Final Project

PSTAT122: Design and Analysis of Experiments

Fall 2025

STUDENT NAME

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Due Date

Due Date: Monday, December 8, 2025, 11:59 PM

1 Introduction

Productivity during academic tasks is commonly influenced by various study behaviors, yet the extent to which these behaviors improve performance remains unclear. This study investigates how two conventional study treatments—listening to music and chewing gum—affect performance on a cognitive–motor task. To operationalize "productivity," we narrowed the scope of our research question to examine measurable performance outcomes on a typing speed test.

Typing speed (measured in words per minute, WPM) was selected as the response variable because it represents a skill-based task that can be completed repeatedly within a short time frame, making it suitable for controlled experimentation. Although we initially planned to evaluate the effect of caffeine consumption on typing performance, practical constraints related to caffeine metabolism and required waiting periods made this approach infeasible for an in-session factorial experiment.

Therefore, our study focuses on the following research question: **Is there an interaction effect between listening to music and chewing gum on typing speed?** In addition to evaluating potential interaction effects, we also assess whether each factor independently influences performance.

This question is motivated by common student behaviors. Many students rely on music, fidgets, or small sensory stimuli (such as chewing gum) to improve concentration during extended study periods. By systematically testing these factors in a controlled setting, this experiment aims to determine whether these commonly used strategies enhance, hinder, or have no measurable effect on performance in a specific cognitive–motor task. We acknowledge that the effectiveness of sensory stimuli may vary across different types of tasks; however, this study seeks to provide preliminary evidence that may offer at least some broader insight into how such strategies influence academic performance.

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2 Experimental Design

The response variable for this experiment was words per minute (WPM) recorded using Monkeytype. This platform was selected because its scoring system incorporates accuracy penalties, thereby providing a more reliable measure of typing performance than raw speed alone. The two study treatments—listening to music (Yes/No) and chewing gum (Yes/No)—were arranged in a full 2×2 factorial design, resulting in four treatment combinations. All participants used some sort of earpiece device to listen to music keeping this method consistent across participants to reduce variability.

Participants were allowed to choose the type of music they typically listen to in a productive setting. Although music genres varied across individuals, we treated "listening to music" as a single categorical factor to maintain feasibility and focus, as the experiment was not designed to examine genre-specific effects. The same principle was applied to chewing gum: participants used their preferred flavor, but flavor differences were not considered as part of the experimental factors.

All participants completed the typing task under standardized Monkeytype default settings to maintain consistency across trials. WPM values were recorded for each thirty second run, with the platform automatically adjusting scores downward when accuracy declined. To reduce bias, each participant's order of treatment conditions was randomized. Within each assigned condition, participants completed ten consecutive typing trials, yielding ten WPM observations per condition. This replication served to reduce the influence of outliers and increase the precision of the estimated treatment effects.

Participants were treated as blocks in the design to account for inherent differences in baseline typing proficiency. With four participants and four conditions, this resulted in a total of 40 observations per condition and 160 observations overall. The experiment was completed in under one hour. To minimize fatigue effects, participants took 15-minute breaks between conditions. Thus, for each participant, the ten trials within a condition constitute ten replicates of the corresponding treatment combination.

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3 Data Collection

Procedure & Challenges/Adjustments

The experiment was conducted remotely within a one-hour window due to participants being out of town and unable to meet in person. Each participant completed the study in a private, distraction-free environment to minimize uncontrolled external influences. For each assigned treatment condition, participants completed ten typing runs, recording their WPM score after each run. Upon completing a condition, participants were given a 15-minute break before moving on to the next randomized treatment.

One practical challenge of the study was the inability to gather all participants in the same physical location. As a result, clear instructions emphasized the importance of selecting a quiet, comfortable workspace to ensure that environmental variability did not confound the effects of the experimental factors.

Data Presentation

	Participant	Music	Gum	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Avg
3	Isaac	No	Yes	62	51	54	55	63	61	60	64	54	60	59.4
2	Isaac	Yes	No	66	61	53	67	62	62	63	62	66	66	62.1
4	Isaac	Yes	Yes	60	56	46	54	58	55	64	73	59	66	68.0
1	Isaac	No	No	65	62	58	60	61	60	60	66	60	65	59.5

	Participant	Music	Gum	Run1	Run2	Run3	Run4	Run5	Run6	Run7	Run8	Run9	Run10	Avg
31	Tommy	No	Yes	57	51	54	84	79	90	68	81	82	87	91.3
11	Tommy	No	No	91	65	94	76	76	88	69	78	86	76	79.9
21	Tommy	Yes	No	94	86	81	81	79	74	71	78	86	70	78.0
41	Tommy	Yes	Yes	82	84	82	83	81	74	80	77	83	84	76.8
22	Chris	Yes	No	78	79	96	90	89	82	97	93	90	90	98.1
12	Chris	No	No	82	76	69	86	91	85	90	58	65	83	78.6
42	Chris	Yes	Yes	82	91	87	88	97	79	87	84	84	80	88.9
32	Chris	No	Yes	82	82	74	84	88	87	70	81	74	70	81.0
43	Christian	Yes	Yes	60	66	58	60	64	56	62	59	66	72	62.5
13	Christian	No	No	66	65	58	65	70	67	62	44	67	66	62.0
33	Christian	No	Yes	72	49	80	70	56	59	58	56	64	60	90.4
23	Christian	Yes	No	62	65	67	62	67	67	63	56	67	71	63.7

