# Assignment 4 - Factorial Experiment Design*

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2025-04-10

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*Code available at: [https://github.com/eeeee-cmd/Factorial-Experiment-Design/].

# 1 Description of the design

## 1.1 Objective

This experiment aims to evaluate how different study methods (Active Recall vs. Passive Reading), environmental conditions (Quiet vs. Noisy), and study duration (Short vs. Long) affect learning performance, measured by scores. By implementing a structured factorial design, we ensure that all individual and potential interactions between the factors are examined systematically.

## 1.2 Factorial Experiment Design

This experiment design utilizes a full factorial $2^3$ experimental design (three factors each two levels):

1. `Method` (Active Recall vs. Passive Reading)
2. `Environment` (Quiet vs. Noisy)
3. `Time` (Short vs. Long)

`Test scores` (0–100) is the response variable, quantifying learning retention and application.

Since there are 3 factors with 2 levels, a full factorial design results in 8 unique conditions. To reduce variability and improve statistical reliability, this experiment replicates each combination of the factors 5 times. All possible factor-level combinations are included multiple times, making this a replicated full factorial design. This design captures not only the individual impact of each factor but also how they interact with each other.

To conduct this factorial experiment, we first collected data from university students fitting one of the eight combinations in this $2^3$ factorial design using a short survey. The survey asked participants to self-report their typical study method (Active Recall or Passive Reading), usual study environment (Quiet or Noisy), and average study duration before a recent test (Short or Long). Additionally, students provided their most recent test score where they applied that study pattern.

To complete the design with five replicates per condition, we simulated additional data points for each combination based on the observed scores, maintaining reasonable variation and patterns consistent with the original data. We used these initial eight scores to estimate reasonable means and then generated additional scores using normally distributed random values with a standard deviation of 2. This approach allowed us to create a balanced dataset of 40 observations while preserving the structure of a replicated factorial experiment. Although part of the dataset is simulated, the analysis reflects how the design and interpretation would proceed in a real experimental setting.

## 1.3 Expected Outcomes

This factorial experiment aims to gain a deeper understanding of how different study strategies and environmental conditions influence learning performance. Specifically, understanding whether Active Recall leads to higher scores than Passive Reading, how a noisy environment affects learning outcomes, and whether longer study duration significantly improve performance. Additionally, we hope to identify interactions between these factors, such as whether Active Recall mitigates the negative effects of noise or if longer study time benefits one method more than the other. Ultimately, the goal is to help optimize study strategies for better learning outcomes.

## 2 Analysis of the data

Three way ANOVA results for the effects of study method, environment, time, and their interactions on test scores. All of the main effects are statistical significance ($\alpha = 0.05$) such that the study duration `Time` (F = 492.595) has the largest effect, which means longer study duration greatly improves the grade. The main effect of `Method` (F = 23.252) and `Environment` (F = 86.807) are also substantial, which means that active study is generally more effective than passive reading and a quiet environment enhances performance.

The two-way interactions of Method with Environment (F = 5.010, p = 0.0323) and Method with Time (F = 4.497, p = 0.0418) suggest that the study method slightly depends on the study environment and duration. However, the interaction between Environment and Time (F = 1.084, p = 0.3055) is not significant, so that we cannot conclude the effect of study time depend on the study environment.

The three-way interaction (F = 10.674, p = 0.0026) shows that the impact of study method on performance varies depending on both the study environment and duration, with active recall showing the greatest advantage in quiet, long study sessions compared to noisy or short ones. Overall, these results highlight the importance of both study strategy and environmental conditions in optimizing learning.

Table 1: Three way ANOVA results for the effects of study method, environment, time, and their interactions on test scores.

| | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| Method | 1 | 118.1 | 118.06 | 23.252 | 0.000 |
| Environment | 1 | 440.8 | 440.76 | 86.807 | 0.000 |
| Time | 1 | 2501.1 | 2501.14 | 492.595 | 0.000 |
| Method:Environment | 1 | 25.4 | 25.44 | 5.010 | 0.032 |
| Method:Time | 1 | 22.8 | 22.83 | 4.497 | 0.042 |
| Environment:Time | 1 | 5.5 | 5.51 | 1.084 | 0.306 |
| Method:Environment:Time | 1 | 54.2 | 54.20 | 10.674 | 0.003 |
| Residuals | 32 | 162.5 | 5.08 | NA | NA |

The model has strong explanatory power such that 95.12% of the variation in the response variable (`score`) being explained by all the factors and their interactions. The adjusted R-squared tells 94.05% of the variance in the outcome is explained by significant predictors. The Method, Environment, and Time factors all have highly significant main effects, and the three-way interaction between these factors is also significant.

