The Effect of Caffeine on Reaction Time

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Data Collection Plan

Introduction

1.1 Importance of Study

The consumption of coffee/caffeine started from the late 15th century and up until now there is a huge consumption of coffee/caffeine worldwide. Its popularity is attributed to the effects that consumption brings, some of which being heightened awareness, increased cognitive and physical function and a decrease in fatigue (McLellan, 2016). Amongst the effects of cognitive functions, the speed of reaction is shown to have an increase after the consumption of coffee (McLellan, 2016).

Circadian rhythms are an internal clock that controls the fluctuation of hormones released over a 24 hour cycle. These fluctuations in hormones govern the times that animals feel alert, energetic, and cognitively sharp. Typically, peak performance is after waking up, usually day time, and with a decline as it reaches night-time. During the circadian rhythms, reaction time fluctuates across the day with mid morning being the peak performance with a steady decrease till night time (Riley, 2017).

These effects on speed of reaction time have caught the attention of the QUT esports team which has hired our team of statisticians to investigate. They are interested in the effects of caffeine as well as the interaction that circadian rhythms have on reaction times as the games they compete in require fast reaction times to achieve high performances against opposing teams. Thus our investigation aims to provide insights for the esports team regarding the optimal timing for caffeine consumption to counteract natural dips in body's performance experienced by players.

1.2 Aims and Variables of Study

According to researchers, consumption of caffeine would lead to a faster reaction time and lower decision making errors when performing both simple and choice based reaction time tests.

The evaluation of the experiment used in this report will provide evidence for the possible effect of caffeine and time after awakening on reaction time which will inform the QUT esports team on whether they should provide their teams with caffeine and what time they should be

scheduling events to maximise reaction time. The variables taken into account for this experiment are caffeine dosage, the individual and time since individuals have woken up.

1.2.1 Questions to be answered

- Does the dosage of caffeine have a significant effect on reaction time of an individual?
- Does the same amount of caffeine have a different effect for each individual due to their difference in their metabolic activity?
- Does time since waking up have an effect on reaction time with or without caffeine ingestion?
- How long after being awake has the fastest reaction time with or without caffeine?
- Does being awake longer have an effect on reaction time?
- Is there a relationship between being awake longer and reaction time?

1.3 Measurement of variables

This section will describe and justify the factors chosen for this experiment. The variables were chosen due to their reasonability:

1.3.1 Individual (categorical, blocking)

There are four individual participants, each serving as a blocking factor due to the varying differences in characteristics and traits that each participant may have, which could affect their reaction time. This consideration nullifies confounding variables that are not a primary interest in the study. This helps improve the validity of the analysis as it accounts for variations between individuals that could have affected their reaction time other than caffeine dosage.

1.3.2 Caffeine (binary)

Caffeine is a binary variable that describes whether the experimental unit (person) has ingested coffee, known to contain caffeine. Since, the experiment is set up according to within-subject design, each participant will ingest 8 grams of coffee or no coffee everyday the experiment is conducted. The effects of newly ingested caffeine is known to wear off after 6 hours in a healthy adult body, therefore it is appropriate for the participants to repeat the experiment after a day, meaning the results of the reaction times will be independent. The participants will also wait 30 minutes after consuming coffee before they record their reaction time. This delay allows their body to fully absorb caffeine and ensure maximum effects.

1.3.3 Time since woken up (Continuous)

The participants will record the duration in hours since they've woken up when conducting the test. Each individual has the flexibility to intake coffee anytime after waking up. While the duration of wakefulness is not regulated within the experimental design, participants are encouraged to undertake the reaction test at different intervals after waking up to facilitate more comprehensive analysis.

1.4 Assumptions and limitations

The following section outlines the limitations and assumptions with respect to the experiment.

1.4.1 Limitations

- Each person intakes caffeine at different rates. It is dependent on their size and metabolism so the wait period can't properly enclose the wait time for each person measured in the study.
- Due to time constraints, each factor had 2 replicants.
- Only caffeine intake, time after waking and different individuals was taken into consideration on the effects of reaction time.
- The amount of food intake before caffeine consumption was not controlled in the experiment.

1.4.2 Assumptions

- Each dosage of caffeine taken is 8 grams.
- Each measurement is accurate and precise.
- Uncontrollable factors will have negligible effects on the results (e.g. differing testing locations, amount of adrenaline,diet).
- The time since waking will be a continuous variable with a restriction preventing it from being zero or less.
- The effects of participants knowing if they've taken caffeine or not will not change the results of reaction time.
- The participant has waited for 30 to 35 minutes before completing the reaction test.
- The participant has not ingested other stimulants that could have a significant effect on their reaction time.

2. Literature Review

As previously stated, the experiment involves testing the reaction time of individuals, which will be recorded for each treatment. Caffeine dosage and person will be manipulated to measure their effects on reaction time of humans. While the time since an individual has been awake for, will not be manipulated yet still be recorded to allow for further analysis.

Two levels of caffeine were chosen: a control group without caffeine and an experimental group with a single dose of caffeine. As a discrete variable, a single dose was chosen as that is the standard dosage used in one single shot of coffee. A single dose being 7-8 grams of coffee grounds. Given the properties of caffeine consumption to increase cognitive processing the increase of dosage is hypothesised to provide an increase in reaction time to stimuli (McLellan, 2016). From this, it can be predicted that no caffeine will perform worse in respect to reaction compared to one dose of caffeine.

Caffeine is a psychoactive stimulant which when consumed will affect the brain's processing. Caffeine achieves this by preventing the neurotransmitter adenosine, a neurotransmitter that promotes drowsiness (Denise, 2021). By blocking this molecule, it promotes faster reaction time and alertness. It also causes an increase in release of dopamine and norepinephrine, which are involved in cognitive processes.
The time since waking up was selected as the variable of interest because melatonin levels, responsible for sleep and tiredness, vary throughout the day due to the circadian rhythms (Brown, 1994). Melatonin levels are lowest after waking up, leading to increased alertness, while they gradually increase in the evening and night, causing drowsiness. By examining reaction time at different intervals since waking up, we can assess the effects of caffeine at different times of day. Research suggests that caffeine consumption decreases melatonin levels, resulting in increased alertness and activity (Burke & Markwald, 2016).

The blocking factor used in the experiment will be each individual who partakes in the experiment. Individuals have unique characteristics and traits that may influence their reaction time, therefore it was deemed important to block this variable as it will allow for the removal of the nuisance variable. Research shows that factors such as someone's genetics, age, gender, and physical fitness can influence reaction time in individuals(Jain, 2015).

Based on the gathered evidence, it is anticipated that caffeine will enhance reaction time, particularly during periods of decreased performance.

3. Methods

The factors of interest:

- **Reaction Time ~ caffeine dosage + time since woken up + individual**

The following experimental design will be implemented as follows:

1. The study is conducted among four people (aged between 18 and 20).
2. Each participant will serve as their own control group, meaning they will experience both conditions (caffeine or no caffeine).
3. Participants will consume either 8 grams of coffee or no coffee on different trial days, with the order randomised using R studio.
4. The participants will not be allowed to consume substances containing caffeine at least 6 hours prior to the trail day.
5. Participants will ensure to conduct the experiment after a certain amount of time since waking up.
6. The participants should wait until the next day, ensuring a minimum of 6 hour between trials, to maintain consistency and control for potential confounding variables.
7. Reaction time will be measured using the website https://humanbenchmark.com/tests/reactiontime.
8. Measurements will be taken 30 minutes after caffeine intake and recorded in an Excel table.
9. Each participant will complete the same number of trails with both treatments.