Table 2: Summary Statistics for Each Treatment Combination (Music × Gum)

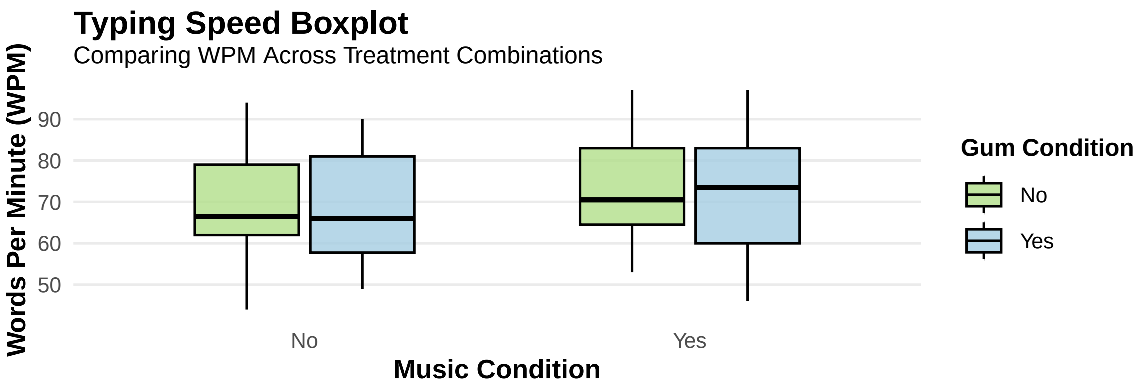
Music	Gum	Mean_WPM	SD_WPM	N_Runs	Min_WPM	Max_WPM
No	No	70.78	11.71	40	44	94
No	Yes	68.33	12.43	40	49	90
Yes	No	73.97	12.14	40	53	97
Yes	Yes	72.08	12.81	40	46	97

Table 3: Summary Statistics by Participant (Block) and Treatment

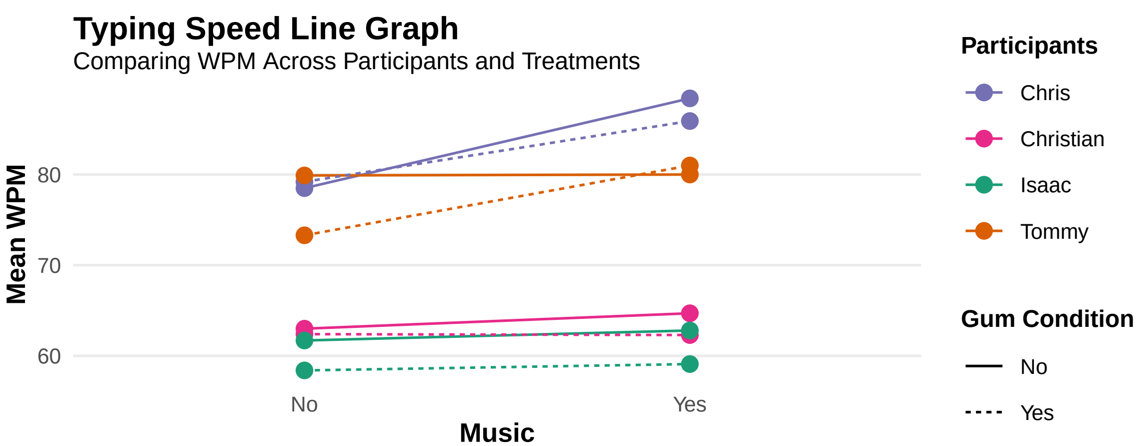
Participant	Music	Gum	Mean_WPM	SD_WPM	N_Runs	Min_WPM	Max_WPM
Chris	No	No	78.5	11.15	10	58	91
Chris	No	Yes	79.2	6.70	10	70	88
Chris	Yes	No	88.4	6.65	10	78	97
Chris	Yes	Yes	85.9	5.38	10	79	97
Christian	No	No	63.0	7.41	10	44	70
Christian	No	Yes	62.4	9.19	10	49	80
Christian	Yes	No	64.7	4.14	10	56	71
Christian	Yes	Yes	62.3	4.76	10	56	72
Isaac	No	No	61.7	2.71	10	58	66
Isaac	No	Yes	58.4	4.50	10	51	64
Isaac	Yes	No	62.8	4.08	10	53	67
Isaac	Yes	Yes	59.1	7.39	10	46	73
Tommy	No	No	79.9	9.52	10	65	94
Tommy	No	Yes	73.3	14.58	10	51	90
Tommy	Yes	No	80.0	7.39	10	70	94
Tommy	Yes	Yes	81.0	3.23	10	74	84

4 Analysis

Exploratory Data



Initially, the data leads to the initial observation that neither the gum nor music treatments appear to have a strong effect on the average WPM. This is primarily evident in the above box plot, which displays the four means(corresponding to the four treatment conditions) as being all within each others' standard deviations. However, there is a slight indication that music may have a positive effect on WPM, as the two "Yes" music conditions have marginally higher means than their "No" music counterparts.
All four of the means are relatively close together, with the highest mean (73.97 WPM for Yes Music and No Gum) being only about 5 WPM higher than the lowest mean (68.33 WPM for No Music and Yes Gum). Additionally, all of the observations have relatively high standard deviations(all of which hover around 12 WPM), indicating a high level of variability in typing speeds across all treatment conditions. This suggests that individual differences between participants may be a more significant factor in typing speed than the treatments themselves.