Table 2: Confidence Intervals for true values of effects

| | 2.5 % | 97.5 % |
|---|---|---|
| (Intercept) | 68.86 | 70.31 |
| Method | 0.99 | 2.44 |
| Environment | 2.59 | 4.05 |
| Time | 7.18 | 8.63 |
| Method:Environment | 0.07 | 1.52 |
| Method:Time | 0.03 | 1.48 |
| Environment:Time | -0.35 | 1.10 |
| Method:Environment:Time | 0.44 | 1.89 |

Figure 1 displays the absolute effects of various factors and their interactions from a test score study, allowing us to assess which effects are most significant. The main effects (Time, Environment, Method) are more influential than their interactions in this study. Time is the dominant factor affecting test scores. While interaction effects exist, they are relatively small compared to the main effects. The study might benefit from focusing more on the individual factors rather than their complex interactions

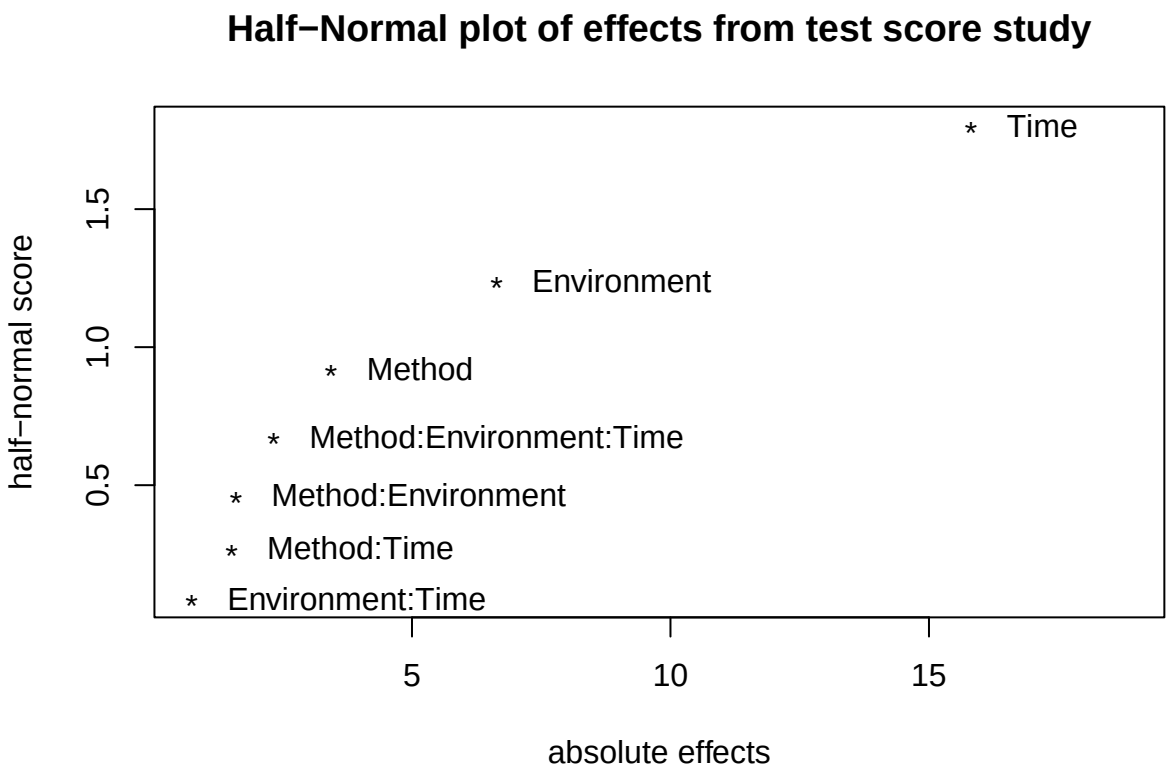


Figure 1: Half-Normal plot of effects from test score study. Points that lie furthest from the origin(`time`) represent the most influential factors in predicting test performance. Interaction terms like Method:Environment:Time and Method:Environment also show some effects, whereas Environment:Time has the smallest contribution. The plot helps visually distinguish significant effects from those likely due to random variation.

## 3 Conclusion

This factorial experiment demonstrated that study method, environment, and study duration significantly influence learning outcomes. The study duration had the most positive effect on test scores, suggesting that longer study sessions lead to better performance. Quiet environments and active recall strategies also contributed positively to learning outcomes. The two-way interaction between Method and Environment as well as the interaction between Method and Time was statistically significant, suggesting that the effectiveness of active recall depends on context. In addition, the three-way interaction was also significant, suggesting that active recall works best during long, quiet study sessions.

Overall, these findings support the adoption of active recall techniques in quiet settings with sufficient study durations. Despite the interaction effects, the main takeaway is the dominant role of individual factors, especially time, in shaping academic performance. This analysis offers practical recommendations for students to improve study effectiveness through intentional choices in strategy, setting, and time management.