# The Effect of Sound on Player Performance in Mario Kart 8 Deluxe

Group 6

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# 1 Data Collection

We received our proposal with minor revisions back on Sunday, April 3rd, so our data collection date was pushed back to Saturday, April 9th and all steps and guidelines were followed as stated in our final proposal in section 5.2. Our collected data can be found in appendix 6.1.

# 2 Analysis

## 2.1 Introduction of the model

As outlined in our proposal in section 5.2, we designed our experiment based off of a three factor factorial randomized block design with fixed effects using the number of players playing at one time, the difficulty of the game, and the presence or lack of sound (referred to simply as number of players, difficulty, and sound respectively) as our three factors and used the participants as our blocking factor. Our reasons for including these as factors can be referenced in our proposal in section 5.2.2. The equation of our model is:

$$y_{ijkl} = \mu + \tau_i + \gamma_j + \delta_k + (\tau\gamma)_{ij} + (\tau\delta)_{ik} + (\gamma\delta)_{jk} + (\tau\gamma\delta)_{ijk} + \beta_l + \varepsilon_{ijkl}$$

$$i = 1, \dots, a, \quad j = 1, \dots, b, \quad k = 1, \dots, c, \quad l = 1, \dots, n$$

$$\varepsilon_{ijkl} \overset{iid}{\sim} N(0, \sigma^2)$$

## 2.2 ANOVA table

*Table 2-1 Analysis of Variance Table*

| Source of Variation | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| Number of Players | 1 | 14.29 | 14.29 | 0.4835 | 0.49 |
| Game Difficulty | 2 | 3512 | 1756 | 59.39 | 4.793e-14 |
| Sound | 2 | 89.04 | 44.52 | 1.506 | 0.2315 |
| Participants (Block) | 3 | 1661 | 553.6 | 18.73 | 2.539e-08 |
| Number of Players:Difficulty | 2 | 21.69 | 10.84 | 0.3668 | 0.6948 |
| Number of Players:Sound | 2 | 38.67 | 19.34 | 0.654 | 0.5243 |
| Difficulty:Sound | 4 | 172 | 43.01 | 1.455 | 0.2297 |
| Number of Players:Difficulty:Sound | 4 | 167.2 | 41.8 | 1.414 | 0.2427 |
| Residuals | 51 | 1508 | 29.56 | NA | NA |

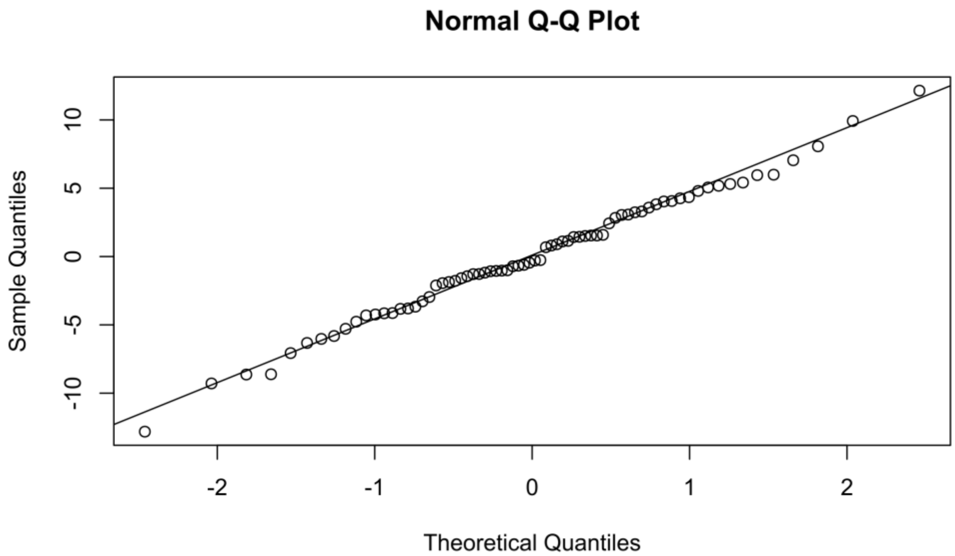
As seen in Table 2-1, neither sound nor the number of players has a significant effect on the length of time it takes a player to complete one seven-lap race on the Baby Park Circuit in Mario Kart 8 Deluxe, but game difficulty does.

## 2.3 Assumptions

Blocked three-factor factorial models require that the error terms are independent and identically distributed and follow a normal distribution with a mean of 0 and a constant variance. The factorial model used in the design of this experiment is robust to deviations away from normality for small sample sizes.  We also assume that the residuals have equal variance among the levels of each factor and no interaction between our blocking factor and our treatments.

