Effects of Different Pain Relievers and Dosages on Cognitive Retention

Exploratory Data Analysis (EDA)

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1 Introduction

1.1 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.

1.2 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?*

1.3 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** ($8 \times 30 = 240$).

1.4 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

1.5 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)

1.6 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.

Table 1: Summary Statistics for Quantitative Variables

Statistic	Game_Before	Game_After	Cards_Before	Cards_After
Mean	62.79667	62.57583	8.079167	7.945833
Median	60.95000	61.50000	9.000000	9.000000
SD	15.82383	15.63703	1.927011	1.960164
IQR	23.32500	23.35000	3.000000	2.000000

Table 2: Mean Improvement in Game Scores by Drug

drug	Mean_Improvement	SD_Improvement	Median_Improvement
Aspirin	-1.581667	5.278723	-1.55
Paracetamol	1.713333	5.249551	1.30
Placebo	-0.600000	5.178868	0.10
Tramadol	-0.415000	6.014836	-1.25

2 Summary Statistics

2.1 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 Table 2, 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.

2.2 Summary of counts and percentage for qualitative variables

Table 3 shows the distribution of participants across drug types. Aspirin, Paracetamol, and Tramadol, and Placebo each have 60 participants (25%), ensuring balance.

Table 4 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.

Table 3: Summary of Drug Types

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

Table 4: Summary of Dosage Levels

Dosage	Count	Percentage
High	120	50
Low	120	50

2.3 Confounding Variable

Table 5 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%).

3 Plots

3.1 Game Score Distribution Before and After Treatment

Figure 1 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.

