Effects of Different Pain Relievers and Dosages on Cognitive Retention

Exploratory Data Analysis (EDA)

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Painkillers are commonly used to manage pain, but their effects extend beyond physical relief. While they provide immediate physical comfort, their impact on cognitive performance is often overlooked. This study explores how different painkillers and dosages influence cognitive function. Using simulated testing, participants were randomly assigned a treatment (drug type and dosage) while controlling for variables such as age. Our findings indicate no significant relationship between drug type, dosage, and overall cognitive performance post-treatment. However, we observed some correlation between certain drug-dosage combinations and memory improvement, suggesting a potential area for further research. While the results were not statistically significant, this study contributes to a deeper understanding of the cognitive effects of painkillers and highlights the need for further investigation into their potential impact on memory and cognition.

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1 Acknowledgements

We extend our gratitude to the academic community for their contributions to this research.No auto-complete tools such as co-pilot were used in the course of this project, however, Language Learning Model ChatGPT was used while writing this paper. It was used for the purpose of code debugging, understanding models, and knowledge of certain topics, which we were not aware of. The chat with the AI bot is also attached as a reference under Section 6

2 Introduction

2.1 Relevant Background

Pain can make everyday tasks harder, particularly when mental focus and clarity are required. Common pain relievers like Aspirin, Paracetamol, and Tramadol are often used to reduce physical discomfort, but their impact on cognitive functions is not well understood. Recalling information, a task that demands mental effort, becomes more difficult when we're in pain. This study investigates how different pain relievers (Aspirin, Paracetamol, and Tramadol) at standard dosages affect memory performance. It also looks at how varying dosages of each drug influence memory function. Since the ability to recall information is essential in many situations, understanding how pain relief might impact cognitive performance is important for managing pain without affecting productivity.

2.2 Research Questions

1. *How does the type of pain reliever (Aspirin 500 mg, Paracetamol 500 mg, Tramadol 50 mg, and Placebo) affect cognitive task performance?*

2. *How does the dosage (low vs. high) of each drug affect cognitive retention, while accounting for confounding factors like age?*

2.3 Study Design

This study involves 2 factors, pain reliever type (4 levels) and dosage(2 levels). Crossing them provides us with *8 treatment groups*, with **30 participants** assigned to each. The groups are as follows:

1. Aspirin 500 mg (Low)
2. Aspirin 1000 mg (High)
3. Paracetamol 500 mg (Low)
4. Paracetamol 1000 mg (High)
5. Tramadol 50 mg (Low)
6. Tramadol 100 mg (High)
7. Placebo (Low)
8. Placebo (High)

This results in **240 total observations** ($8 \times 30 = 240$).

2.4 Confounding Variable: Age

To reduce bias, we consider to control the experiment by controlling participant ages to be 18+. Hence in this study **age** acts as a **confounding variable**. Participants will be categorized into three groups evenly to prevent bias created through age. The groups are as follows:

1. 18–34 years
2. 35–50 years
3. 50+ years

2.5 Quantitative and Qualitative Variables

In our study the quantitative and qualitative variables are as follows:

1. Quantitative variables: Memory Game Scores, Memory Test Cards Scores
2. Qualitative variables: Type of pain reliever, dosage level (low/high)

Table 1: Summary Statistics for Quantitative Variables

Statistic	Memory Game Score	Memory Cards Score
Mean	62.57583	7.945833
Median	61.50000	9.000000
SD	15.63703	1.960164
IQR	23.35000	2.000000

Table 2: Summary of Drug Types

Drug	Count	Percentage
Aspirin	60	25
Paracetamol	60	25
Placebo	60	25
Tramadol	60	25

2.6 Data Analysis Method

We will use **one-way ANOVA** to analyze the effects of different pain relievers on memory performance. Similarly, we will use **two-way ANOVA** to analyze the effects of different dosage levels per drug type on memory performance and cognitive retention.

3 Summary Statistics

3.1 Summary of quantitative variables

Table 1 shows the summary statistics of memory game scores before and after the treatment. The mean is similar across all groups, however, the standard deviation (SD) is relatively high. The median game scores remain close to the mean, and the IQR (Interquartile Range) is smaller than the SD. The cards memory task shows little change before and after treatment, suggesting that pain relievers may not have a major effect on this specific task.

Evident through the results on **?@tbl-summary-6**, Paracetamol is the drug that has the greatest mean & median improvement in the game scores after administering the drug (without dosage taken into account). Aspirin appears to negatively impact the results of the game after being given to people, this was seen through the mean and median improvements.

Table 3: Summary of Dosage Levels

Dosage	Count	Percentage
High	120	50
Low	120	50

Table 4: Summary of Age Groups

Age_Group	Count	Percentage
18-34	80	33.33
35-50	80	33.33
50+	80	33.33

3.2 Summary of counts and percentage for qualitative variables

Table 2 shows the distribution of participants across drug types. Aspirin, Paracetamol, and Tramadol, and Placebo each have 60 participants (25%), ensuring balance.

Table 3 shows the dosage levels assigned to participants. There is an equal split between high-dose (120 participants, 50%) and low-dose (120 participants, 50%) conditions.

3.3 Confounding Variable

Table 4 shows the breakdown of age groups, which is a confounding variable in this study. The three age groups: 18–34, 35–50, and 50+ each have 80 participants (33.33%).

4 Plots

4.1 Game Score Distribution Before and After Treatment

?@fig-boxplot-scores shows the distribution of memory game scores before and after treatment across different drug types using box plots.

1. The median scores for all drugs appear similar before treatment.
2. Tramadol has a higher median than other drugs both before and after treatment.
3. The Placebo group has a slightly lower median score compared to other drugs.
4. There is one outlier in the Tramadol group before treatment.
5. The (IQR) is **similar across all drug types**, though Tramadol sees a decrease in its IQR in the memory game scores after treatment.