The predictor variables of this experiment:

1. Caffeine intake.
2. The time of caffeine consumption (time since waking up).
3. Individual (blocking).

Hence the experiment follows a factorial, complete, balanced and randomised design. It is designed according to within-subject design where each participant ingests 8 grams of coffee or no coffee, at various intervals since waking up. This allows the team to investigate how caffeine affects reaction time during different cycles during the circadian rhythm. Coffee has been

selected as the caffeine source due to its accessibility and affordability compared to other sources.

The major limitation faced by the experiment is the effectiveness of caffeine in each individual. Metabolism is different in each individual because it depends on gender, age and other individual characteristics. Other factors like sleep quality and duration also play a crucial role as poor sleep quality or less sleep can interfere with caffeine's impact on reaction time, and combining caffeine with sleep deprivation may also exacerbate its effects.

There are constraints with the time after sleep as the variable is not being controlled, preventing detailed exploration of its effects on reaction time. Other uncontrollable factors such as medications, nutrients, hydration and psychological factors like anxiety, stress and mood influence reaction time. Furthermore due to limitations in time, it may not be feasible to measure more than two replicates of each treatment. This will limit the statistical power of the experiment.

4.0 Analysis

The original methods of the experiment were varied to have the original covariate time as a controlled variable with three levels - morning (6-10 am), midday (10am to 2 pm) and afternoon (2-6pm).

Exploratory analysis:

From the exploratory analysis of the data collected, initial summaries can be provided. This initial evidence will allow for predictions of what will be found through formal data analysis. These predictions that will be discussed will be of the relationships between reaction time, coffee intake, time of day and person in relation to the hypothesis and the reliability of this data.

Figure 1: The overall change in reaction time depending on each separate factor

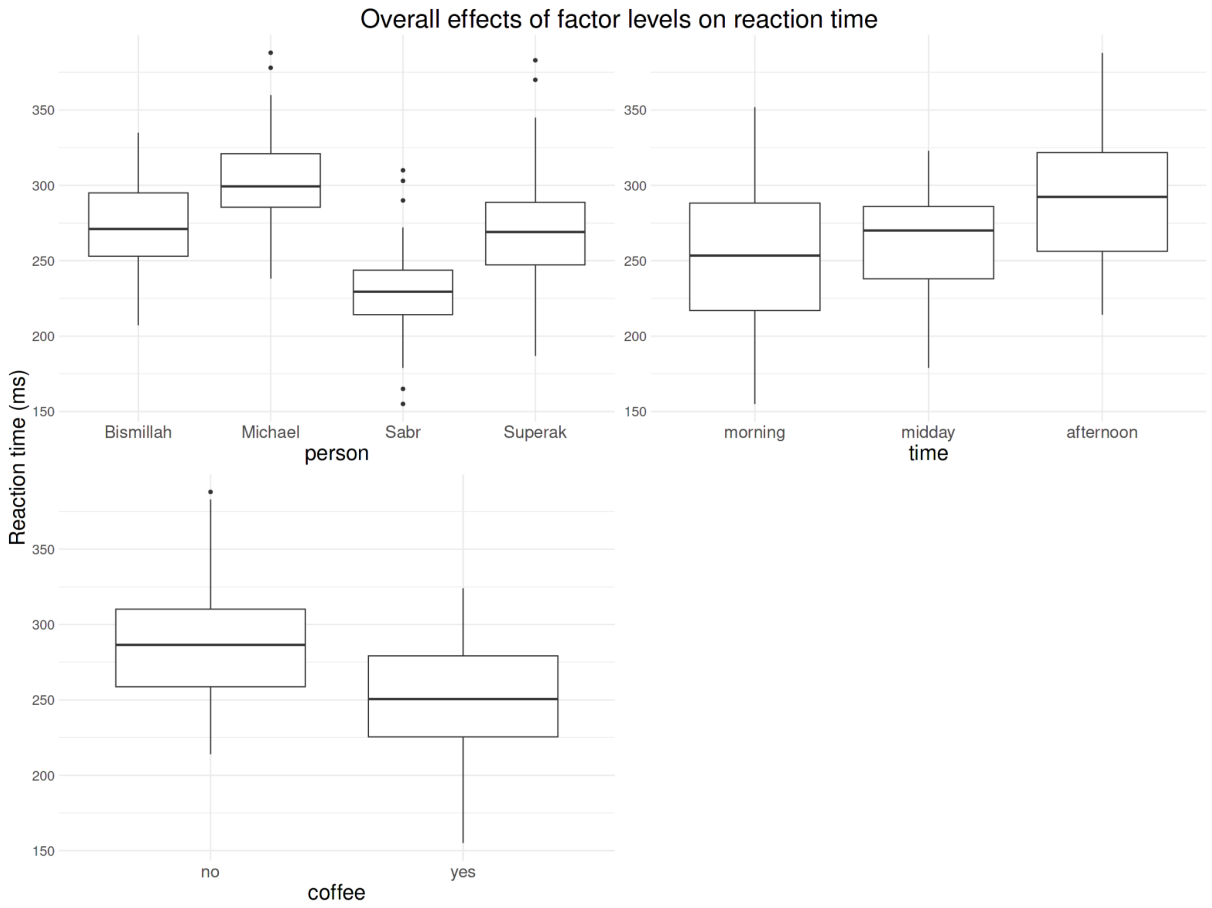


Figure 2: the summary statistic of each group of coffee and time

A grouped_df: 6 × 3

coffee	time	mean_reaction_time
<chr>	<fct>	<dbl>
no	morning	277.30
no	midday	265.90
no	afternoon	320.85
yes	morning	222.30
yes	midday	260.55
yes	afternoon	264.10

The first relationships to discuss are the base relationships of each factor on reaction time, these relationships can be seen through figure 1. The first of these will be reaction time's dependency on the participant. From Figure 1 it can be seen that there is a small difference in reaction times

between participants, with most of the whisker plots having overlapping quartiles. The outlier being Sabr's results having an overall lower result. This suggests that participants are a small factor in determining reaction time. This factor is consistent for all but one participant which suggests that there may be a problem with participant sampling in the data likely caused by participants having similar characteristics (eg. age, sex) or that the sample size is not large enough to fully show the extent.