Table 5: Summary of Age Groups

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

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

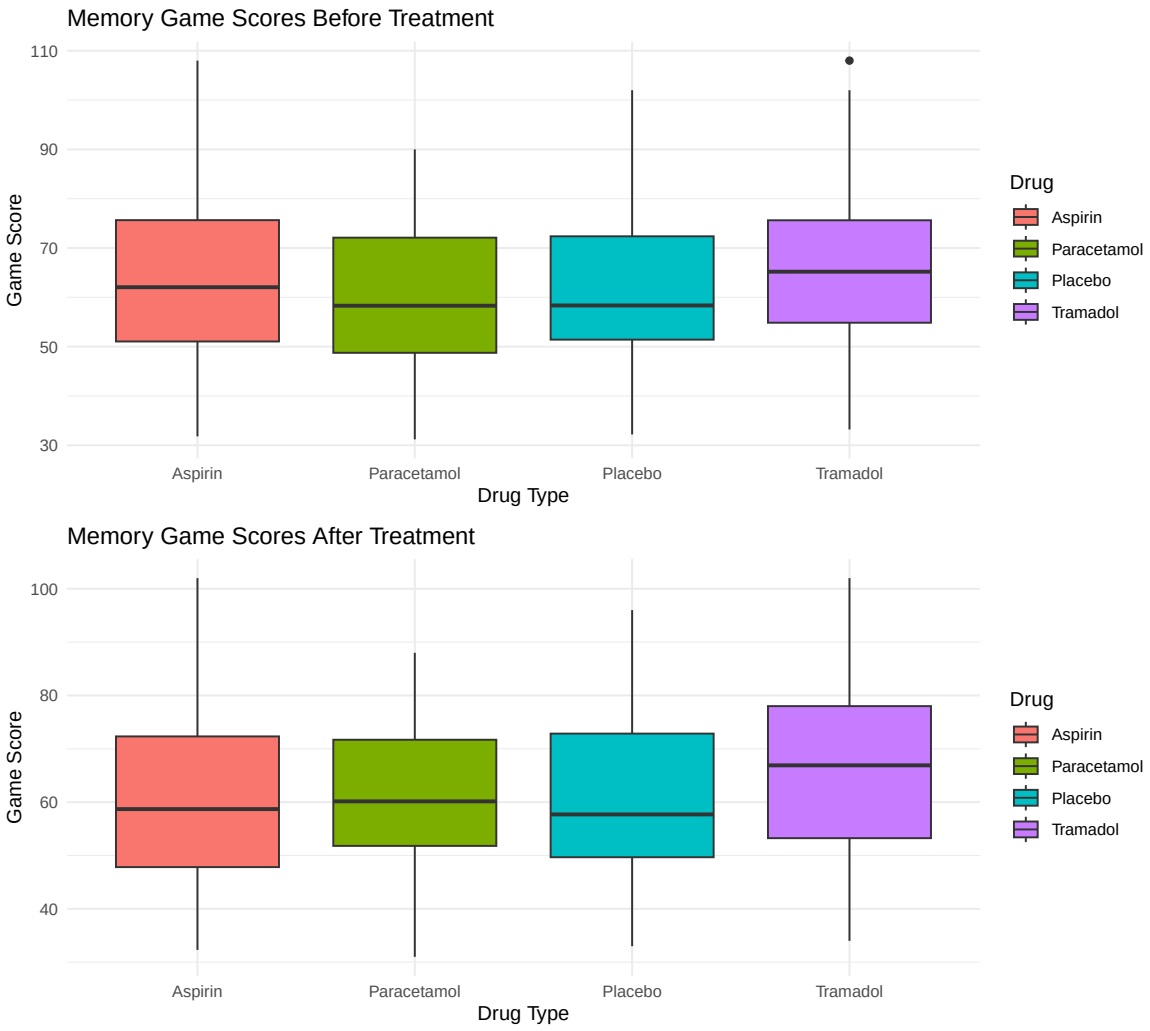


Figure 1: Boxplot of Memory Game Scores Before and After Treatment by Drug Type

3.2 Memory Card Score Distribution Before and After Treatment

Figure 2 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.