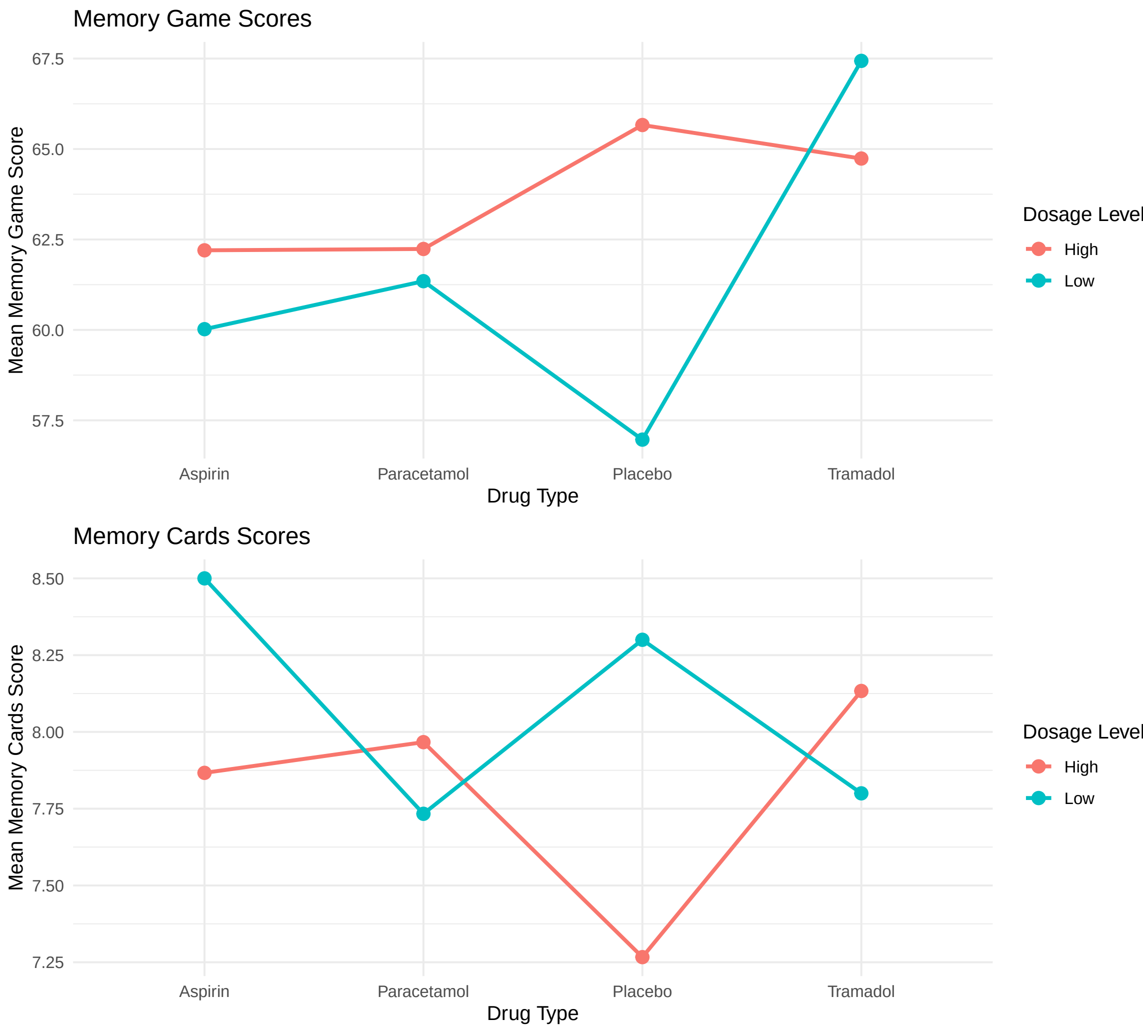


Figure 1: Interaction Plot: Drug Type vs. Dosage Level

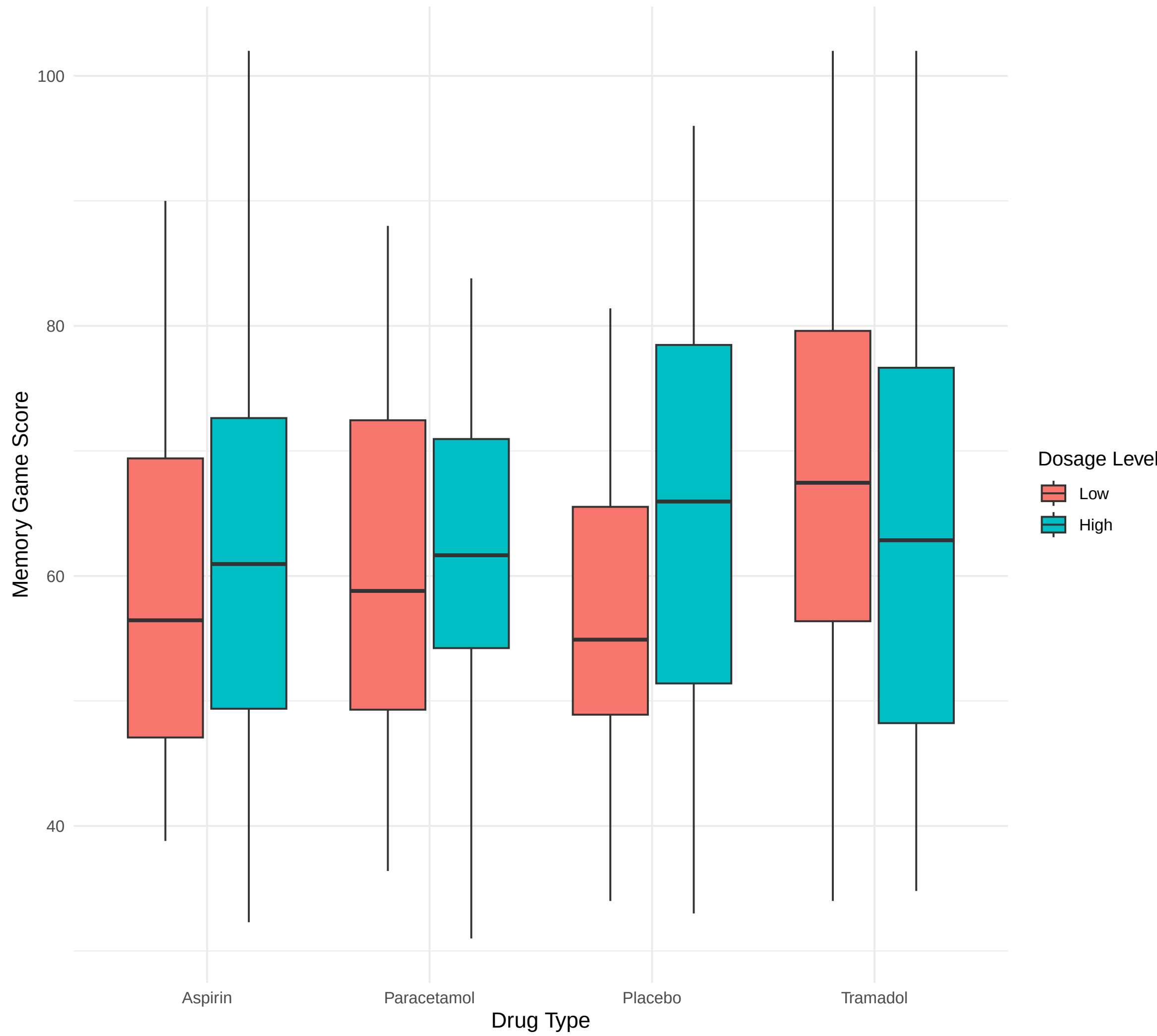


Figure 2: Memory Game Scores by Drug Type and Dosage Level

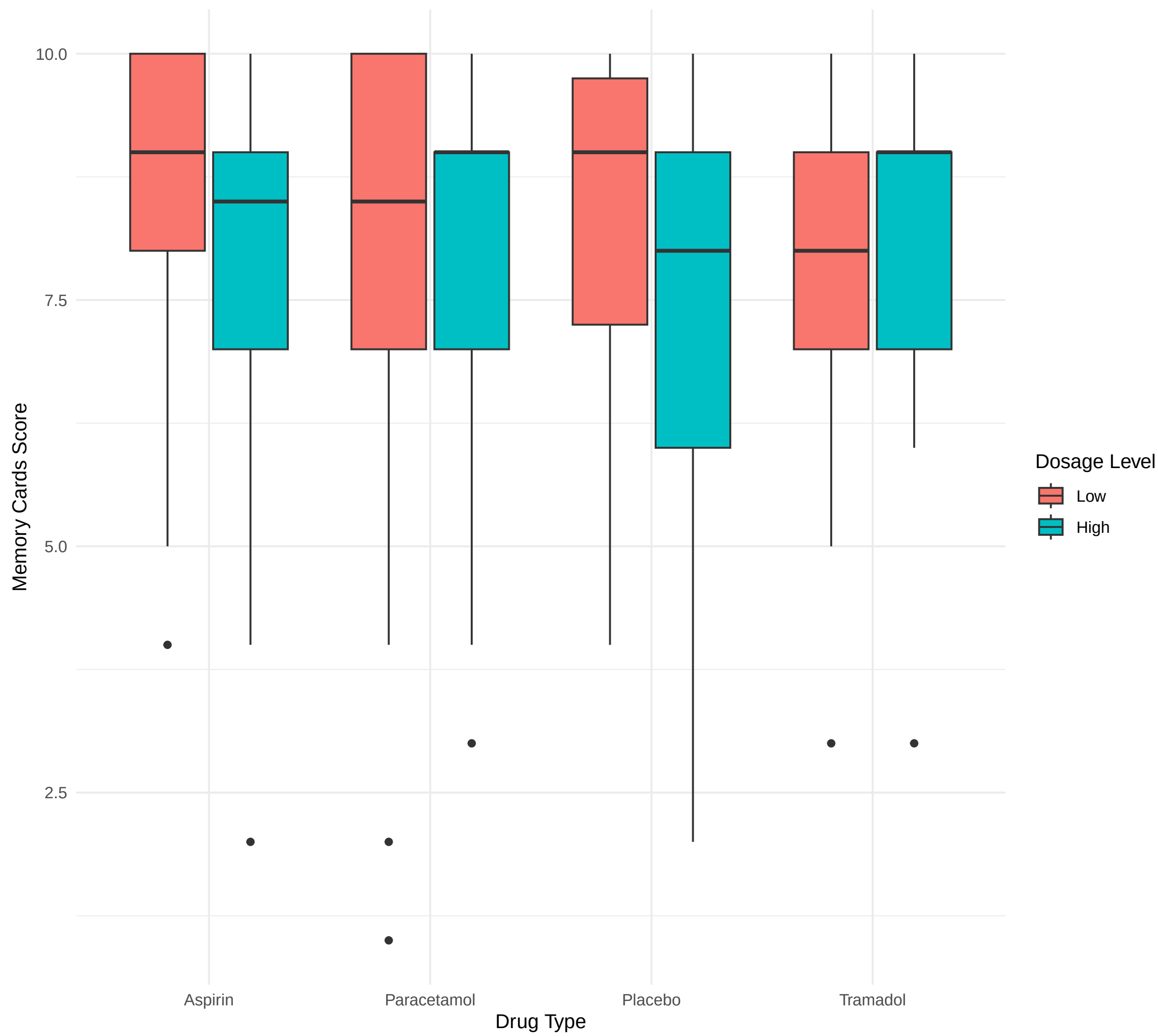


Figure 3: Memory Game Scores by Drug Type and Dosage Level

These boxplots provide an initial comparison of cognitive performance changes before and after drug administration.

4.2 Memory Card Score Distribution Before and After Treatment

?@fig-boxplot-cards shows the distribution of **memory card scores before and after treatment** across drug types.