Upon looking at the line graph above, we can see that there are substantial individual differences in typing speed among the four participants. Chris and Tommy consistently type at much higher speeds than Christian and Isaac across all treatment conditions. This suggests that individual baseline typing ability may play a more significant role in determining typing speed than the experimental treatments of music and gum. These strong block effects indicate that **participant variability is far larger than any music or gum effect**, and any conclusions about treatment differences must account for these baseline performance differences. Despite this, no definitive conclusions can be drawn from these initial observations alone, and further statistical analysis is necessary to determine the significance of any observed effects.

Hypothesis Testing

Before we conduct the ANOVA, we must first ensure that the assumptions of the test are met. The independence assumption is satisfied as each run was randomized for each participant, and there were breaks between runs to minimize fatigue or practice effects. The normality assumption is reasonably met, as indicated by the QQ plot and the Shapiro-Wilk test, which shows that while the data is not perfectly normal, the ANOVA is robust to moderate violations of normality with a sufficiently large sample size (n=160). The homoscedasticity assumption is also satisfied, as shown by the residuals vs. fitted plot and the Bartlett test, which indicates homogeneity of variances across treatment groups(all of the R processes used for validating the aforementioned asssumptions can be found in the *Tables, Figures, & Code* section). We then conducted AIC and BIC model selection procedures to identify the most appropriate model for our data(these processes can be found in the *Tables, Figures, & Code* section). Both methods suggested that the interaction term between music and gum did not significantly improve the model fit, leading us to exclude it from the final model. **The final model followed: WPM ~ music + gum + participants.** We establish the following hypotheses:

$$\begin{aligned} H_0 &: \beta_{\text{music}} = 0 \\ H_1 &: \beta_{\text{music}} \neq 0 \\ H_0 &: \beta_{\text{gum}} = 0 \\ H_1 &: \beta_{\text{gum}} \neq 0 \end{aligned} \tag{1}$$

We test these hypotheses using the following ANOVA table:

Table 4: Regression Results for WPM ~ music + gum + participants

term	estimate	std.error	statistic	p.value	conf.low	conf.high
(Intercept)	82.350	1.446	56.942	0.000	79.493	85.207
musicYes	3.475	1.181	2.943	0.004	1.142	5.808
gumYes	-2.175	1.181	-1.842	0.067	-4.508	0.158
participantsChristian	-19.900	1.670	-11.917	0.000	-23.199	-16.601
participantsIsaac	-22.500	1.670	-13.473	0.000	-25.799	-19.201
participantsTommy	-4.450	1.670	-2.665	0.009	-7.749	-1.151

Based on the aforementioned ANOVA results, we find that the p-value for the music treatment is 0.004, which is less than our significance level of 0.05. Therefore, we reject the null hypothesis for music and conclude that listening to music has a statistically significant effect on typing speed. On the other hand, the p-value for the gum treatment is 0.067, which is greater than 0.05. Thus, we fail to reject the null hypothesis for gum and conclude that chewing gum does not have a statistically significant effect on typing speed. Additionally, the three participants also show that they have statistically significant typing speeds than the baseline participant(Chris). This indicates that individual differences between participants play a significant role in typing speed, further emphasizing the importance of accounting for participant variability in our analysis.

Essentially, we are able to conclude the following:

- Listening to music has a statistically significant positive effect on typing speed. In our experiment, participants who listened to music typed, on average, about 3.5 WPM faster than those who did not listen to music. - Chewing gum does not have a statistically significant effect on typing speed. The data suggests a slight decrease in WPM when chewing gum, but this effect is only significant at the 0.1 level, not the required 0.05 level. Therefore, this conclusion is marginal, but we cannot confidently state that gum has a meaningful impact on typing speed.
- There is no significant interaction effect between music and gum on typing speed. The lack of a significant interaction term in our model indicates that the effects of music and gum on typing speed are independent

of each other.
- The largest source of variation and significance in typing speed comes from individual differences between participants. The participants themselves were consistent around their own average WPM, but there were large differences in average WPM between participants. This suggests that inherent typing ability or other individual factors play a more substantial role in determining typing speed than the experimental treatments.

Tables, Figures, & Code:

Validity of the ANOVA Assumptions

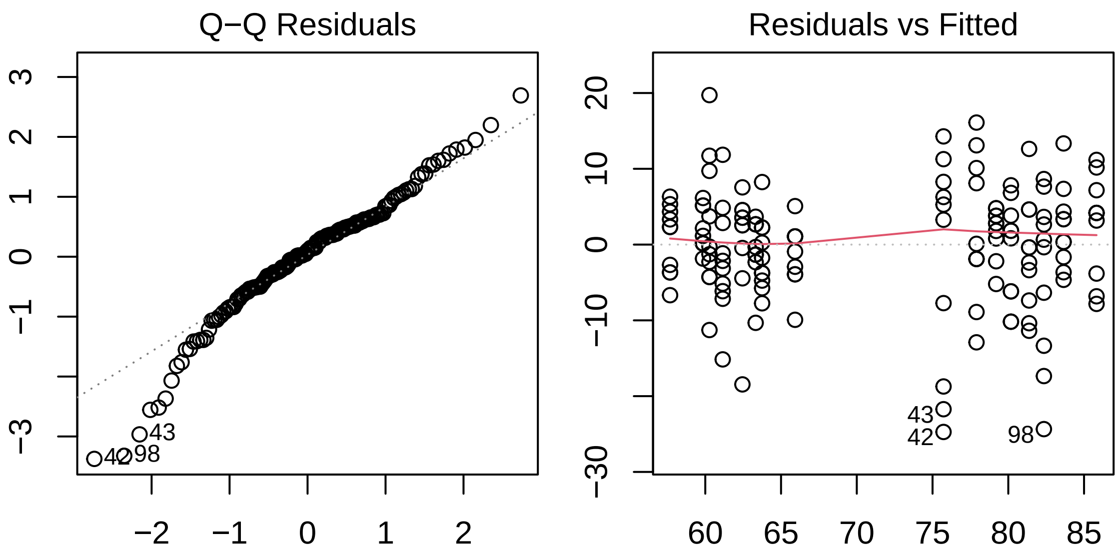


Figure 1: ANOVA Diagnostic Plots (Q-Q and Residuals vs Fitted)

Table 5: Shapiro–Wilk Normality Test

	Statistic	P_Value
W	0.96554	0.0005095

Table 6: Bartlett Test for Homogeneity of Variances

	K_Squared	df	P_Value
Bartlett's K-squared	0.32859	3	0.95456

AIC and BIC Model Selection

Table 7: Stepwise Model Selection for WPM

Step	Model	AIC	RSS
Start	WPM ~ music + gum + music*gum + participants	651.24	8586.2
Remove music	WPM ~ music + gum + participants	649.29	8589.2
Remove gum	WPM ~ music + participants	650.78	8778.5

Step	Model	AIC	RSS
Remove music	WPM ~ gum + participants	656.05	9072.3
Remove participants	WPM ~ music + gum	804.49	23522.5

Additional Code Found in Appendices
The following code is organized and found in the appendices section in the following order:
6.1) Summary Statistics from Section 3(Data Collection~Data Presentation)
6.2) Box Plot and Line Graph from Section 4(Analysis~Exploratory Data)
6.3) Regression Table from Section 4(Analysis~Hypothesis Testing)
6.4) Assumption Graphs from Section 4(Analysis~Tables, Figures, & Code)
6.5) Assumption Tables from Section 4(Analysis~Tables, Figures, & Code)
6.6) AIC and BIC Model Selection from Section 4(Analysis~Tables, Figures, & Code)
6.7) Initial Data Frame of Experiment Results
6.8) ANOVA Model Using Averages(instead of raw data)
6.9) ANOVA Model Using Raw Data(before AIC/BIC optimization)
6.10) Full AIC/BIC Model Selection
6.11) Interaction Plot Visual
[6.1 - 6.6 are snippets of code that were used in the report's sections 1-5; the output of these snippets are hidden in the appendix, but visible in the report sections]
[6.7 - 6.11 are snippets of code that were NOT used in the report's sections 1-5; the output of these snippets are visible in the appendix]

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5 Conclusions

- Based on the ANOVA results, we conclude that listening to music has a statistically significant positive effect on typing speed, while chewing gum does not have a statistically significant effect. There is no significant interaction effect between music and gum on typing speed. The largest source of variation in typing speed comes from individual differences between participants.
- However, due to the nature of our experimentation, these results can only be generalized to similar individuals performing similar tasks to the task in our experiment. Further research with a larger and more diverse sample size would be necessary to generalize these findings to a broader population. However, it is safe to say that for the participants in our study, listening to music had a significant effect by increasing the typing speed by ~3.5 WPM.
- The results of our experiments can be attributed to a number of possible reasons. For example, music may have had a positive, significant effect on typing speed since the participants could choose music they would typically study to, which may have enhanced their focus on the task at hand. Adversely, the music could have provided rhythm that the participants could have subconsciously followed while typing, leading to increased speed. On the other hand, chewing gum may not have had a significant effect because it could have been a distraction for some participants, or the act of chewing may not have provided any cognitive benefits that would translate to improved typing performance.
- Our experiment was limited in its findings mostly to the small sample size and the inability to control certain confounding variables. Despite our randomization, blocking, and replication of trials, there is no way to control the fact that people all have different inherent typing speeds and styles. Additionally, if this experiment were to be repeated, certain confounding variables should be controlled for, such as the type of music the participants listened to, the manufacturer of the keyboards used,

the gum flavor and brand, the time of day the experiment was conducted, and the environment in which the participants completed the task. Future studies could also explore different types of tasks beyond typing speed to see if the effects of music and gum vary across different cognitive or motor activities.