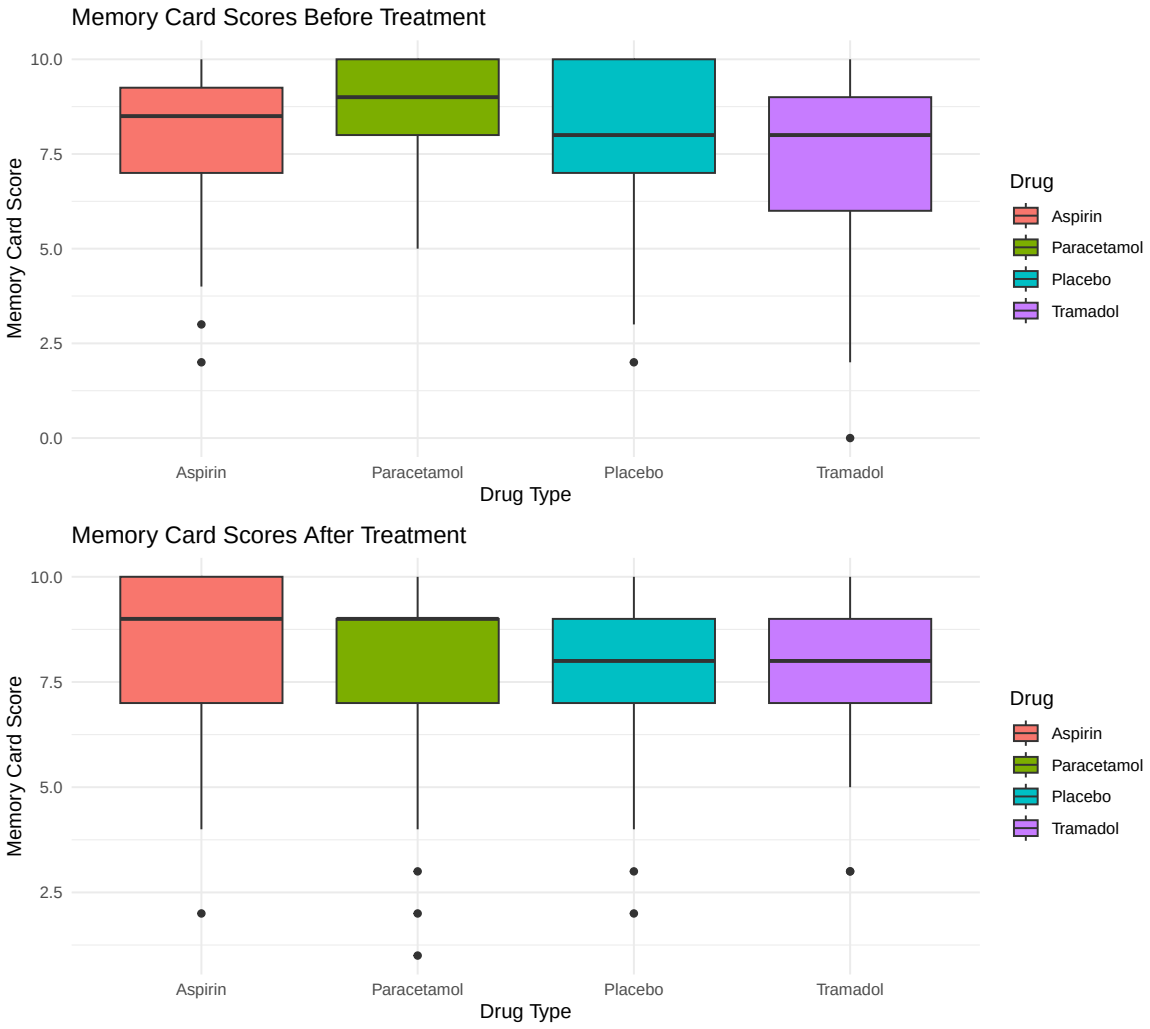


Figure 2: Boxplot of Memory Card Scores Before and After by Drug

4 Assumptions

4.1 Checking Model Assumptions

We assessed the homogeneity of variance and normality of residuals using diagnostic plots to validate the assumptions of our ANOVA tests. (Figure 3 & Figure 4).

One-way ANOVA

Independence: For our one-way ANOVA model, we have independence because our observations are independent within and across the groups i.e all participants were randomly assigned a pain reliever, and there was no relationships between observations (i.e repeated participants, treatments etc.)

Homogeneity of Variance: The reference line in Figure 3 relatively flat and horizontal which indicates that variance is approximately equal across groups. Thus, the assumption of homogeneity of variance is not significantly violated.

Normality of Residuals: The residuals are approximately normally distributed in Figure 3 since the density plot on the right appears close to a normal distribution.

Two-way ANOVA

Independence: For our two-way ANOVA model, the different combinations of pain reliever type and dosage levels were randomly assigned to all participants, in random order.

Homogeneity of Variance: In Figure 4 the left plot shows some deviation from a perfectly flat line and has minor fluctuations, especially at certain levels of drug type and dosage. Despite some variation, the overall trend does not show extreme violations of homogeneity.

Normality of Residuals: In Figure 4 the density plot on the right shows that the residuals follow a roughly normal distribution even though minor deviations are present.

Conclusion

Both models satisfy the assumptions of homogeneity of variance and normality of residuals well enough. There are slight deviations in the two-way ANOVA model, but they are not severe enough to invalidate the analysis. Therefore, we proceed with the ANOVA tests.