1. Before treatment, the scores are relatively high across all groups, with Paracetamol and Placebo showing slightly higher medians than the others.
2. After treatment, the distributions remain similar, though there is a slight increase in spread for Aspirin, Paracetamol, and Placebo.
3. There is a slight decrease in the IQR of Tramadol.
4. Outliers are present in all groups, indicating some variability in memory card performance across individuals.

5 Assumptions

5.1 Model

$\text{memory\_game\_score}_i = \beta_0 + \beta_1 \cdot \text{drug}_i + \beta_2 \cdot \text{dosage\_level}_i + \beta_3 \cdot (\text{drug}_i \times \text{dosage\_level}_i) + \varepsilon_i$

Where:

- β_0 is the intercept.
- β_1, β_2, and β_3 are coefficients for the predictors and interaction term.
- ε_i is the random error term.

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk}$$

Where:

- Y_{ijk}: Memory score
- μ: Overall mean
- α_i: Effect of the i^{th} drug
- β_j: Effect of the j^{th} dosage level

Table 5: Regression Results for Memory Game Score

term	estimate	std.error	statistic	p.value
(Intercept)	60.020000	2.839371	21.1384816	0.0000000
drugParacetamol	1.326667	4.015478	0.3303883	0.7414048
drugPlacebo	-3.053333	4.015478	-0.7603911	0.4477929
drugTramadol	7.416667	4.015478	1.8470198	0.0660176
dosage_levelHigh	2.180000	4.015478	0.5428993	0.5877203
drugParacetamol:dosage_levelHigh	-1.290000	5.678743	-0.2271630	0.8204971
drugPlacebo:dosage_levelHigh	6.516667	5.678743	1.1475545	0.2523345
drugTramadol:dosage_levelHigh	-4.880000	5.678743	-0.8593451	0.3910372

Table 6: Model Fit Statistics for Memory Game Score

r.squared	adj.r.squared	sigma	statistic	p.value	df	logLik	AIC	BIC	deviance	df.residual	nobs
0.0398318	0.0108612	15.55188	1.374906	0.216744	7	-995.0806	2008.161	2039.487	56111.73	232	240

- $(\alpha\beta)_{ij}$: Interaction effect between drug and dosage
- $\varepsilon_{ijk} \sim \mathcal{N}(0, \sigma^2)$: Random error

6 Appendix

```
library(tidyverse)
library(janitor)
library(here)
library(lubridate)
library(patchwork)
library(arrow)
library(dplyr)
```

Table 7: Two-Way ANOVA Results for Memory Game Score

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
drug	3	1000.7542	333.5847	1.379242	0.2498211
dosage_level	1	308.2667	308.2667	1.274562	0.2600786
drug:dosage_level	3	1018.7310	339.5770	1.404018	0.2423452
Residuals	232	56111.7280	241.8609	NA	NA