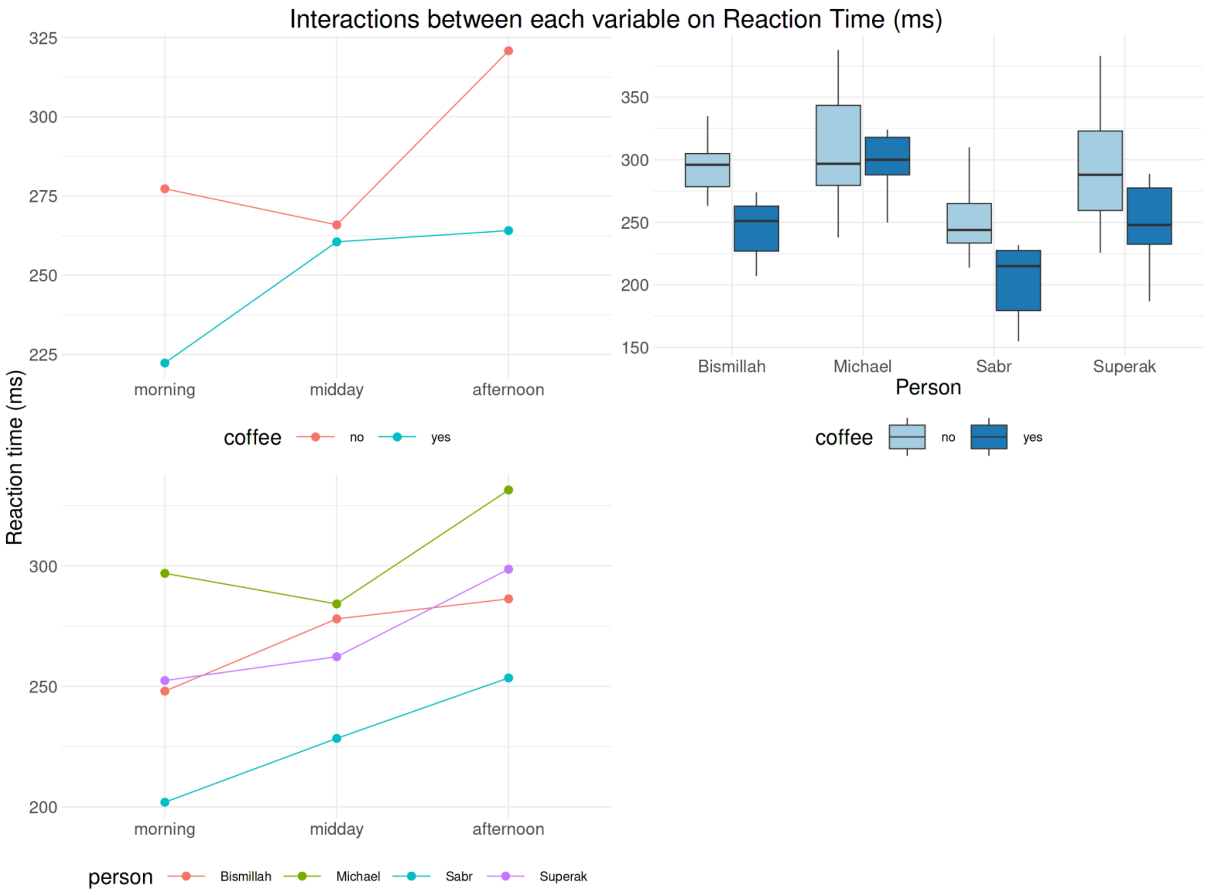
The second is the effects of time of day on reaction time, as seen in Figure 1 there can be a general positive relationship across all data. With the medians increasing from morning to midday to afternoon. However in figure 2 it can be seen that in the category of no coffee, mornings have a greater reaction time than midday's this indicates that the relationship is only a general trend and is not true for all data. Through these reasons the increase can be small with each grouping being within each quartile. These reasons suggest that there is a possible weak link between time of day and reaction time.

The third effect is the relationship of coffee on reaction time and from figure 1 and 2 a difference can be observed. This difference is in favour of coffee as its categories are consistently faster across the summary statistic in figure 2. This relationship suggests that coffee has a positive effect.

Interactions between variables.

In figure 3 the possible interactions between each variable can be seen graphically. It can be seen that all of the lines in both of the time interaction figures are not parallel, also following a general positive trend in reaction time with time's increase. In addition, the second facet shows that each person has different non parallel relation with coffee on reaction time having a general downwards trend from no coffee to 1 shot for all except michael. There is a possibility for a three way interaction between each variable but it is difficult to tell from graphical means. From the combination of the visualisations a suggestion can be made that there is an interaction between each factor separately: One for coffee and time, one for coffee and participant and the last one for time and participant.

Figure 3 : the interaction between variables, note for Coffee and Person, the mean reaction times are plotted.



5.1 Reliability and Accuracy of the Data

The data collected for the study follows the methodology previously outlined in the report resulting in data with minimised error. The results of the data generally adhere to the predictions made in the literature review which was that coffee will improve your reaction time and that morning would be the time for the fastest reaction.

6.0 Results

The experimental results were loaded in R using the tidy data principles, ready for modelling as seen in figure 4.

Figure 4: Snippet of the experimental data loaded into R.

A tibble: 6 × 4

time	coffee	reaction_time	person
<fct>	<chr>	<dbl>	<chr>
morning	yes	289	Michael
morning	yes	287	Michael
morning	yes	267	Michael
midday	yes	323	Michael
afternoon	yes	321	Michael
midday	yes	250	Michael

6.1 Statistical Methods

The alpha chosen for significant value is 0.05, with rejection of p-values that are >0.05. For this experiment, two types of statistical analysis were conducted - ANOVA and linear regression.

6.1.2 Linear Regression

Linear regression estimates the effects of predictors and how it can be used for prediction. The equation is as follows:

$$E\left[Y \mid X\right] = B_0 + B_1X_1 + B_2X_2 + \ldots + B_iX_i$$

$$Y_i|X_i = B_0 + B_1X_{i1} + B_2X_{i2} + \ldots + B_iX_{ij} + \epsilon_i$$

In this experiment, linear regression was used to find the relationship between the continuous response variable - reaction time - and explanatory variables, person (categorical), coffee (binary) and time (categorical). In order to make a linear model, the predictor variables were encoded using reference coding. This method involves encoding each factor level as a new variable in the equation, with values of 0 and 1 to represent the absence and presence of that level in a given observation, respectively.

The variables for the our specific experiment were encoded as follows:

$$coffee = \begin{cases} 0 \; if \;\; no \\ 1 \; if \;\; yes \end{cases}$$

Time

$$morning = \begin{cases} 0\ if\ \ no \\ 1\ if\ \ yes \end{cases} \quad midday = \begin{cases} 0\ if\ \ no \\ 1\ if\ \ yes \end{cases} \quad afternoon = \begin{cases} 0\ if\ \ no \\ 1\ if\ \ yes \end{cases}$$

Person

$$Bismillah = \begin{cases} 0\ if\ \ no \\ 1\ if\ \ yes \end{cases} \quad Michael = \begin{cases} 0\ if\ \ no \\ 1\ if\ \ yes \end{cases} \quad Sabr = \begin{cases} 0\ if\ \ no \\ 1\ if\ \ yes \end{cases} \quad Superak = \begin{cases} 0\ if\ \ no \\ 1\ if\ \ yes \end{cases}$$

It is important to note that reference coding involves dropping a level (known as the reference level) from each factor when constructing the linear equation. This allows for interpretation of the levels in reference to the dropped level and avoids multicollinearity.