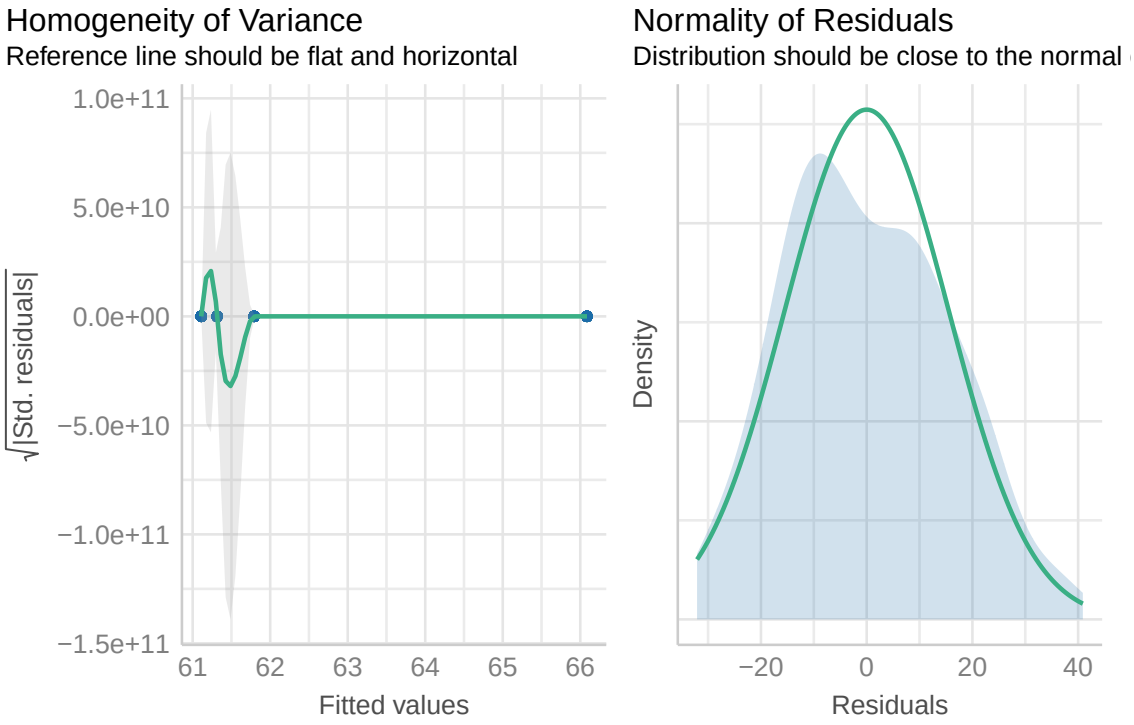


Figure 3: Homogeneity and Normality (One-way ANOVA)

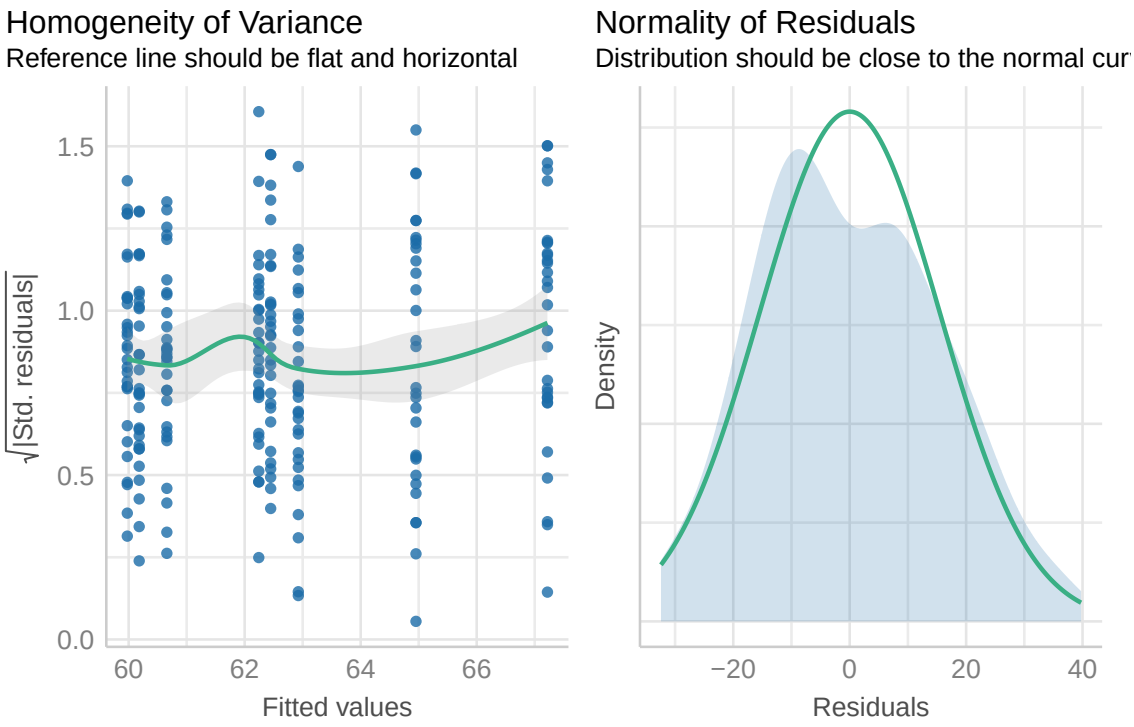


Figure 4: Normality & Homegenity (Two-way ANOVA)