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6 Appendices

6.1) Summary Statistics from Section 3(Data Collection~Data Presentation)

```
library(tidyverse)
library(knitr)
set.seed(123)

participants <- c("Chris", "Christian", "Isaac", "Tommy")
conditions <- data.frame(
  Music = c("No", "Yes", "No", "Yes"),
  Gum   = c("No", "No", "Yes", "Yes")
)


randomize_conditions <- function(name) {
  cond <- conditions[sample(1:4), ]
  cond$Participant <- name
  cond
}

design_list <- lapply(sample(participants), randomize_conditions)
design_df <- do.call(rbind, design_list)

design_df$Run1 <- c(62, 66, 60, 65, 57, 91, 94, 82, 78, 82, 82, 82, 60, 66, 72, 62)
design_df$Run2 <- c(51, 61, 56, 62, 51, 65, 86, 84, 79, 76, 91, 82, 66, 65, 49, 65)
design_df$Run3 <- c(54, 53, 46, 58, 54, 94, 81, 82, 96, 69, 87, 74, 58, 58, 80, 67)
design_df$Run4 <- c(55, 67, 54, 60, 84, 76, 81, 83, 90, 86, 88, 84, 60, 65, 70, 62)
design_df$Run5 <- c(63, 62, 58, 61, 79, 76, 79, 81, 89, 91, 97, 88, 64, 70, 56, 67)
design_df$Run6 <- c(61, 62, 55, 60, 90, 88, 74, 74, 82, 85, 79, 87, 56, 67, 59, 67)
design_df$Run7 <- c(60, 63, 64, 60, 68, 69, 71, 80, 97, 90, 87, 70, 62, 62, 58, 63)
design_df$Run8 <- c(64, 62, 73, 66, 81, 78, 78, 77, 93, 58, 84, 81, 59, 44, 56, 56)
design_df$Run9 <- c(54, 66, 59, 60, 82, 86, 86, 83, 90, 65, 84, 74, 66, 67, 64, 67)
design_df$Run10 <- c(60, 66, 66, 65, 87, 76, 70, 84, 90, 83, 80, 70, 72, 66, 60, 71)
design_df$Avg <- c(59.4, 62.1, 68, 59.5, 91.3, 79.9, 78, 76.8, 98.1, 78.6, 88.9, 81,
                   62.5, 62, 90.4, 63.7)

design_df <- design_df[, c("Participant", "Music", "Gum",
                           "Run1", "Run2", "Run3", "Run4", "Run5", "Run6", "Run7",
                           "Run8","Run9", "Run10","Avg")]

```

```r

knitr::kable(design_df)


# Convert wide → long format for summary statistics
long_df <- design_df |>
  pivot_longer(
    cols = starts_with("Run"),
    names_to = "Run",
    values_to = "WPM"
  )

# Compute summary statistics by Music × Gum
treatment_summary <- long_df |>
  group_by(Music, Gum) |>
  summarise(
    Mean_WPM = mean(WPM),
    SD_WPM   = sd(WPM),
    N_Runs   = n(),
    Min_WPM  = min(WPM),
    Max_WPM  = max(WPM),
    .groups = "drop"
  )

# Knit summary table
kable(
  treatment_summary,
  caption = "Summary Statistics for Each Treatment Combination (Music × Gum)",
  digits = 2,
  align = "c"
)

# Summary by participant block (Participant × Music × Gum)
participant_summary <- long_df |>
  group_by(Participant, Music, Gum) |>
  summarise(
    Mean_WPM = mean(WPM),
    SD_WPM   = sd(WPM),
    N_Runs   = n(),
    Min_WPM  = min(WPM),
    Max_WPM  = max(WPM),
    .groups = "drop"
  ) |>
  arrange(Participant, Music, Gum)

kable(
  participant_summary,
  caption = "Summary Statistics by Participant (Block) and Treatment",
  digits = 2,
  align = "c"
```

```
)
```

