in young adults[1]. Additionally, research by Zuniga, Mueller, Santana, and Kelemen (2019) found that exercise can improve recall at both light and high intensities[2]. Naturally, this led to the question of whether caffeine and exercise together have a measurable effect on memory recall. As a result, this study focuses on whether caffeine and exercise influence memory retention in students at the University of Arcadia, located in the town of Arcadia on the island of Providence.

Design of the experiment

This experiment is a randomized block design with a 3x3 factorial design. To control for potential confounding variables, the experiment included two nuisance factors: weight (above or below the median) and gender (male or female). These were broken into four groups. There were two factors, each with three levels of treatment: caffeine (250 mL of tea, coffee, or energy drink) and exercise (5 minutes of light jogging, 5 minutes of stretching and holding, or a 30-minute relaxing walk outdoors). As for the response variable, the study focused on the difference in Memory Test Vocabulary Score before and after the treatment. There was also a 15-minute period taken to ensure that caffeine had been absorbed before the second memory test.

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[1] Sherman, S. M., Buckley, T. P., Baena, E., & Ryan, L. (2016). Caffeine Enhances Memory Performance in Young Adults during Their Non-optimal Time of Day. *Frontiers in psychology*, *7*, 1764. https://doi.org/10.3389/fpsyg.2016.01764

[2] Zuniga, K. E., Mueller, M., Santana, A. R., & Kelemen, W. L. (2019). Acute aerobic exercise improves memory across intensity and fitness levels. *Memory*, *27*(5), 628–636. https://doi.org/10.1080/09658211.2018.1546875

To find the total sample size of the experiment, we conducted a power analysis test. This involved identifying the maximum difference among treatment means (d=1.074) and calculating the effect size using the formula $f = d/\sqrt{MS_{\text{Residual}}}$, which yielded an effect size of f=0.4902117. With k=3×3=9 treatment combinations, a significance level of 0.05, and a desired power of 0.95, we ran the analysis in R. As shown in the figure below, the R output indicated a required sample size of 11.41 per treatment group, which we rounded up to 12. Therefore, the total number of participants needed for the experiment is 12×9=108 students.

```
     Balanced one-way analysis of variance power calculation

              k = 9
              n = 11.41035
              f = 0.4902117
      sig.level = 0.05
          power = 0.95

NOTE: n is number in each group
```

As for the methodology, we randomly selected a sample of 108 students from the University of Arcadia. If a selected islander declined to participate in the study, another individual was randomly selected as a replacement. Then we recorded each participant's weight and gender, and blocked participants based on weight and gender. Within each block, the participants were then randomly assigned 1 caffeine type and 1 exercise type. We administered a standardized memory test (Memory Test Vocabulary), which was scored out of 20, to all participants before treatment. Then the participants were given an exercise, immediately followed by caffeine. After waiting for 15 minutes for the caffeine to kick in, we conducted a post-memory test and calculated the difference between pre-treatment and post-treatment scores for analysis.

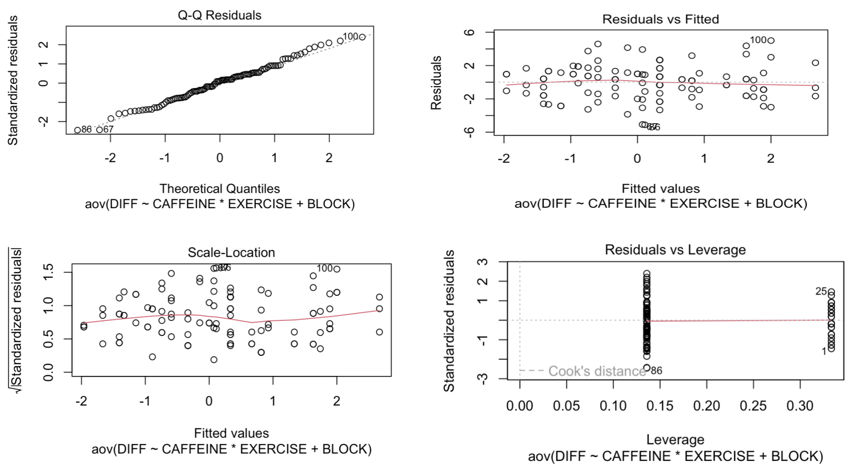
name <chr>	block <chr>	exercise <chr>	caffeine <chr>	diff <int>
Arya Kaur	Weight LOW FEMALE	Light Jogging	Coffee	-4
Lyn Marshall	Weight LOW FEMALE	Light Jogging	Coffee	0
Hanima Kulkarni	Weight LOW FEMALE	Light Jogging	Coffee	0
Karen Carlsen	Weight LOW FEMALE	Stretching and Holding	Coffee	1
Pernille Svendsen	Weight LOW FEMALE	Stretching and Holding	Coffee	-2
Nanami Connolly	Weight LOW FEMALE	Stretching and Holding	Coffee	1
Jeneve Eklund	Weight LOW FEMALE	Relaxing Walk Outdoors	Coffee	1
Juliette Lavigne	Weight LOW FEMALE	Relaxing Walk Outdoors	Coffee	1
Megumi Maeda	Weight LOW FEMALE	Relaxing Walk Outdoors	Coffee	0
Mariko Endo	Weight LOW FEMALE	Light Jogging	Tea	-2