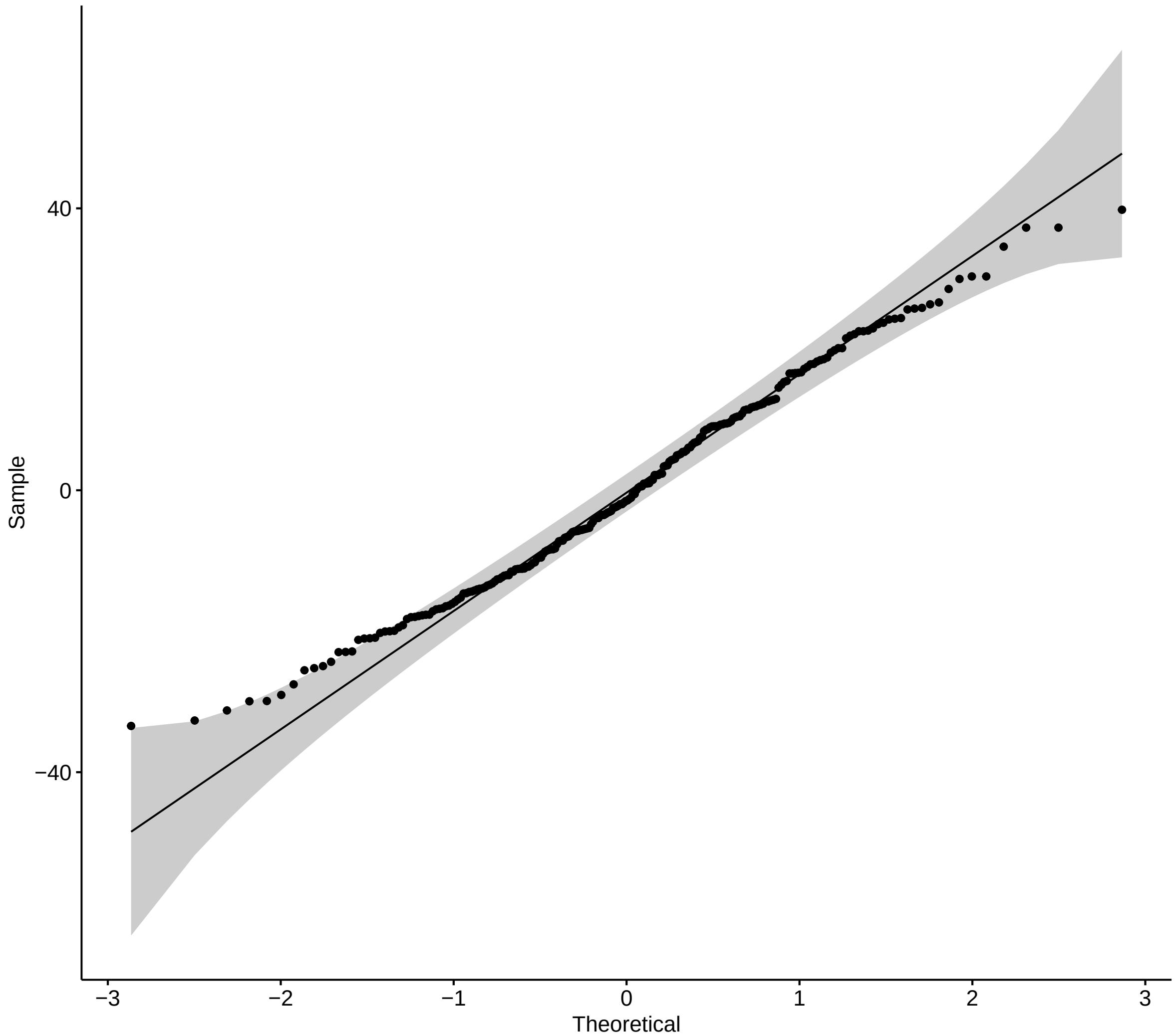


Figure 4: Q-Q Plot of Residuals

Table 8: Shapiro-Wilk Test for Normality

	Statistic	P_Value	Method
W	0.9886	0.0555	Shapiro-Wilk normality test

Table 9: Bartlett's Test for Homogeneity of Variance

	Statistic	DF	P_Value	Method
Bartlett's K-squared	7.9776	7	0.3346	Bartlett test of homogeneity of variances

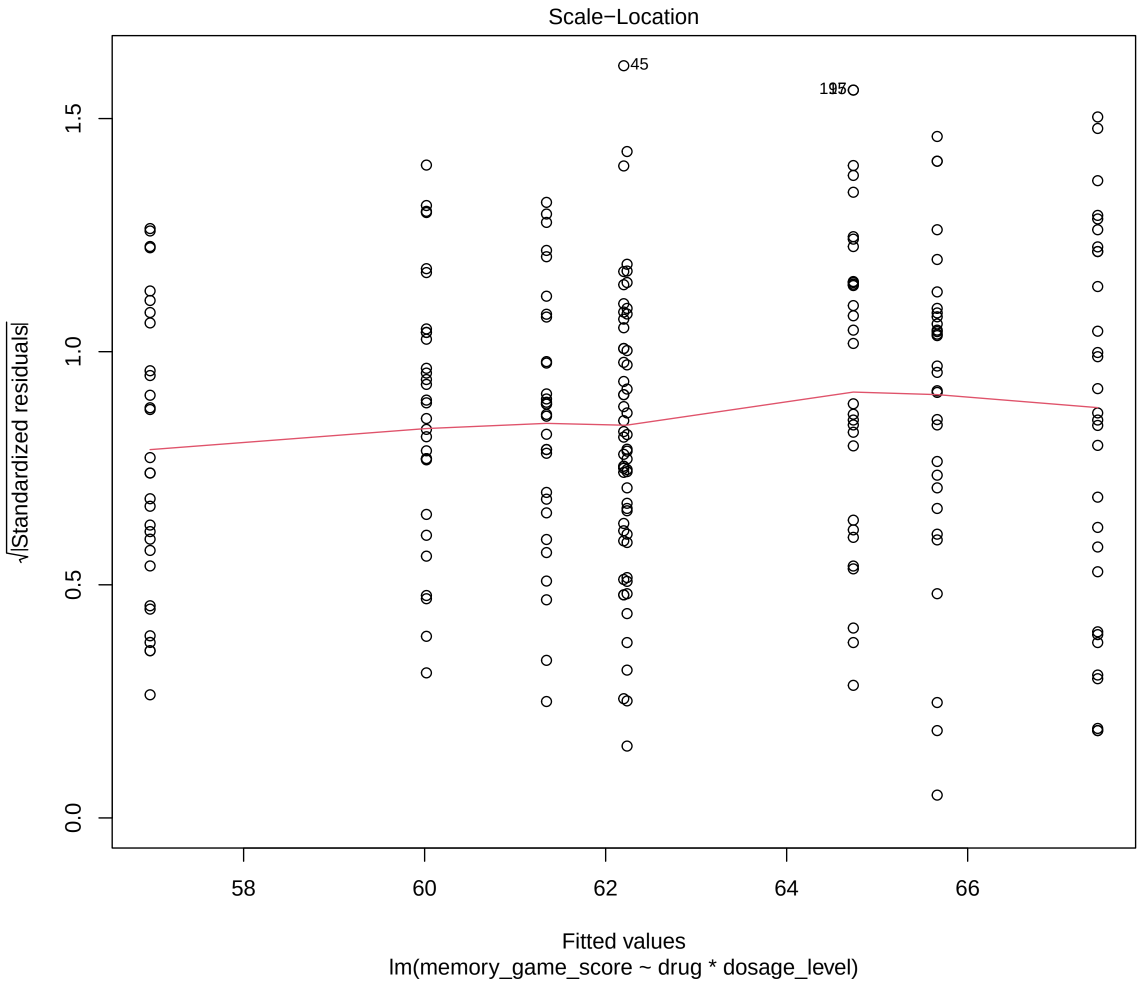


Figure 5: Q-Q Plot of Residuals

```r
library(knitr)
library(performance)
library(modelsummary)
library(kableExtra)
library(performance)
library(ggpubr)

clean_data <- read.csv(here("data", "analysis_data", "clean_data.csv"))
```

```r
# Compute statistics for Memory Game Score
mean_game <- mean(clean_data$memory_game_score, na.rm = TRUE)
median_game <- median(clean_data$memory_game_score, na.rm = TRUE)
sd_game <- sd(clean_data$memory_game_score, na.rm = TRUE)
iqr_game <- IQR(clean_data$memory_game_score, na.rm = TRUE)

# Compute statistics for Memory Cards Score
mean_cards <- mean(clean_data$memory_cards_score, na.rm = TRUE)
median_cards <- median(clean_data$memory_cards_score, na.rm = TRUE)
sd_cards <- sd(clean_data$memory_cards_score, na.rm = TRUE)
iqr_cards <- IQR(clean_data$memory_cards_score, na.rm = TRUE)

# Combine into a summary table
summary_table <- data.frame(
  Statistic = c("Mean", "Median", "SD", "IQR"),
  `Memory Game Score` = c(mean_game, median_game, sd_game, iqr_game),
  `Memory Cards Score` = c(mean_cards, median_cards, sd_cards, iqr_cards)
)

colnames(summary_table) <- c("Statistic", "Memory Game Score", "Memory Cards Score")

# Display table

kable(summary_table, format = "latex", booktabs = TRUE)
```