5 Appendix

```
library(tidyverse)
library(janitor)
library(here)
library(lubridate)
library(arrow)
library(dplyr)
library(knitr)
library(performance)
library(kableExtra)
library(performance)
library(ggpubr)

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

```
# References:
# https://tellingstorieswithdata.com/
# https://q.utoronto.ca/courses/376099/pages/project-descriptions?module_item_id=6379323


m1_game_before <- mean(clean_data$game_before, na.rm = TRUE)
m2_game_before <- median(clean_data$game_before, na.rm = TRUE)
m3_game_before <- sd(clean_data$game_before, na.rm = TRUE)
m4_game_before <- IQR(clean_data$game_before, na.rm = TRUE)

m1_game_after <- mean(clean_data$game_after, na.rm = TRUE)
m2_game_after <- median(clean_data$game_after, na.rm = TRUE)
m3_game_after <- sd(clean_data$game_after, na.rm = TRUE)
m4_game_after <- IQR(clean_data$game_after, na.rm = TRUE)

m1_cards_before <- mean(clean_data$cards_before, na.rm = TRUE)
m2_cards_before <- median(clean_data$cards_before, na.rm = TRUE)
m3_cards_before <- sd(clean_data$cards_before, na.rm = TRUE)
m4_cards_before <- IQR(clean_data$cards_before, na.rm = TRUE)

m1_cards_after <- mean(clean_data$cards_after, na.rm = TRUE)
m2_cards_after <- median(clean_data$cards_after, na.rm = TRUE)
m3_cards_after <- sd(clean_data$cards_after, na.rm = TRUE)
m4_cards_after <- IQR(clean_data$cards_after, na.rm = TRUE)
```

```r
# Combine into a table
summary_table <- data.frame(
  Statistic = c("Mean", "Median", "SD", "IQR"),
  Game_Before = c(m1_game_before, m2_game_before, m3_game_before, m4_game_before),
  Game_After = c(m1_game_after, m2_game_after, m3_game_after, m4_game_after),
  Cards_Before = c(m1_cards_before, m2_cards_before, m3_cards_before, m4_cards_before),
  Cards_After = c(m1_cards_after, m2_cards_after, m3_cards_after, m4_cards_after)
)

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

Statistic	Game_Before	Game_After	Cards_Before	Cards_After
Mean	62.79667	62.57583	8.079167	7.945833
Median	60.95000	61.50000	9.000000	9.000000
SD	15.82383	15.63703	1.927011	1.960164
IQR	23.32500	23.35000	3.000000	2.000000

```r
# Count and percentage for Drug
drug_counts <- table(clean_data$drug)
drug_percentages <- prop.table(drug_counts) * 100
drug_summary <- data.frame(Drug = names(drug_counts), Count = as.numeric(drug_counts), Per
colnames(drug_summary) <- c("Drug", "Count", "Percentage")
kable(drug_summary, format = "latex", booktabs = TRUE)
```

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

```r
# Count and percentage for Dosage Level
dosage_counts <- table(clean_data$dosage_level)
dosage_percentages <- prop.table(dosage_counts) * 100
dosage_summary <- data.frame(Dosage = names(dosage_counts), Count = as.numeric(dosage_coun

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

Dosage	Count	Percentage
High	120	50
Low	120	50

```
# Count and percentage for Age Group
age_counts <- table(clean_data$age_group)
age_percentages <- prop.table(age_counts) * 100
age_summary <- data.frame(Age_Group = names(age_counts), Count = as.numeric(age_counts), P