6.2) Box Plot and Line Graph from Section 4(Analysis~Exploratory Data)

```
library(ggplot2)
library(tidyr)
library(dplyr)

monkey_data_frame <- data.frame(
    participants = rep(c("Isaac", "Tommy", "Chris", "Christian"), each = 4) ,

    music = c("No", "Yes", "Yes", "No",
              "No", "No", "Yes", "Yes",
              "Yes", "No", "Yes", "No",
              "Yes", "No", "No", "Yes") ,

    gum = c("Yes", "No", "Yes", "No",
              "Yes", "No", "No", "Yes",
              "No", "No", "Yes", "Yes",
              "Yes", "No", "Yes", "No") ,

    run1 = c(62, 66, 60, 65, 57, 91, 94, 82, 78, 82, 82, 82, 60, 66, 72, 62),
    run2 = c(51, 61, 56, 62, 51, 65, 86, 84, 79, 76, 91, 82, 66, 65, 49, 65),
    run3 = c(54, 53, 46, 58, 54, 94, 81, 82, 96, 69, 87, 74, 58, 58, 80, 67),
    run4 = c(55, 67, 54, 60, 84, 76, 81, 83, 90, 86, 88, 84, 60, 65, 70, 62),
    run5 = c(63, 62, 58, 61, 79, 76, 79, 81, 89, 91, 97, 88, 64, 70, 56, 67),
    run6 = c(61, 62, 55, 60, 90, 88, 74, 74, 82, 85, 79, 87, 56, 67, 59, 67),
    run7 = c(60, 63, 64, 60, 68, 69, 71, 80, 97, 90, 87, 70, 62, 62, 58, 63),
    run8 = c(64, 62, 73, 66, 81, 78, 78, 77, 93, 58, 84, 81, 59, 44, 56, 56),
    run9 = c(54, 66, 59, 60, 82, 86, 86, 83, 90, 65, 84, 74, 66, 67, 64, 67),
    run10 = c(60, 66, 66, 65, 87, 76, 70, 84, 90, 83, 80, 70, 72, 66, 60, 71),
    average = c(59.4, 62.1, 68, 59.6, 91.3, 79.9, 78, 76.8, 98.1, 78.6, 88.9,
                81, 62.5, 62, 90.4, 63.7)
)

long_data <- monkey_data_frame |>
    pivot_longer(
        cols = starts_with("run"),
        names_to = "run",
        values_to = "WPM"
    )
tight_theme <- theme_minimal(base_size = 10, base_family = "sans") +
  theme(
    plot.title = element_text(face = "bold", size = 12, margin = margin(b = 2)),
    plot.subtitle = element_text(size = 9, margin = margin(b = 4)),
    axis.title = element_text(face = "bold", size = 10),
    axis.text = element_text(size = 8),
    legend.title = element_text(face = "bold", size = 9),
    legend.text = element_text(size = 8),
    panel.grid.minor = element_blank(),
```

```r
    panel.grid.major.x = element_blank(),
    plot.margin = margin(t = 2, r = 2, b = 2, l = 2)
  )

theme_set(tight_theme)

# participants color palette (used in line graph)
my_colors <- c(
  "Isaac" = "#1b9e77",
  "Tommy" = "#d95f02",
  "Chris" = "#7570b3",
  "Christian" = "#e7298a"
)

# gum fill palette (used in both)
gum_colors <- c(
  "Yes" = "#a6cee3",
  "No" = "#b2df8a"
)

monkey_boxplot <- ggplot(long_data, aes(x = music, y = WPM, fill = gum)) +
    geom_boxplot(alpha = 0.8, width = 0.6, color = "black") +
    scale_fill_manual(values = gum_colors) +
    labs(
        title = "Typing Speed Boxplot",
        subtitle = "Comparing WPM Across Treatment Combinations",
        x = "Music Condition",
        y = "Words Per Minute (WPM)",
        fill = "Gum Condition"
    )

monkey_boxplot

participant_means <- long_data |>
  group_by(participants, music, gum) |>
  summarise(Mean_WPM = mean(WPM), .groups = "drop")

monkey_lineplot <- ggplot(
  participant_means,
  aes(
    x = music,
    y = Mean_WPM,
    color = participants,
    group = interaction(participants, gum),
    linetype = gum
  )
) +
  geom_line() +
  geom_point(size = 2.5) +
  scale_color_manual(values = my_colors) +
```

```r
  labs(
    title = "Typing Speed Line Graph",
    subtitle = "Comparing WPM Across Participants and Treatments",
    x = "Music",
    y = "Mean WPM",
    color = "Participants",
    linetype = "Gum Condition"
  )

monkey_lineplot
```

6.3) Regression Table from Section 4(Analysis~Hypothesis Testing)

```r
library(broom)
library(knitr)

model <- lm(WPM ~ music + gum + participants, data = long_data)

kable(
  tidy(model, conf.int = TRUE),
  digits = 3,
  caption = "Regression Results for WPM ~ music + gum + participants",
  align = "c"
)
```

6.4) Assumption Graphs from Section 4(Analysis~Tables, Figures, & Code)

```r
model <- lm(WPM ~ music + gum + participants, data = long_data)
par(mfrow = c(1,2), mar = c(2,2,2,1), oma = c(0,0,0,0), asp=NA)
plot(model, which = 2)
plot(model, which = 1)
par(mfrow = c(1,1))
```

6.5) Assumption Tables from Section 4(Analysis~Tables, Figures, & Code)

```r
sw <- shapiro.test(residuals(model))

sw_table <- data.frame(
  Statistic = round(sw$statistic, 5),
  P_Value   = signif(sw$p.value, 5)
)

knitr::kable(sw_table, align = "c", caption = "Shapiro-Wilk Normality Test")
long_data$group <- paste(long_data$music, long_data$gum, sep = "_")

bt <- bartlett.test(WPM ~ group, data = long_data)

bt_table <- data.frame(
```

```
  K_Squared = round(bt$statistic, 5),
  df        = bt$parameter,
  P_Value   = signif(bt$p.value, 5)
)

knitr::kable(bt_table,
             align = "c",
             caption = "Bartlett Test for Homogeneity of Variances")
```

6.6) AIC and BIC Model Selection from Section 4(Analysis~Tables, Figures, & Code)

```
library(knitr)
model_summary <- data.frame(
Step = c("Start", "Remove music", "Remove gum", "Remove music", "Remove participants"),
Model = c(
"WPM ~ music + gum + music*gum + participants",
"WPM ~ music + gum + participants",
"WPM ~ music + participants",
"WPM ~ gum + participants",
"WPM ~ music + gum"
),
AIC = c(651.24, 649.29, 650.78, 656.05, 804.49),
RSS = c(8586.2, 8589.2, 8778.5, 9072.3, 23522.5)
)

kable(model_summary, digits = 2, caption = "Stepwise Model Selection for WPM")
```