Statistic	Memory Game Score	Memory Cards Score
Mean	62.57583	7.945833
Median	61.50000	9.000000
SD	15.63703	1.960164
IQR	23.35000	2.000000

```r
drug_counts <- table(clean_data$drug)

# percentages
drug_percentages <- prop.table(drug_counts) * 100

#  summary dataframe
drug_summary <- data.frame(
  Drug = names(drug_counts),
  Count = as.numeric(drug_counts),
  Percentage = round(as.numeric(drug_percentages), 2)
)

# Display table
kable(drug_summary, format = "latex", booktabs = TRUE)
```

Drug	Count	Percentage
Aspirin	60	25
Paracetamol	60	25
Placebo	60	25
Tramadol	60	25

```r
dosage_counts <- table(clean_data$dosage_level)

# percentage for each dosage level
dosage_percentages <- prop.table(dosage_counts) * 100

# summary dataframe
dosage_summary <- data.frame(
  Dosage = names(dosage_counts),
  Count = as.numeric(dosage_counts),
  Percentage = round(as.numeric(dosage_percentages), 2)
)


# Display table
kable(dosage_summary, booktabs = TRUE, row.names = FALSE)
```

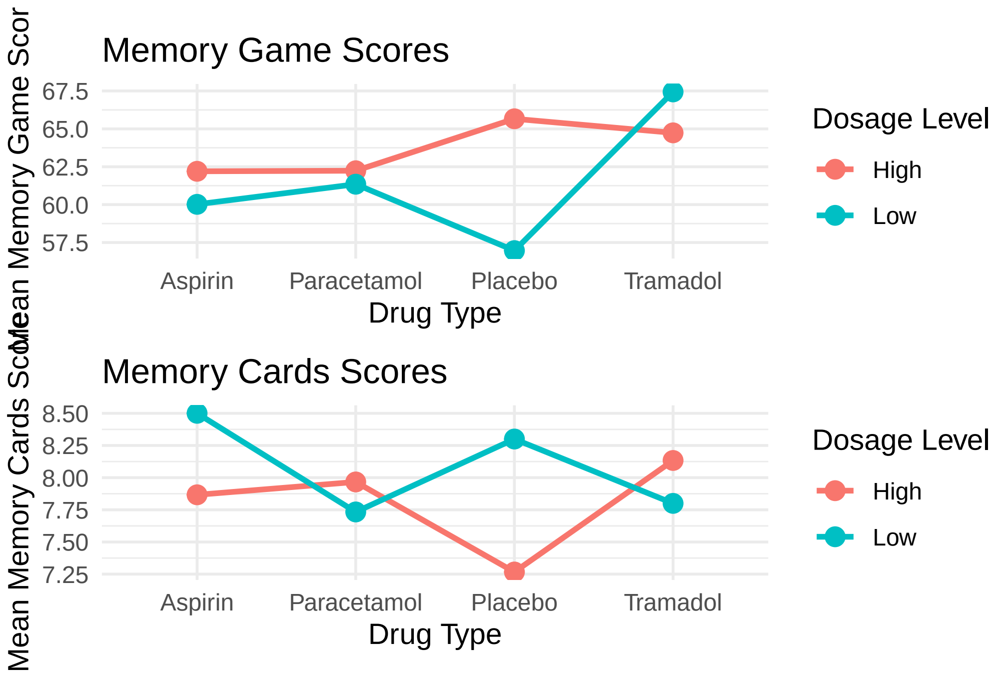
Dosage	Count	Percentage
High	120	50
Low	120	50

```r
age_counts <- table(clean_data$age_group)

# percentages for each age group
age_percentages <- prop.table(age_counts) * 100

# summary dataframe
age_summary <- data.frame(
  Age_Group = names(age_counts),
  Count = as.numeric(age_counts),
  Percentage = round(as.numeric(age_percentages), 2)
)

# Display table
kable(age_summary, booktabs = TRUE, row.names = FALSE)
```

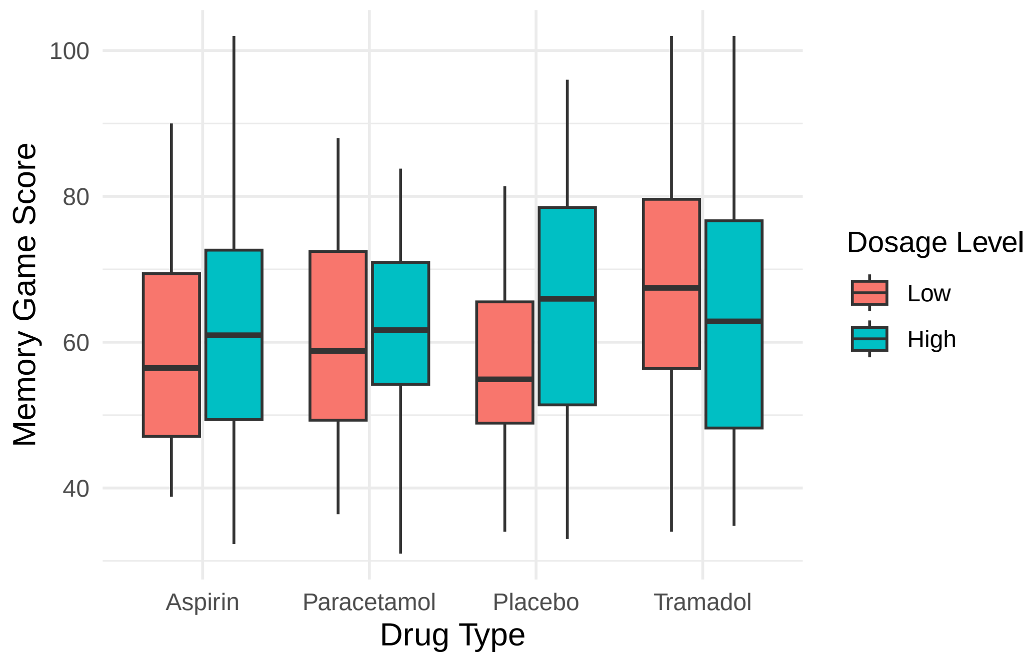
Age_Group	Count	Percentage
18-34	80	33.33
35-50	80	33.33
50+	80	33.33

```r
p1 <- ggplot(clean_data, aes(x = drug, y = memory_game_score, color = dosage_level, group = d
  stat_summary(fun = mean, geom = "point", size = 3) +
  stat_summary(fun = mean, geom = "line", size = 1) +
  labs(title = "Memory Game Scores",
       x = "Drug Type",
       y = "Mean Memory Game Score",
       color = "Dosage Level") +
  theme_minimal()

# Interaction plot for Memory Cards Scores
p2 <- ggplot(clean_data, aes(x = drug, y = memory_cards_score, color = dosage_level, group =
  stat_summary(fun = mean, geom = "point", size = 3) +
  stat_summary(fun = mean, geom = "line", size = 1) +
  labs(title = "Memory Cards Scores",
       x = "Drug Type",
       y = "Mean Memory Cards Score",
       color = "Dosage Level") +
  theme_minimal()

# Combine the two plots vertically
```