Thus, the linear model would resemble the following equation:

$$E[Reaction\ Time \mid X_i] = B_0 + B_1 Coffeeyes + B_2 midday + .. + B_4 Michael + ... + B_k Superak$$

Since the experiment had a single response variable and multiple predictors, multiple linear regression model was constructed as follows:

$$Reaction\ Time = XB + \epsilon$$

Where:

B is a matrix of the coefficients and X is a matrix of observation:

$$B = \begin{bmatrix} B_0 \\ B_1 \\ B_2 \\ B_3 \\ \vdots \end{bmatrix}$$

$$X = \begin{bmatrix} 1 & coffeeyes & midday & afternoon & Michael & \cdots \\ 1 & \vdots & \vdots & \vdots & \vdots & \cdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \cdots \end{bmatrix}$$

Furthermore, the multiple linear equations must also adhere to the following assumptions:

- Linearity: the relationship between response and explanatory variable should be linear or approximately linear. If the assumption is met, it suggests that a linear model best describes the relationship between the variables.
- Constant variance (Homoscedasticity): the variance of residuals should be constant as proven in Appendix 3.
- Normality: the residuals should be normally distributed (as proven in Appendix 3).
- Independence: the residuals should be independent of each other. If they are not, other methods such as time series analysis should be considered.
- No multicollinearity: there is no relationship between the explanatory variables. Although this would not affect the predictive power of the model, it obscures the effects of the predictors and would result in inaccurate interpretation of the model (See Appendix 4 for further information).

6.1.2 ANOVA (analysis of variance)

ANOVA is used to test the significance of categorical predictors in the case of this experiment the categorical predictors will be time of day, participant and coffee. The total sum of squares is the sum of the sum of squares within each group and the sum of squares between each group.

$$SST = SS_{within} + SS_{between}$$

When incorporating the degrees of freedom for both sum of squares, an F statistic can be constructed under these assumptions which apply to the residuals:

- Normality
- Constance variance
- Independence

To test which hypothesis to be chosen these two statements are used:

$$H_0: \mu_0 = \mu_1 = \mu_2 = \cdots = \mu_n$$

$$H_a: \text{at least two differ}$$

6.2 The Regression Method

6.2.1 Initial Model

To build the initial model, the data was splitted into training and testing sets, stratified by the blocking variable 'Person', ensuring there is representative data in the training and testing for each block. The training set was used to choose a model fit and build the model, whilst the testing set was used to check model performance.

Stepwise regression approaches (forward, backward and both) were used with both Akaike information criterion (AIC) and Bayesian information criterion (BIC) to select a model based on the training set. The combination of regression approaches didn't produce different best models, but the criterions used did; the results are shown in below:

AIC

$$AIC=616.23$$

$$reaction\_time \sim person + coffee + time + coffee:time + person:coffee$$

BIC

$$AIC=645.19$$

$$reaction\_time \sim person + coffee + time + coffee:time$$

It was decided to use the model generated using Bayesian Information criterion due to its simplicity.

Figure 4:Linearity assumptions for the initial model

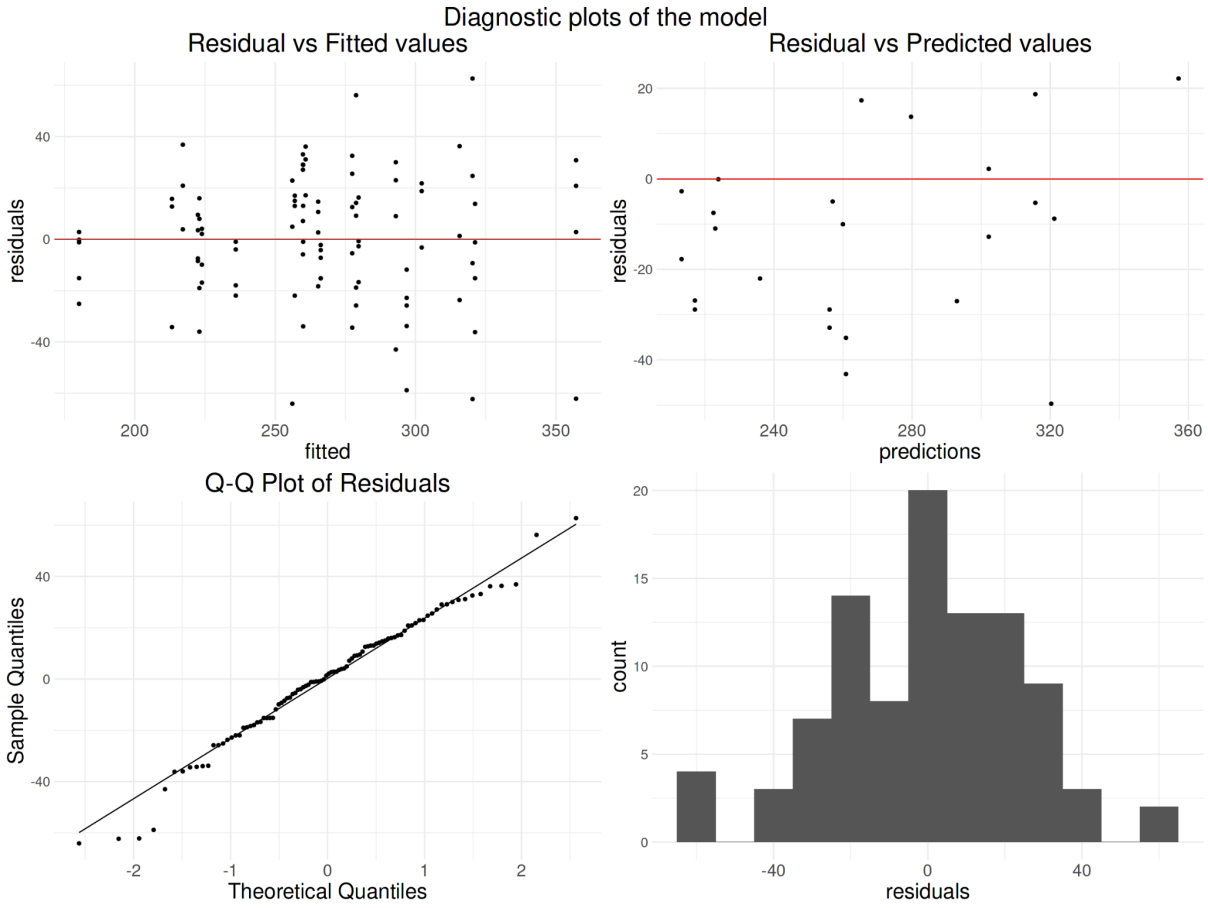
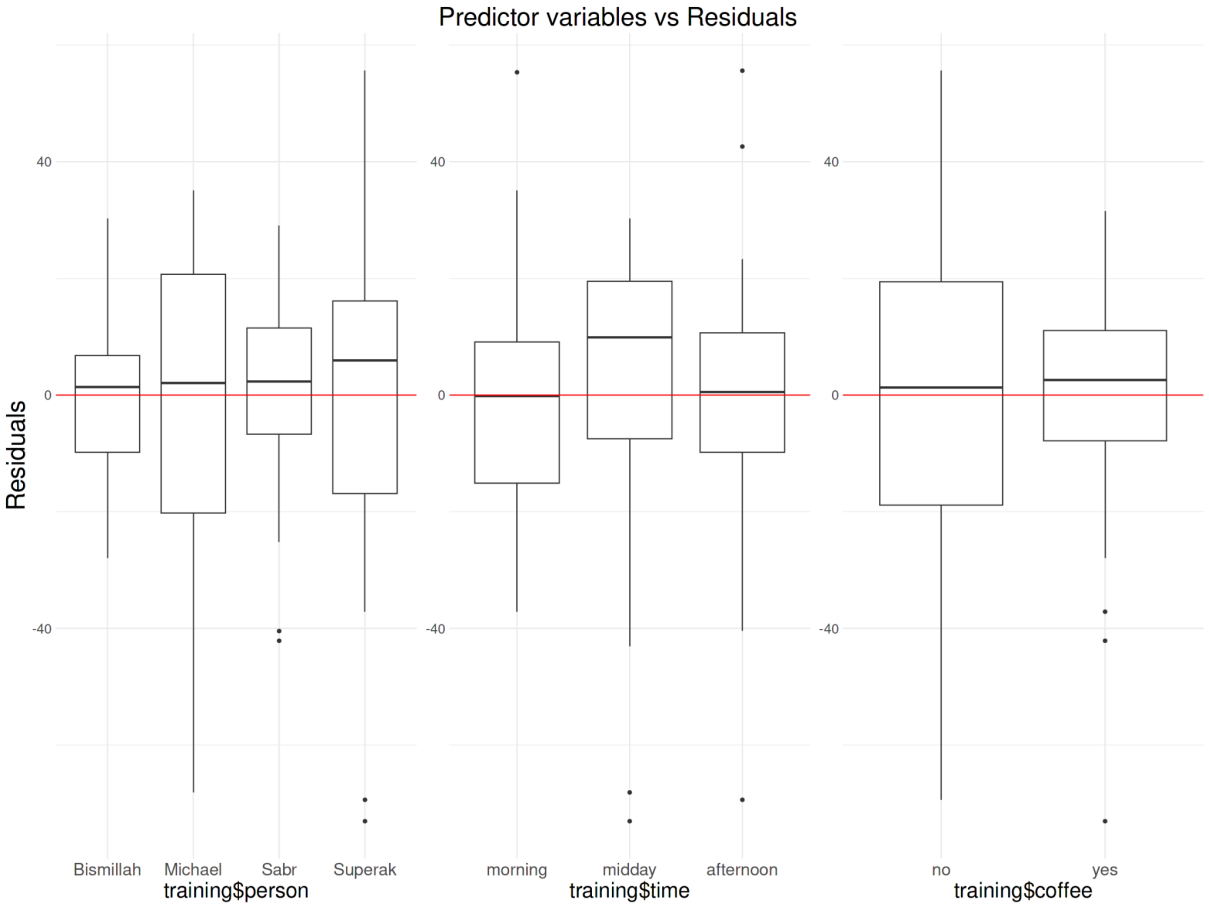