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

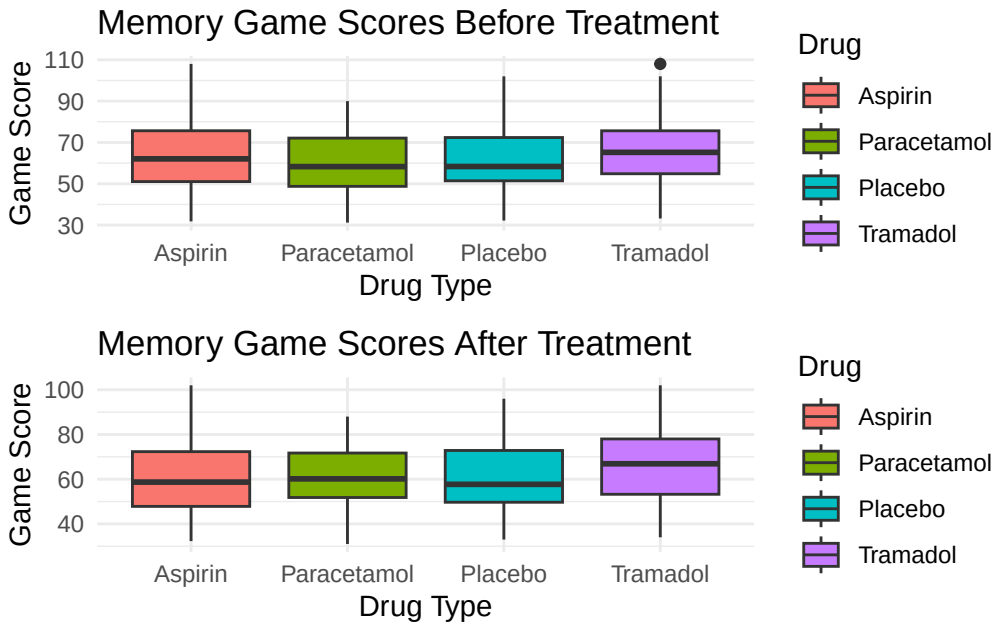
Age_Group	Count	Percentage
18-34	80	33.33
35-50	80	33.33
50+	80	33.33

```
clean_data$improvement <- clean_data$game_after - clean_data$game_before

improvement_summary <- clean_data %>%
  group_by(drug) %>%
  summarise(
    Mean_Improvement = mean(improvement, na.rm = TRUE),
    SD_Improvement = sd(improvement, na.rm = TRUE),
    Median_Improvement = median(improvement, na.rm = TRUE)
  )

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

drug	Mean_Improvement	SD_Improvement	Median_Improvement
Aspirin	-1.581667	5.278723	-1.55
Paracetamol	1.713333	5.249551	1.30
Placebo	-0.600000	5.178868	0.10
Tramadol	-0.415000	6.014836	-1.25

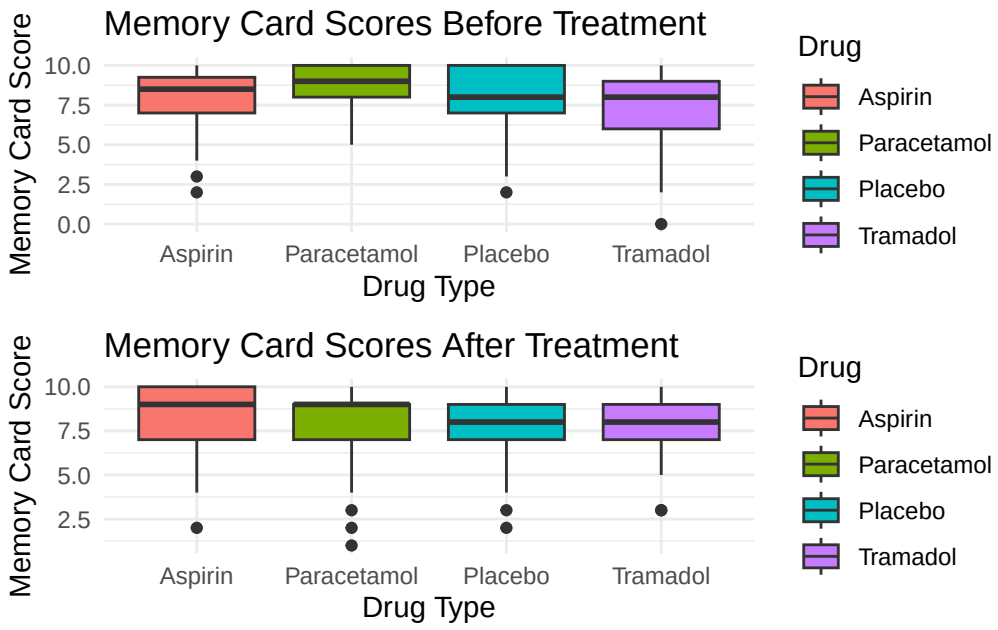
```
library(ggplot2)
library(patchwork)