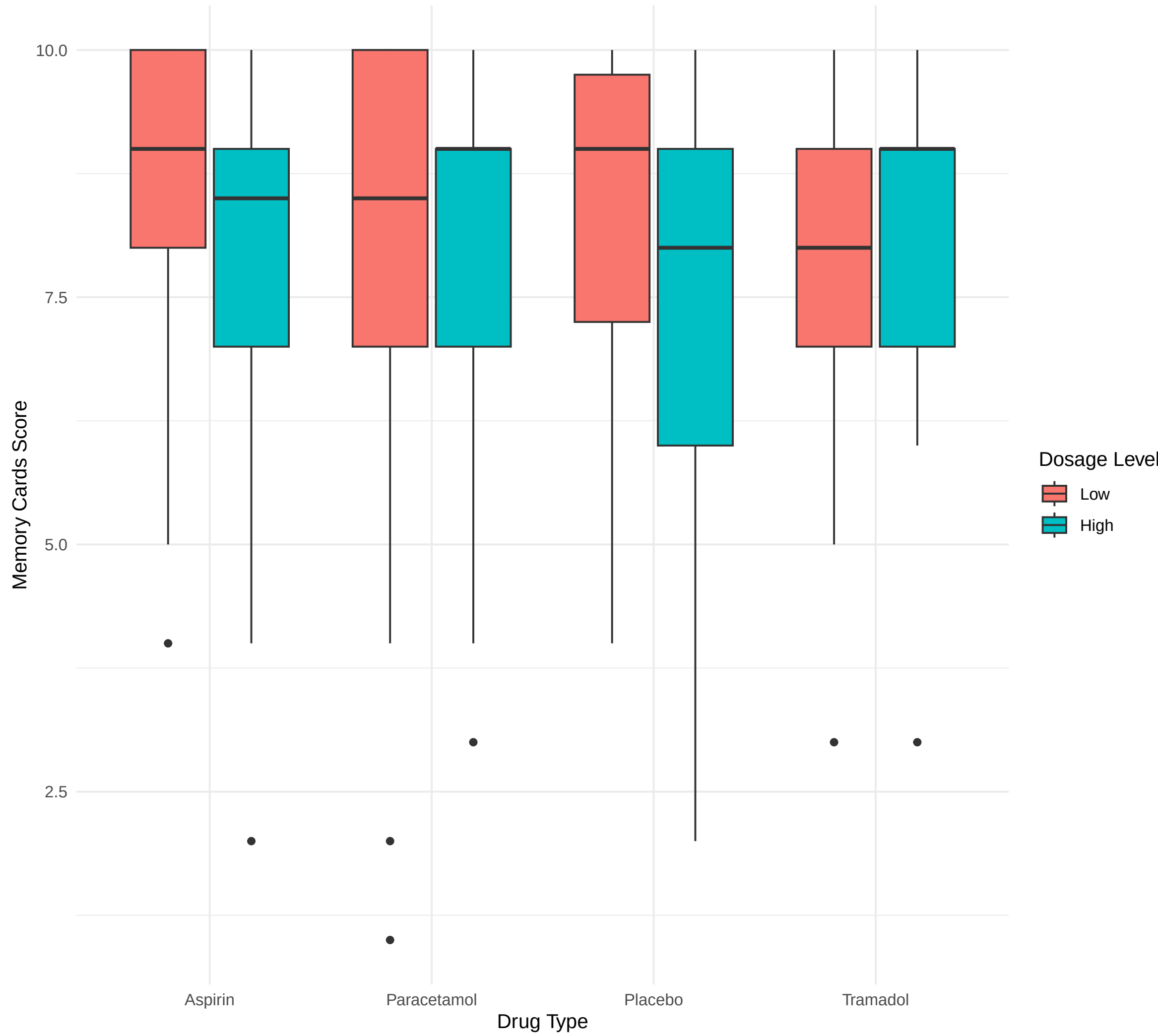
```r
combined_plot <- p1 / p2
combined_plot
```




```r
clean_data$dosage_level <- factor(clean_data$dosage_level, levels = c("Low", "High"))

# Boxplot of Memory Game Scores by Drug, colored by Dosage Level
ggplot(clean_data, aes(x = drug, y = memory_game_score, fill = dosage_level)) +
  geom_boxplot() +
  labs(
    x = "Drug Type",
    y = "Memory Game Score",
    fill = "Dosage Level"
  ) +
  theme_minimal() +
  theme(
    plot.title = element_text(size = 14, face = "bold"),
    axis.title = element_text(size = 12)
  )
```




```r
ggplot(clean_data, aes(x = drug, y = memory_cards_score, fill = dosage_level)) +
  geom_boxplot() +
  labs(
    x = "Drug Type",
    y = "Memory Cards Score",
    fill = "Dosage Level"
  ) +
  theme_minimal()
```




```
# References: https://cran.r-project.org/web/packages/broom/vignettes/broom.html

library(broom)

# Regression Model results
anova_model <- lm(memory_game_score ~ drug * dosage_level, data = clean_data)

model_tidy <- tidy(anova_model)

kable(model_tidy, format = "latex", booktabs = TRUE)
```