Figure 5: The predictor variables vs residuals



Normality

The histogram shows a normal distribution with a mean approximately at 0. The normality is further shown by the Q-Q plot which shows the residuals being normal distributed from -1 to 1. Above and below these values deviations to the y = x line with a greater deviation on the negative side suggests that there is a negative skew. With the residuals being mostly normal with only outliers contradicting the assumption of normality is not violated.

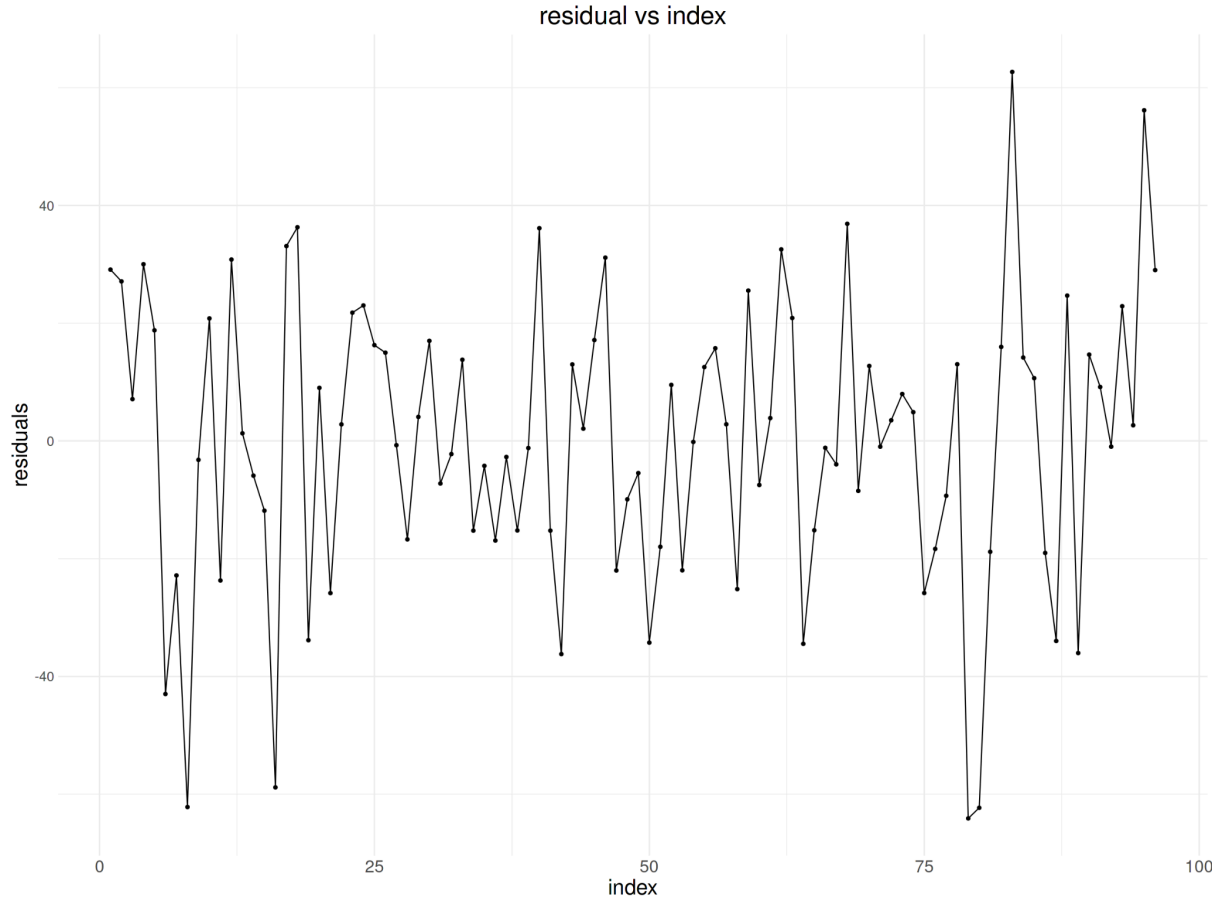
Homoscedasticity

As the Residual vs Fitted values show in figure 4 there is a possibility of non constant variance as there is clumping in specific areas of the graph. Further showing this the Residual vs the fitted values with midday variable having an overestimation in its residual. This shows that there is some violation of the homoscedasticity within the residuals. The violation may have arisen from erroneous data but is not substantial enough to change the model.