#References
```

```r
#https://r-graph-gallery.com/package/patchwork.html

clean_data$drug <- factor(clean_data$drug, labels = c("Aspirin", "Paracetamol", "Placebo",

# Create first boxplot
p1 <- ggplot(clean_data, aes(x = drug, y = game_before, fill = drug)) +
  geom_boxplot() +
  labs(title = "Memory Game Scores Before Treatment", x = "Drug Type", y = "Game Score", f
  theme_minimal()

# Create second boxplot
p2 <- ggplot(clean_data, aes(x = drug, y = game_after, fill = drug)) +
  geom_boxplot() +
  labs(title = "Memory Game Scores After Treatment", x = "Drug Type", y = "Game Score", fi
  theme_minimal()

p1 / p2 + plot_annotation()
```

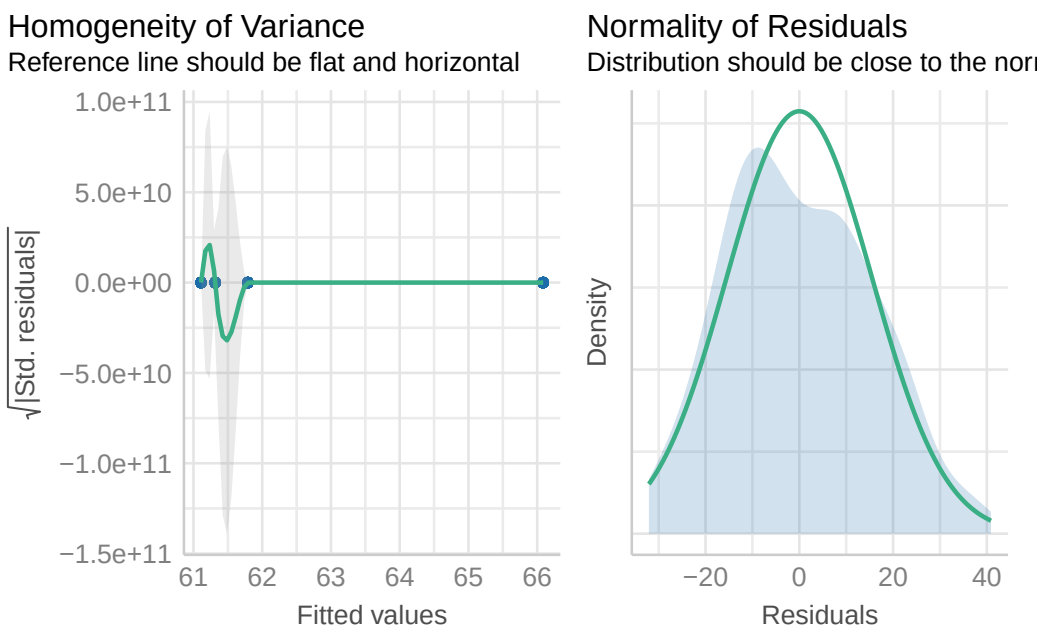



```r
library(ggplot2)
library(patchwork)
```

```r
clean_data$drug <- factor(clean_data$drug, labels = c("Aspirin", "Paracetamol", "Placebo",