r.squared	adj.r.squared	sigma	statistic	p.value	df	logLik	AIC	BIC	deviance	df.residual	nobs
0.0398318	0.0108612	15.55188	1.374906	0.216744	7	-995.0806	2008.161	2039.487	56111.73	232	240

term	estimate	std.error	statistic	p.value
(Intercept)	60.020000	2.839371	21.1384816	0.0000000
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drugTramadol:dosage_levelHigh	-4.880000	5.678743	-0.8593451	0.3910372

```r
model_glance <- glance(anova_model)
kable(model_glance, format = "latex", booktabs = TRUE) %>%
  kable_styling(latex_options = "scale_down")
```

```r
# Two way ANOVA result
anova_result <- anova(anova_model)

anova_table_df <- as.data.frame(anova_result)

kable(anova_table_df, format = "latex", booktabs = TRUE)
```

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
drug	3	1000.7542	333.5847	1.379242	0.2498211
dosage_level	1	308.2667	308.2667	1.274562	0.2600786
drug:dosage_level	3	1018.7310	339.5770	1.404018	0.2423452
Residuals	232	56111.7280	241.8609	NA	NA

```r
# Normality Check
ggqqplot(residuals(anova_model))
```

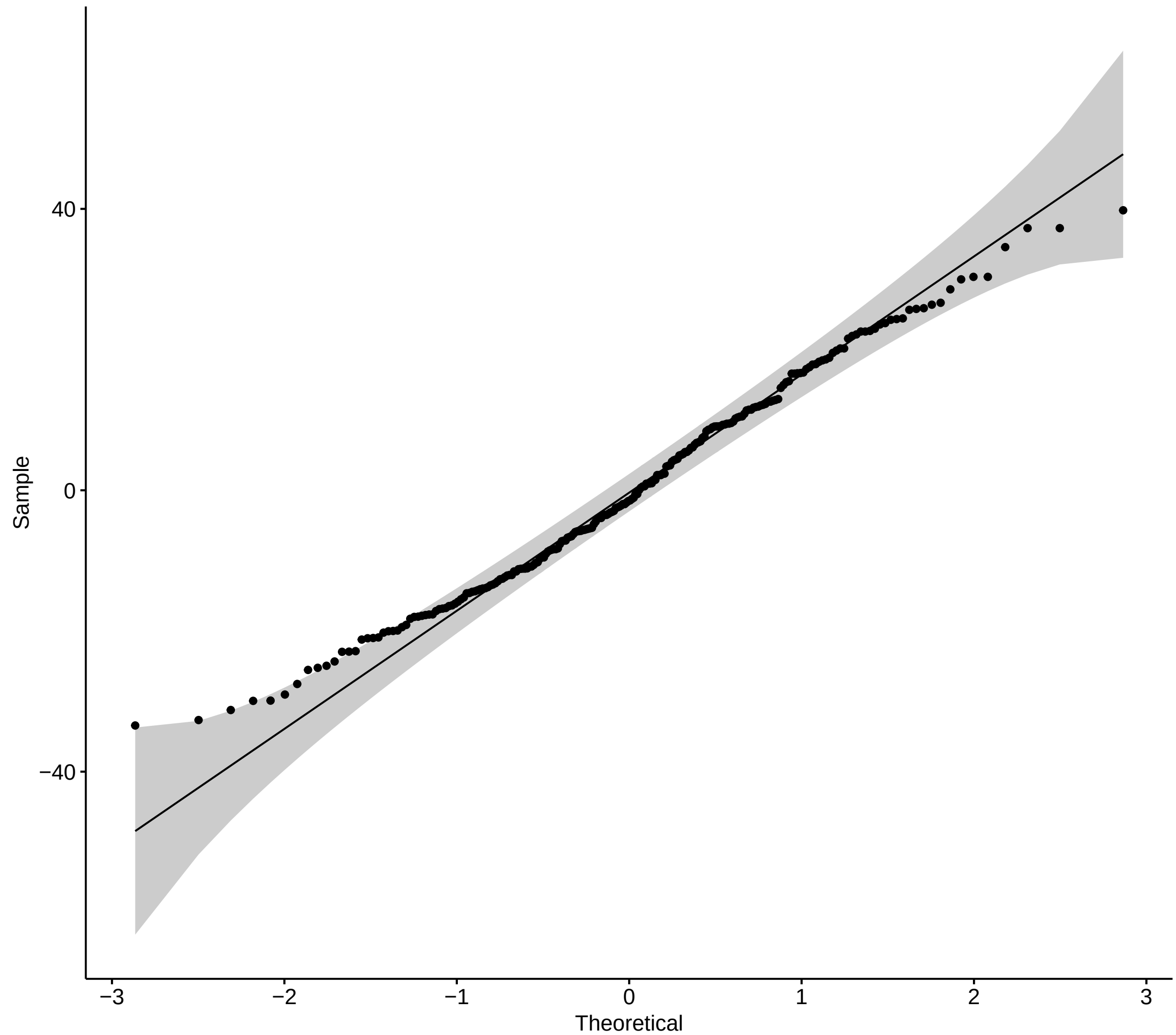

Figure 6: Q-Q Plot of Residuals

```r
# Shapiro-Wilk Normality Test
shapiro_test <- shapiro.test(residuals(anova_model))
shapiro_table <- data.frame(
  Statistic = round(shapiro_test$statistic, 4),
  P_Value = round(shapiro_test$p.value, 4),
  Method = shapiro_test$method
```

```r
)

kable(shapiro_table, format = "latex", booktabs = TRUE)
```

	Statistic	P_Value	Method
W	0.9886	0.0555	Shapiro-Wilk normality test

```r
plot(anova_model, which = 3)
```