Linearity

As for the linearity assumption through observations of the Residuals vs fitted there appears to be no curvature or unusual values present in Residual vs Fitted plot. In predictor vs response plot (Figure 5), most factor levels have residuals with a mean of zero, suggesting a linear fit, with exception to Midday in time with relatively higher, non-zero mean. This suggests the model is underestimating for this level. Overall the assumption of linearity is met.

Figure 6: The residual vs index plot



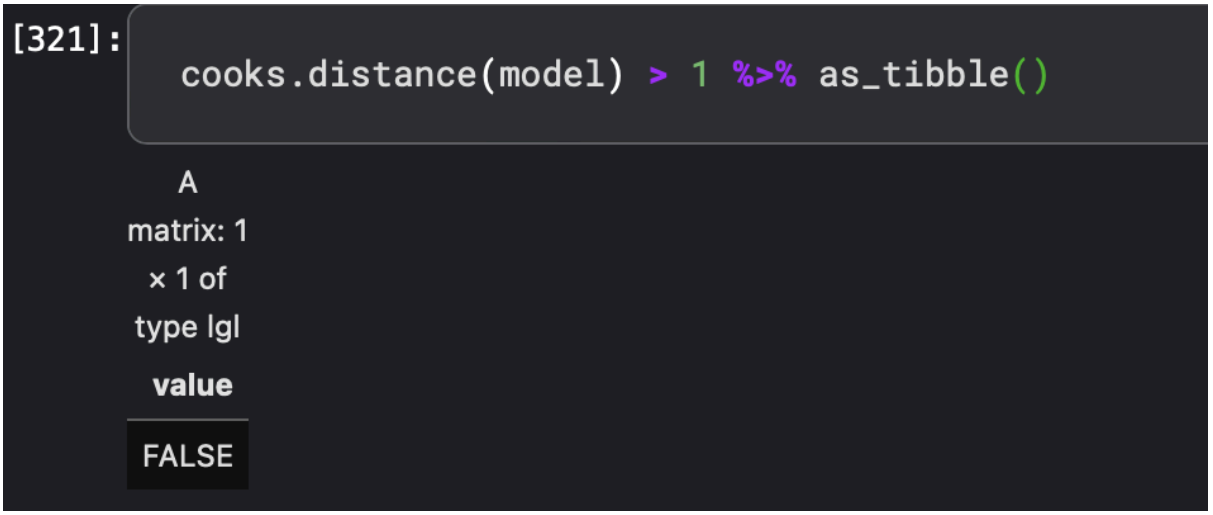
Independence

For the assumption of independence there is no sign of the data showing dependency on previous results. This can be shown through the residuals vs index in figure 6 as there is no clear trend in the data. This shows that it does not violate the assumption of independence.

Note that each participant's data was appended to a dataframe, still keeping the order in which their results were taken.

From the assumptions the linear model is able to explain the overall variance in the data except for the extremities which may be outliers.

6.2.3 Unusual observations



6.2.4 Interpreting the model

The relationship between the response variable (Reaction Time) and predictor variables is as follows:

Figure 7: The summary results of the model

```
Call:
lm(formula = reaction_time ~ person + coffee + time + coffee:time,
    data = training)

Residuals:
    Min      1Q  Median      3Q     Max
-64.109 -15.598   1.696  16.055  62.692

Coefficients:
                       Estimate Std. Error t value Pr(>|t|)
(Intercept)             279.7179     7.9189  35.323  < 2e-16 ***
personMichael            35.9808     7.4942   4.801 6.51e-06 ***
personSabr              -43.7452     7.4638  -5.861 8.06e-08 ***
personSuperak            -0.8897     7.4649  -0.119 0.905400
coffeeyes               -55.8079     8.8888  -6.278 1.30e-08 ***
timemidday              -18.8586     9.3112  -2.025 0.045895 *
timeafternoon            41.4798     8.9986   4.610 1.37e-05 ***
coffeeyes:timemidday     51.9472    13.0878   3.969 0.000148 ***
coffeeyes:timeafternoon   0.8350    12.6686   0.066 0.947601
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 25.79 on 87 degrees of freedom
Multiple R-squared:  0.7314,    Adjusted R-squared:  0.7067
F-statistic: 29.61 on 8 and 87 DF,  p-value: < 2.2e-16
```

The model was deemed useful based on its utility test with a p-value of 2.2e-16. This indicates a non-zero slope and a linear relationship between the reaction time and one of the predictor variables:

$$H_0: B_1 = B_2 = \ \ldots \ = B_k = 0$$

$$H_A: \ at\ least\ one\ of\ the\ coefficient\ is\ non\ zero$$

Moreover, it achieved an exceptional adjusted R^2 values of ≈ 0.71 meaning it was able to explain most (71%) of the variations in the response variable from the training data.

$$R^2 = 1 - \frac{SS_{RES}}{SS_{TOT}}$$

$$adjusted\ R^2 = 1 - \frac{(1-R^2)(N-1)}{N-p-1}$$

This high performance in the model is due to many of the significant predictors (with p-values (< 0.05)), indicating the variables had an effect on the response variable greater than the threshold a, explaining the variations in the response variable..

$$H_0: B = a$$
$$H_A: B_j != a$$

Note that the model uses reference coding, as such the coefficients of the factor levels are interpreted according to a reference group. For example, 'coffeeyes' has an estimated coefficient of -55 meaning the response variable (Reaction Time) is expected to be lower by that amount when a person drank coffee (yes) compared to when they didn't (No - the reference group for that factor).

There is also an interaction term between coffee and time. With the interaction between coffeeyes and time midday being significant.