p1 <- ggplot(clean_data, aes(x = drug, y = cards_before, fill = drug)) +
  geom_boxplot() +
  labs(title = "Memory Card Scores Before Treatment", x = "Drug Type", y = "Memory Card Sc
  theme_minimal()

p2 <- ggplot(clean_data, aes(x = drug, y = cards_after, fill = drug)) +
  geom_boxplot() +
  labs(title = "Memory Card Scores After Treatment", x = "Drug Type", y = "Memory Card Sco
  theme_minimal()

p1 / p2 + plot_annotation()
```




```r
# we fit One-Way ANOVA Model for our research question 1
model_1 <- aov(game_after ~ drug, data = clean_data)

# Check Model Assumptions
check_model(model_1, check = c("normality", "homogeneity"))
```




```
# Corrected Two-Way ANOVA Model for our research question 2
model_2 <- aov(game_after ~ drug + dosage_level, data = clean_data)

# Check Model Assumptions
check_model(model_2, check = c("normality", "homogeneity"))
```

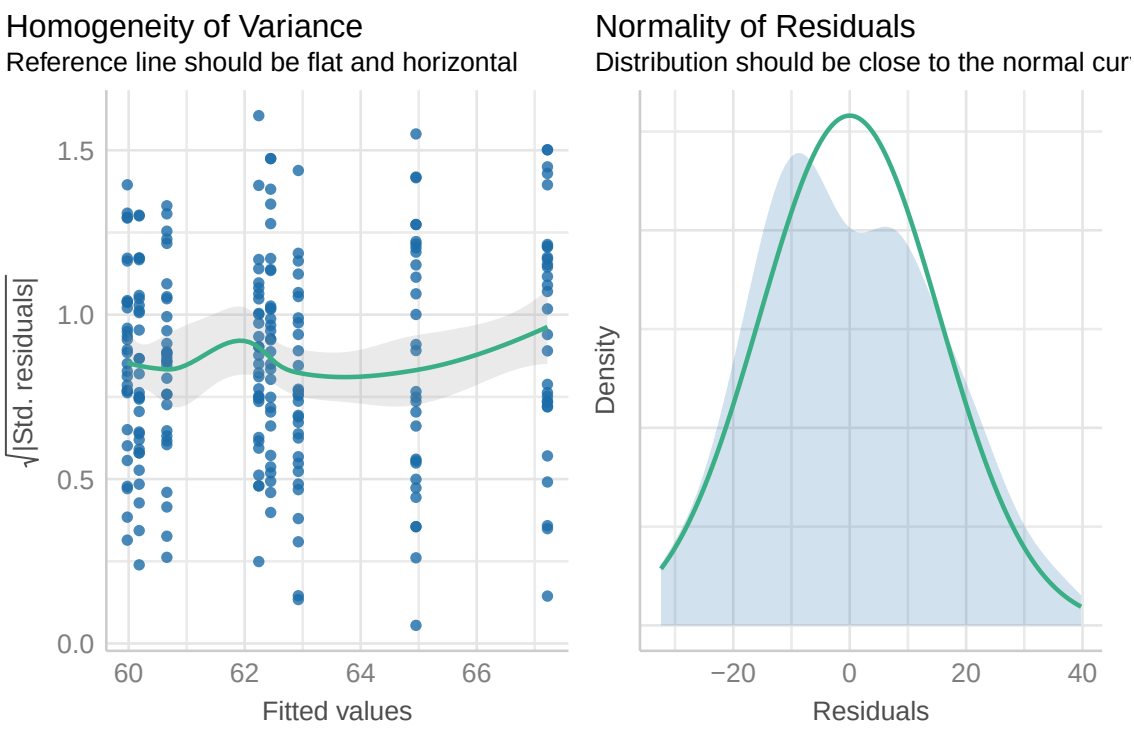


Figure 5: Normality & Homegenity (Two-way ANOVA)