Results and interpretation

We analyzed the model: $\mathbf{y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \delta_k + \varepsilon_{ijk}}$, where τ_i represents the effect of the i^{th} level of caffeine treatment, β_j the effect of the j^{th} level of exercise, $(\tau\beta)_{ij}$ the interaction effect between caffeine and exercise, δ_k the block effect, and ε_{ijk} the random error. With a hypothesis test consisting of

- The main effect of caffeine (factor A)
    - H_0: $\tau_1 = \tau_2 = \tau_3 = 0$
    - H_1: $\tau_i \neq 0$ for at least one $i \in \{1,2,3\}$
- The main effect of exercise (factor B)
    - H_0: $\beta_1 = \beta_2 = \beta_3 = 0$
    - H_1: $\beta_j \neq 0$ for at least one $i \in \{1,2,3\}$
- The interaction effect (caffeine × exercise)
    - H_0: $(\tau\beta)_{ij} = 0$ for all i and j
    - H_1: $(\tau\beta)_{ij} \neq 0$ for at least one $i \in \{1,2,3\}$

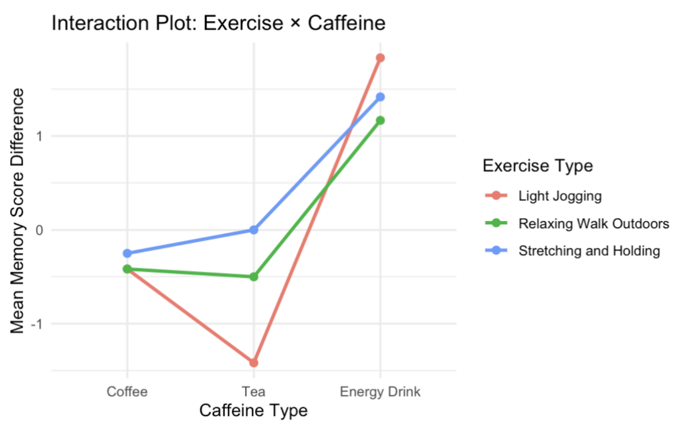
The normal Q-Q plot below indicates that the normality assumption is met, as the points closely follow the theoretical linear trend. Additionally, the linearity assumption is met by the residuals vs. fitted plot shown below, which exhibits a random scatter of points around the horizontal axis with relatively constant variability and a relatively horizontal line across the plot. Furthermore, the plot of standardized residuals squared vs. fitted values displays a horizontal pattern with an average error near zero, confirming the assumption that $\varepsilon \sim N(0,\sigma^2)$. Lastly, while inspecting the residuals vs leverage plot, we can assume that the few outliers that fall outside of the (-2,2) standardized residual range would not significantly hinder the predictability of our model, as the data points are all within the Cook's Distance. Therefore, overall, the plots below imply that the key assumptions of linear regression are reasonably met.