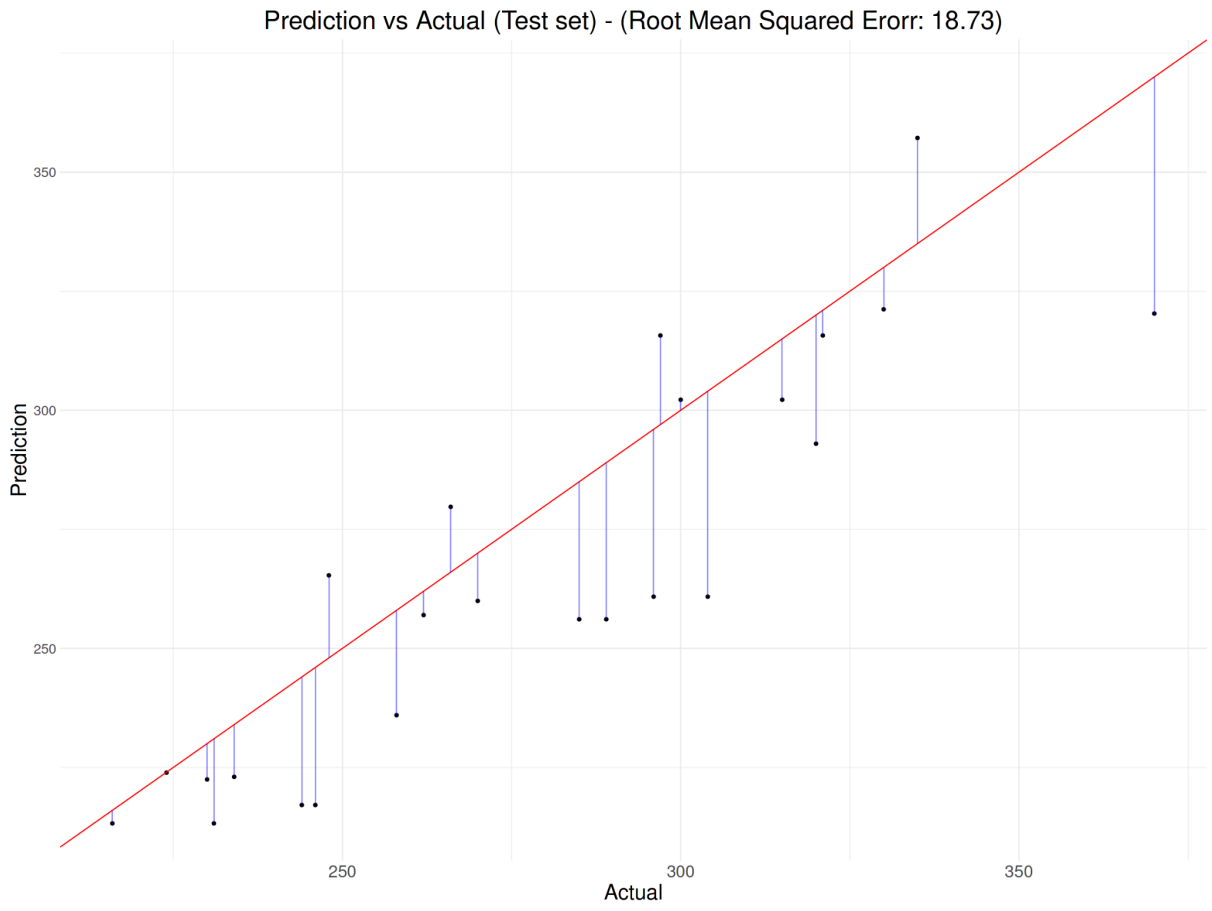
The intercept had an estimated value of ≈ 279.79, meaning that the Reaction Time is that amount when all the independent variables are at their reference group (categorical) - when the person is 'Bismillah' and drank 'No' coffee and the interaction between 'No coffee' and 'time'.

$$t = \hat{\beta}_0 - a/(s\sqrt{\frac{1}{n} + \frac{\bar{x}^{-2}}{(n-1)s_x^2}}$$

$$x \pm t^*_{(n-1),(1-\frac{a}{2})} \frac{s}{\sqrt{n}}$$

6.2.5 Assessing model performance (test set)

Figure 8: graph showing the prediction vs actual on the test set



Assessing the model's performance on the test set, it achieved an Root Mean Squared Error (RMSE) of ≈ 18ms (Figure 8), indicating that on average the model's prediction deviated that amount. Such precision is particularly advantageous for its intended application of helping the QUT sports team, enabling informed strategy formulation and play selection. Furthermore, this value can be used as a benchmark for comparing performance of future models.

6.3 The ANOVA Method

Anova method is used to estimate between different means from experiment, R can be used to find it.

6.3.2 Summary of ANOVA table (Full Model)

```
                   Df Sum Sq Mean Sq F value   Pr(>F)
coffee              1  39976   39976  65.109 1.14e-11 ***
time                2  30082   15041  24.497 7.66e-09 ***
person              3  74071   24690  40.213 2.24e-15 ***
coffee:time         2  13394    6697  10.907 7.28e-05 ***
coffee:person       3   4901    1634   2.661   0.0545 .
time:person         6   6894    1149   1.871   0.0975 .
coffee:time:person  6   1856     309   0.504   0.8036
Residuals          72  44207     614
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

From the table, it is evident that person, coffee and time have a significant effect on reaction time as they have p-values less than 0.05. While there is also significant evidence for the interaction of coffee and time. There is strong evidence to say that there is a significant difference in the mean populations of each of the categories, this being between each person, with and without coffee and between each time period. As there is significant evidence for an interaction this suggests that there is also difference in the means of each separate factor. To further understand the differences between each of the groups, A Tukey HSD was used to see the significance.

A Tukey HSD report was generated to check the difference between the means of the factor levels using a reduced model with only significant predictors from the ANOVA test. The reduced model was the same as the model generated in stepwise regression.

$$\text{reaction\_time} \sim \text{person} + \text{coffee} + \text{time} + \text{coffee:time}$$

TUKEY HSD RESULTS:

```
Fit: aov(formula = reduced_model)

$time
                      diff       lwr      upr     p adj
midday-morning    14.07302 -1.470449 29.61649 0.0841729
afternoon-morning 43.20677 28.180297 58.23325 0.0000000
afternoon-midday  29.13375 13.482248 44.78525 0.0000779

$coffee
            diff       lwr       upr p adj
yes-no -39.61917 -50.08197 -29.15637     0

$person
                        diff       lwr       upr     p adj
Michael-Bismillah  33.989117  14.48924  53.48900 0.0000948
Sabr-Bismillah    -43.978061 -63.47794 -24.47818 0.0000004
Superak-Bismillah  -1.747973 -21.24785  17.75191 0.9954095
Sabr-Michael      -77.967178 -97.46706 -58.46730 0.0000000
Superak-Michael   -35.737090 -55.23697 -16.23721 0.0000382
Superak-Sabr       42.230088  22.73021  61.72997 0.0000011

$`time:coffee`
                                    diff        lwr       upr     p adj
midday:no-morning:no       -13.5119925  -40.52161  13.49763 0.6916102
afternoon:no-morning:no     40.3976045   14.22085  66.57436 0.0002982
morning:yes-morning:no     -55.5802092  -81.40201 -29.75841 0.0000002
midday:yes-morning:no      -17.3230106  -44.82600  10.17998 0.4487793
afternoon:yes-morning:no   -14.4971685  -41.06758  12.07324 0.6072746
afternoon:no-midday:no      53.9095970   27.28714  80.53206 0.0000010
morning:yes-midday:no      -42.0682167  -68.34174 -15.79469 0.0001572
midday:yes-midday:no        -3.8110181  -31.73855  24.11652 0.9986750
afternoon:yes-midday:no     -0.9851761  -27.99480  26.02445 0.9999980
```