6.7) Initial Data Frame of Experiment Results

```
library(dbplyr)
library(tidyr)
library(tidyverse)
library(DescTools)

# 1) DATAFRAME:
monkey_data_frame <- data.frame(
    participants = rep(c("Isaac", "Tommy", "Chris", "Christian"), each = 4) ,

    music = c("No", "Yes", "Yes", "No",
              "No", "No", "Yes", "Yes",
              "Yes", "No", "Yes", "No",
              "Yes", "No", "No", "Yes") ,

    gum = c("Yes", "No", "Yes", "No",
              "Yes", "No", "No", "Yes",
              "No", "No", "Yes", "Yes",
              "Yes", "No", "Yes", "No") ,

    run1 = c(62, 66, 60, 65, 57, 91, 94, 82, 78, 82, 82, 82, 60, 66, 72, 62),
```

```r
    run2 = c(51, 61, 56, 62, 51, 65, 86, 84, 79, 76, 91, 82, 66, 65, 49, 65),
    run3 = c(54, 53, 46, 58, 54, 94, 81, 82, 96, 69, 87, 74, 58, 58, 80, 67),
    run4 = c(55, 67, 54, 60, 84, 76, 81, 83, 90, 86, 88, 84, 60, 65, 70, 62),
    run5 = c(63, 62, 58, 61, 79, 76, 79, 81, 89, 91, 97, 88, 64, 70, 56, 67),
    run6 = c(61, 62, 55, 60, 90, 88, 74, 74, 82, 85, 79, 87, 56, 67, 59, 67),
    run7 = c(60, 63, 64, 60, 68, 69, 71, 80, 97, 90, 87, 70, 62, 62, 58, 63),
    run8 = c(64, 62, 73, 66, 81, 78, 78, 77, 93, 58, 84, 81, 59, 44, 56, 56),
    run9 = c(54, 66, 59, 60, 82, 86, 86, 83, 90, 65, 84, 74, 66, 67, 64, 67),
    run10 = c(60, 66, 66, 65, 87, 76, 70, 84, 90, 83, 80, 70, 72, 66, 60, 71),
    average = c(59.4, 62.1, 68, 59.6, 91.3, 79.9, 78, 76.8, 98.1, 78.6, 88.9,
                81, 62.5, 62, 90.4, 63.7)
)

monkey_data_frame
```

```
   participants music gum run1 run2 run3 run4 run5 run6 run7 run8 run9 run10
1         Isaac    No Yes   62   51   54   55   63   61   60   64   54    60
2         Isaac   Yes  No   66   61   53   67   62   62   63   62   66    66
3         Isaac   Yes Yes   60   56   46   54   58   55   64   73   59    66
4         Isaac    No  No   65   62   58   60   61   60   60   66   60    65
5         Tommy    No Yes   57   51   54   84   79   90   68   81   82    87
6         Tommy    No  No   91   65   94   76   76   88   69   78   86    76
7         Tommy   Yes  No   94   86   81   81   79   74   71   78   86    70
8         Tommy   Yes Yes   82   84   82   83   81   74   80   77   83    84
9         Chris   Yes  No   78   79   96   90   89   82   97   93   90    90
10        Chris    No  No   82   76   69   86   91   85   90   58   65    83
11        Chris   Yes Yes   82   91   87   88   97   79   87   84   84    80
12        Chris    No Yes   82   82   74   84   88   87   70   81   74    70
13    Christian   Yes Yes   60   66   58   60   64   56   62   59   66    72
14    Christian    No  No   66   65   58   65   70   67   62   44   67    66
15    Christian    No Yes   72   49   80   70   56   59   58   56   64    60
16    Christian   Yes  No   62   65   67   62   67   67   63   56   67    71
   average
1     59.4
2     62.1
3     68.0
4     59.6
5     91.3
6     79.9
7     78.0
8     76.8
9     98.1
10    78.6
11    88.9
12    81.0
13    62.5
14    62.0
15    90.4
16    63.7
```

6.8) ANOVA Model Using Averages(instead of raw data)

```r
model_average <- lm(average ~ gum + music + gum*music + participants,
                    data = monkey_data_frame)
average_anova_result <- anova(model_average)
average_anova_result
```

```
Analysis of Variance Table

Response: average
             Df  Sum Sq Mean Sq F value  Pr(>F)
gum           1   82.36   82.36  0.9701 0.35039
music         1    1.05    1.05  0.0124 0.91386
participants  3 1474.08  491.36  5.7878 0.01742 *
gum:music     1  142.21  142.21  1.6751 0.22780
Residuals     9  764.06   84.90
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
average_summary_result <- summary(model_average)
print(average_summary_result)
```

```
Call:
lm(formula = average ~ gum + music + gum * music + participants,
    data = monkey_data_frame)

Residuals:
    Min      1Q  Median      3Q     Max
-11.156  -4.513  -1.644   3.619  15.244

Coefficients:
                      Estimate Std. Error t value Pr(>|t|)
(Intercept)             81.656      6.094  13.399    3e-07 ***
gumYes                  10.500      6.515   1.612  0.14150
musicYes                 5.450      6.515   0.837  0.42452
participantsChristian  -17.000      6.515  -2.609  0.02830 *
participantsIsaac      -24.375      6.515  -3.741  0.00462 **
participantsTommy       -5.150      6.515  -0.790  0.44958
gumYes:musicYes        -11.925      9.214  -1.294  0.22780
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 9.214 on 9 degrees of freedom
Multiple R-squared:  0.6899,    Adjusted R-squared:  0.4831
F-statistic: 3.337 on 6 and 9 DF,  p-value: 0.05148
```