Running the Analysis of Variance (ANOVA), we get the following result:

```
                  Df Sum Sq Mean Sq F value   Pr(>F)    
caffeine           2   94.7   47.37   9.873 0.000126 ***
exercise           2    3.0    1.51   0.315 0.730852    
block              3   17.7    5.89   1.227 0.304269    
caffeine:exercise  4   12.3    3.08   0.642 0.634064    
Residuals         96  460.6    4.80                     
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Interaction plot shows:



From the plot above, we can infer that there is no interaction between caffeine type and exercise - lines are roughly parallel ($p=0.634$) for interaction. Additionally, energy drinks seem to show the highest mean memory score difference across all exercise types. Moreover, running Tukey's HSD, a type of post-hoc test, we get the following result:

```
$CAFFEINE
                                              diff        lwr        upr     p adj
Energy Drink-Coffee                      1.8888889  0.1079171  3.6698607 0.0310643
Light Jogging-Coffee                     0.2962963 -2.2223781  2.8149707 0.9993552
Relaxing Walk Outdoors-Coffee            0.8518519 -1.6668226  3.3705263 0.9214486
Stretching and Holding-Coffee            0.9629630 -1.5557115  3.4816374 0.8743993
Tea-Coffee                              -0.3333333 -2.1143051  1.4476384 0.9940741
Light Jogging-Energy Drink              -1.5925926 -4.1112670  0.9260819 0.4445415
Relaxing Walk Outdoors-Energy Drink     -1.0370370 -3.5557115  1.4816374 0.8359299
Stretching and Holding-Energy Drink     -0.9259259 -3.4446004  1.5927485 0.8915323
Tea-Energy Drink                        -2.2222222 -4.0031940 -0.4412504 0.0060368
Relaxing Walk Outdoors-Light Jogging     0.5555556 -2.5291781  3.6402892 0.9950492
Stretching and Holding-Light Jogging     0.6666667 -2.4180669  3.7514003 0.9885030
Tea-Light Jogging                       -0.6296296 -3.1483041  1.8890448 0.9779253
Stretching and Holding-Relaxing Walk Outdoors  0.1111111 -2.9736225  3.1958447 0.9999982
Tea-Relaxing Walk Outdoors              -1.1851852 -3.7038596  1.3334893 0.7441038
Tea-Stretching and Holding              -1.2962963 -3.8149707  1.2223781 0.6654948
```

Discussion

After completing the randomized block design with a 3x3 factorial design with 2 blocking factors, the results suggest that caffeine has a significant effect on memory retention with a p-value of approximately 0.001. Specifically, amongst the 3 different caffeine treatments, the energy drink seemed to show the highest mean memory score difference. However, exercise did not seem to be a significant factor in affecting memory retention, as it had a high p-value of approximately 0.731. In addition, there was no clear evidence of interaction between caffeine and exercise. Subsequently, the post-hoc test gave a similar result, as it suggested that coffee and energy drinks had a significant effect on memory retention. Moreover, it also concluded that exercise (all three treatments) did not have a significant effect on memory retention. The results of our experiment came in parallel with other published experiments. The National Library of Medicine conducted a similar study of the effects of caffeine on memory enhancement in college students[3]. They similarly found that caffeine enhanced memory in young adults. In addition, the International Journal of Exercise Science conducted a study and found that there was no significant difference in recall ability across exercise in the form of cycling and memorization[4].

In terms of limitations, one was the inconsistent time of day for consent and treatment. With the islanders' website set in real-time, the time at which we collected data across all the islanders was different, and this could have potentially affected their performance in memory retention. Another limitation we experienced was that we did not check the islanders' stress levels and the amount of sleep they had the night before. Without accounting for these nuisance factors, this could have resulted in a discrepancy in our data collection. Lastly, another limitation we experienced was the sample size constraint. As our experiment had only 108 participants (based on the power-analysis test), this could have limited our ability to detect real effects and caused greater variability. While combined with multiple other studies from several different samples, we may be able to conclude about the effect of caffeine and exercise on the entire student population. With our limited sample, we can only conclude within the scope of students at the University of Arcadia on the island of Providence. For future references, further improvements could be made to our experiment with an increase in resources. With such an increase, we would have been able to collect more data, therefore increasing the sample size, which would have reduced variability and improved generalizability. Furthermore, we would have helped achieve more sophisticated data

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[3] Sherman, S. M., Buckley, T. P., Baena, E., & Ryan, L. (2016). Caffeine Enhances Memory Performance in Young Adults during Their Non-optimal Time of Day. *Frontiers in psychology*, *7*, 1764. https://doi.org/10.3389/fpsyg.2016.01764

[4] Zabriskie, H. A., & Heath, E. M. (2019). Effectiveness of studying when coupled with exercise-induced arousal. International Journal of Exercise Science, 12(5), 764–773. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6719811/

collection, recording for additional confounding variables such as hours of sleep, mood, and other sources of caffeine.