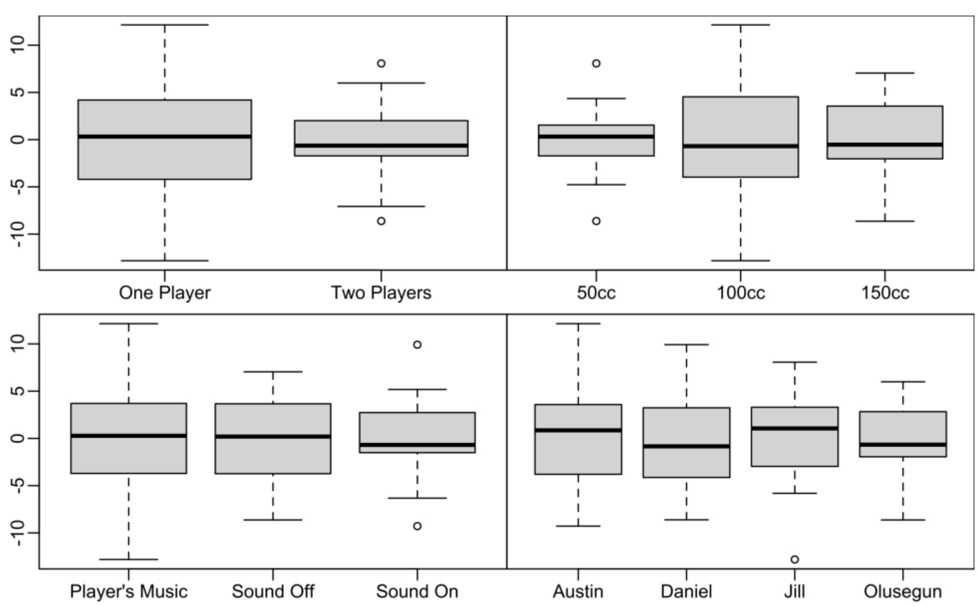
### 2.3.1 Normality

The assumption of normality can be assessed using the normal q-q plot below. Deviations away from normality can be seen as points deviating from the diagonal line. There is little to no deviation from the normal line, so we can assume that the data is normally distributed.

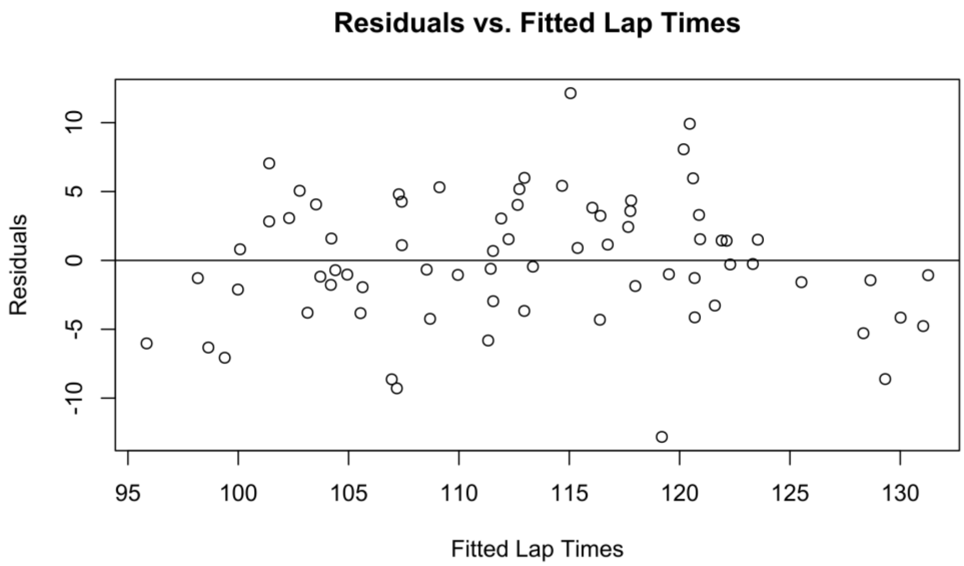



### 2.3.2 Constant Variance

First, we want to check if the residuals have equal variance among the levels of each factor. The graphs below display the spread of the levels of our three treatment factors and our blocking factor against the residuals. We can see that the variance is approximately equal across the levels of our treatments and block so we will state that this assumption holds.