6.9) ANOVA Model Using Raw Data(before AIC/BIC optimization)

```r
long_data <- monkey_data_frame |>
    pivot_longer(
        cols = starts_with("run"),
        names_to = "run",
        values_to = "WPM" )
head(long_data, 50)
```

```
# A tibble: 50 x 6
   participants music gum   average run     WPM
   <chr>        <chr> <chr>   <dbl> <chr> <dbl>
 1 Isaac        No    Yes      59.4 run1     62
 2 Isaac        No    Yes      59.4 run2     51
 3 Isaac        No    Yes      59.4 run3     54
 4 Isaac        No    Yes      59.4 run4     55
 5 Isaac        No    Yes      59.4 run5     63
 6 Isaac        No    Yes      59.4 run6     61
 7 Isaac        No    Yes      59.4 run7     60
 8 Isaac        No    Yes      59.4 run8     64
 9 Isaac        No    Yes      59.4 run9     54
10 Isaac        No    Yes      59.4 run10    60
# i 40 more rows
```

```r
model_all <- lm(WPM ~ music + gum + music*gum + participants, data = long_data)
anova(model_all)
```

```
Analysis of Variance Table

Response: WPM
              Df  Sum Sq Mean Sq F value    Pr(>F)
music          1   483.0   483.0  8.6071  0.003864 **
gum            1   189.2   189.2  3.3718  0.068260 .
participants   3 14933.3  4977.8 88.6999 < 2.2e-16 ***
music:gum      1     3.0     3.0  0.0539  0.816716
Residuals    153  8586.2    56.1
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```r
print(summary(model_all))
```

```
Call:
lm(formula = WPM ~ music + gum + music * gum + participants,
    data = long_data)

Residuals:
     Min       1Q   Median       3Q      Max
-24.5875  -3.7875   0.5875   4.3125  19.8625
```

```
Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)              82.487      1.567  52.643  < 2e-16 ***
musicYes                  3.200      1.675   1.910  0.05796 .
gumYes                   -2.450      1.675  -1.463  0.14563
participantsChristian   -19.900      1.675 -11.880  < 2e-16 ***
participantsIsaac       -22.500      1.675 -13.432  < 2e-16 ***
participantsTommy        -4.450      1.675  -2.657  0.00873 **
musicYes:gumYes           0.550      2.369   0.232  0.81672
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 7.491 on 153 degrees of freedom
Multiple R-squared:  0.6451,	Adjusted R-squared:  0.6312
F-statistic: 46.36 on 6 and 153 DF,  p-value: < 2.2e-16
```

6.10) Full AIC/BIC Model Selection

```r
library(car)
model_all <- lm(WPM ~ music + gum + music*gum + participants, data = long_data)
step(model_all, direction = "both")
```

```
Start:  AIC=651.24
WPM ~ music + gum + music * gum + participants

               Df Sum of Sq     RSS    AIC
- music:gum     1         3  8589.2 649.29
<none>                       8586.2 651.24
- participants  3     14933 23519.5 806.47

Step:  AIC=649.29
WPM ~ music + gum + participants

               Df Sum of Sq     RSS    AIC
<none>                       8589.2 649.29
- gum           1     189.2  8778.5 650.78
+ music:gum     1       3.0  8586.2 651.24
- music         1     483.0  9072.3 656.05
- participants  3   14933.3 23522.5 804.49


Call:
lm(formula = WPM ~ music + gum + participants, data = long_data)

Coefficients:
          (Intercept)               musicYes                 gumYes
               82.350                  3.475                 -2.175
participantsChristian      participantsIsaac      participantsTommy
              -19.900                -22.500                 -4.450
```

```r
n <- nrow(long_data)
step(model_all, direction = "both", k =log(n))
```

```
Start:  AIC=672.76
WPM ~ music + gum + music * gum + participants

               Df Sum of Sq     RSS    AIC
- music:gum     1         3  8589.2 667.75
<none>                       8586.2 672.76
- participants  3     14933 23519.5 818.77

Step:  AIC=667.75
WPM ~ music + gum + participants

               Df Sum of Sq     RSS    AIC
- gum           1     189.2  8778.5 666.16
<none>                       8589.2 667.75
- music         1     483.0  9072.3 671.42
+ music:gum     1       3.0  8586.2 672.76
- participants  3   14933.3 23522.5 813.71

Step:  AIC=666.16
WPM ~ music + participants

               Df Sum of Sq     RSS    AIC
<none>                       8778.5 666.16
+ gum           1     189.2  8589.3 667.75
- music         1     483.0  9261.5 669.65
- participants  3   14933.3 23711.8 809.92


Call:
lm(formula = WPM ~ music + participants, data = long_data)

Coefficients:
          (Intercept)               musicYes  participantsChristian
               81.262                  3.475                -19.900
    participantsIsaac      participantsTommy
              -22.500                 -4.450
```

6.11) Interaction Plot Visual

```r
library(ggplot2)

mean_data <- long_data |>
    group_by(music, gum) |>
    summarise(Mean_WPM = mean(WPM))

```

```
interaction_plot <- ggplot(mean_data, aes(x = music, y = Mean_WPM,
                                           color = gum, group = gum)) +
  geom_line(size = 1.5) +
  geom_point(size = 3) +
  labs(
    title = "Interaction Plot: Music × Gum Effects on Average Typing Speed",
    x = "Music",
    y = "Mean WPM" )

interaction_plot
```