```
morning:yes-afternoon:no   -95.9778137 -121.39436 -70.56126 0.0000000
midday:yes-afternoon:no    -57.7206151  -84.84349 -30.59775 0.0000003
afternoon:yes-afternoon:no -54.8947731  -81.07153 -28.71802 0.0000004
midday:yes-morning:yes      38.2571986   11.47674  65.03766 0.0010124
afternoon:yes-morning:yes   41.0830407   15.26124  66.90484 0.0001761
afternoon:yes-midday:yes     2.8258420  -24.67715  30.32883 0.9996663
```

From the results of the Tukey report, there was a difference of -39.61 ms in the means of drinking coffee and not drinking it, suggesting that drinking coffee reduced the mean by -39 and proved to be a statistically significant difference.

Difference periods of the day also had significant effects on reaction time, on average participants having a 43.20 and 29.13 increase in reaction time in the afternoon compared to morning and midday respectively. Midday and morning didn't have statistically significant means, suggesting a more prolonged time frame during the day for reaction time to slow down because of hormonal changes. However, it is worth considering that the model tended to underestimate Midday values (See Figure 5), which would have contributed to this non-significant conclusion.

Most participants had significant reaction means, with only one exception, further supporting the need to include Person as a blocking factor to account for these variations.

The interaction between time and coffee had statistically significant means, suggesting the coffee affects reaction differently during different times of day. However, with some exceptions of course, i.e. interactions between Midday and Morning (previously found no significant result). Besides this the report found several significant differences in response variable levels across different times of day and coffee consumption conditions.

In the morning, consuming coffee significantly lowers levels by 55.58 units compared to not having coffee (p adj = 0.0000). Moving to midday, levels with coffee are significantly higher by 38.26 units compared to the morning with coffee (p adj = 0.0010), but there are no significant differences between midday and morning without coffee. Additionally, the midday without coffee levels are significantly lower by 53.91 units compared to the afternoon without coffee (p adj = 0.0000), and the levels with coffee in the morning are significantly lower by 42.07 units compared to midday without coffee (p adj = 0.0002).

In the afternoon, levels without coffee are significantly higher by 40.40 units compared to the morning without coffee (p adj = 0.0003). Consuming coffee in the afternoon leads to significantly lower levels by 54.89 units compared to the afternoon without coffee (p adj = 0.0000). Levels in the afternoon with coffee are also significantly higher by 41.08 units compared to the morning with coffee (p adj = 0.0002).

There are no significant differences between most other combinations involving coffee consumption at midday and the afternoon. However, the response variable levels with coffee in the morning are significantly lower by 95.98 units compared to the afternoon without coffee (p adj = 0.0000) and significantly lower by 42.07 units compared to the midday without coffee (p adj = 0.0002).

7.0 Conclusion

In conclusion through the methods of linear regression and ANOVA a recommendation can be proposed to obtain the greatest reaction time in regards to sporting activities. The optimal solution is to drink coffee 30 minutes before reaction based tasks and to conduct the sporting events in the morning.

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Appendix

Appendix 0

Website used to test reaction time:
https://humanbenchmark.com/tests/reactiontime

Appendix 3

Estimating Coefficients:

Where:

$$E[Y \mid X] = BX$$

Where

$$YX^T = XX^T B$$
$$YX^T(XX^T)^{-1} = XX^T(XX^T)^{-1}B$$
$$\widehat{B} = YX^T(XX^T)^{-1}$$

Appendix 3

Proof of normality for the residuals:

Consider:

$$residuals = Y - \widehat{Y}$$

Where:

$$E[Y \mid X] = BX$$

Where

$$YX^T = XX^TB$$
$$YX^T(XX^T)^{-1} = XX^T(XX^T)^{-1}B$$
$$\widehat{B} = YX^T(XX^T)^{-1}$$

Therefore:

$$\begin{aligned}
Var(residuals) &= Var[Y - YX^T(XX^T)^{-1}X] \\
&= Var[Y(I - X^T(XX^T)^{-1}X] && H = X(X^TX)^{-1}X^T \\
&= Var[Y(I - H)] && Var(AY) = AVar(Y)A^T \\
&= (I - H)Var(Y)(I - H)^T \\
&= (I - H)\boldsymbol{\sigma}^2 I(I - H)^T && Var(Y) = \boldsymbol{\sigma}^2 I \\
&= \boldsymbol{\sigma}^2(I - H)(I - H)^T && (I - H)^T = I^T - H^T \\
&= \boldsymbol{\sigma}^2(I - H)(I - H) && H \text{ is a symmetric matrix, so } H^t = H \\
&= \boldsymbol{\sigma}^2(I - H - H + HH) && HH = H, \text{ because H is an idempotent matrix.} \\
&= \boldsymbol{\sigma}^2(I - 2H + H) \\
&= \boldsymbol{\sigma}^2(I - H)
\end{aligned}$$

$$r \sim N(0, \boldsymbol{\sigma}^2(I - H))$$

Appendix 4

The effect of multicollinearity:

Consider:

That there is a linear relationship between
$$E[Y \mid X] = B_0 + B_1x + B_2x$$

$$E[Y \mid X] = B_0 + (B_1 + B_2)x$$

MXB242: Regression and Design

Planning Checklist

Part 1

Please fill in all entries in the following tables and tick boxes to state agreement. It is important as part of your future careers that you take project planning seriously – especially sections relating to ethics (if applicable).

1. We have consulted the unit coordinator and teaching team to discuss this project. ☑
2. We have all successfully completed the "Respect and Safety" quiz. ☑
3. This project will not have any physical, emotional or psychological effects beyond those associated with everyday living. ☑
4. We commit to reporting any changes to our plan after any pilot study or at any subsequent stage. ☑
5. This project will not involve issues that are offensive or sensitive. ☑
6. If this project involves peoples' cooperation or assistance, this cooperation will be requested in person. ☐
7. If this project involves a survey or a non-intrusive experiment/study involving peoples' cooperation or assistance, the following statement will be provided to each participant: ☐

   "For a unit in statistics at QUT, we have been asked to choose a topic of interest to us and collect data to investigate it. We are interested in ..... and would be grateful for your assistance. These data are for educational purposes only and no individual will be able to be identified in any writing or discussion about the data."

Part 2

It is important that each member of the group reviews this document before submission to verify that they have understood the plan before data collection and assessment commences.

Signed by each member of the group:

1.	Bismillah Sultani	Bismillah Sultani	
	(Name)	*(Signature)*	
2.	Suprerak Bidari	Suprerak	
	(Name)	*(Signature)*	
3.	Michael Barnham	michael barnham	
	(Name)	*(Signature)*	
4.	Sabari Chithrangathan Sakunthala	sabari	
	(Name)	*(Signature)*	

If you have four group members, describe the planned additional work in consideration of the fourth member.

the planned additional work in considering the fourth memeber was to come together in a and descuss which group memeber will complete each section as well as include each member in editting and iterating on each others selected sections.

Days	time	coffee
1	afternoon	1
2	afternoon	0
3	afternoon	1
4	midday	1
5	midday	0
6	afternoon	1
7	midday	1
8	Morning	1
9	Morning	0
10	Morning	1
11	midday	0
12	afternoon	0
13	midday	1
14	afternoon	0
15	midday	0
16	Morning	0
17	afternoon	0
18	Morning	0
19	midday	0
20	Morning	1
21	afternoon	1
22	afternoon	1
23	Morning	0
24	Morning	1
25	afternoon	0
26	Morning	1
27	midday	0
28	Morning	0
29	midday	1
30	midday	1