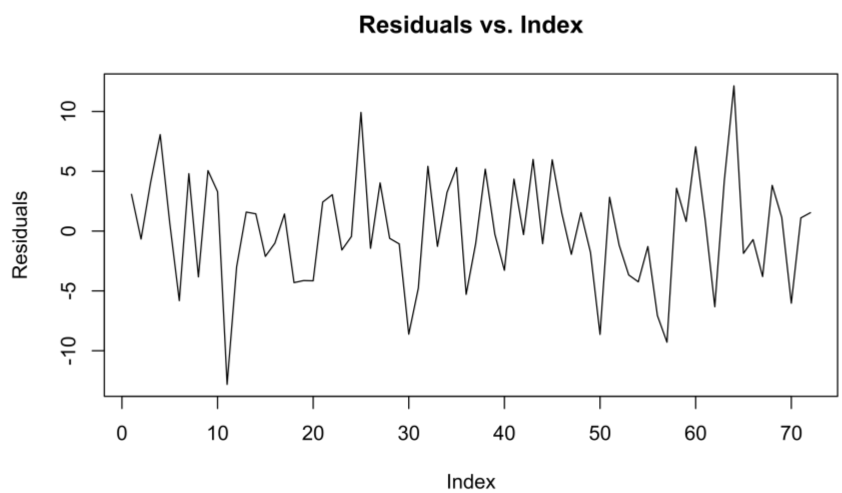


To check whether the variation of our residuals is constant and centered around zero, we refer to the plot below displaying our fitted values from the model against our residuals. We can see that the residuals are centered around zero and mostly equally distributed both along, and above and below the zero line. We will assume that the residuals have constant variance and a mean of 0.



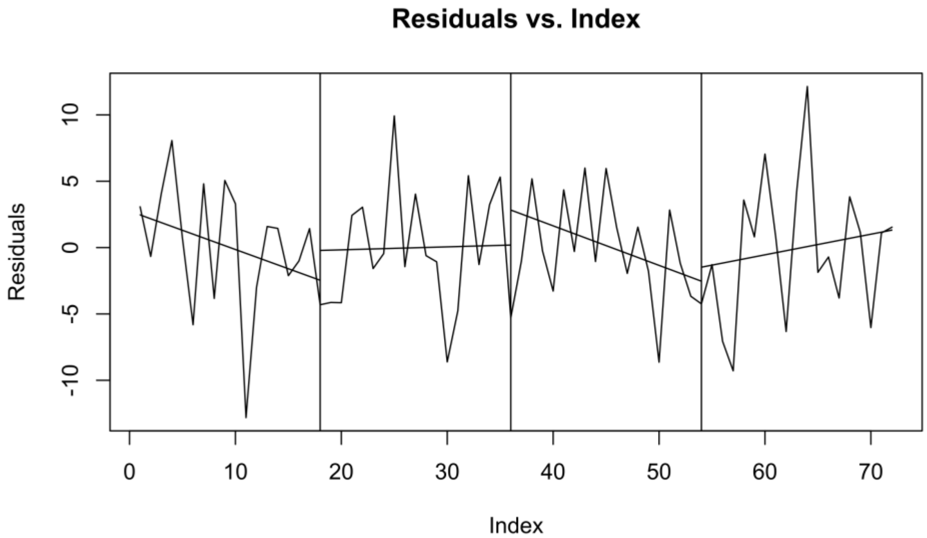

### 2.3.3 Independence

Dependence is present in the data when there is a trend or heteroscedasticity in the residual versus time plot. As we can see in the plot below, there does not appear to be any trend present, and the variance is constant.




Due to the nature of our design, we also want to check for independence within our blocks. The vertical lines in the plot below represents the last treatment in every block. A regression line has also been fit for each block to help distinguish any trend that may not be obvious at first glance.

We can see that although there is a slight positive or negative trend in each block, the trends are not consistent, nor large enough to constitute a declaration of dependence. The variance across each block also appears to be constant so we can accept the assumption of independence.




2.3.4 No Interaction Between Treatments and Blocks

Interaction between our treatment factors and blocking factor can be detected by inspecting the fitted lap times versus residuals plot in section 2.3.2 for a curvilinear shape. Since there is no such pattern present, we can assume that there is no interaction between our block and treatment factors.

2.3.5 Outlier Check

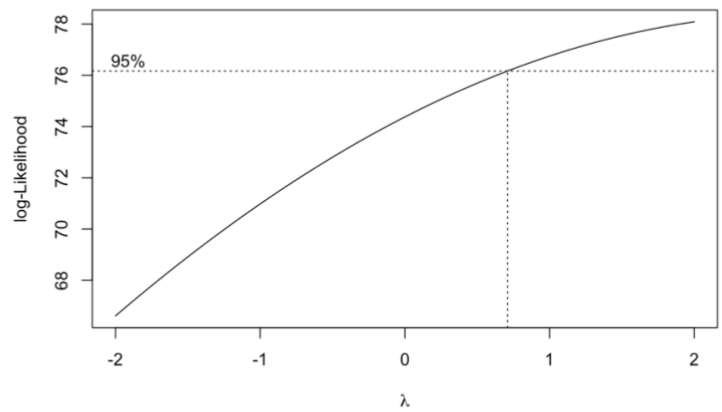
There is no hard rule that constitutes whether a point is an outlier or not, but the rule of thumb is if an observation has a residual satisfying the following condition, then it is an outlier:

$$\left|\frac{e_{ij}}{\sqrt{MS_E}}\right| > 3.$$

No points meet this criterion so we will keep the assumption that there are no outliers.

2.3.6 Box-Cox Transformation

Although all our assumptions have been met, it may be worth checking if a Box-Cox transformation is necessary. From the Box-Cox plot below, we can clearly see that the 95% confidence interval includes one; therefore, no transformation is recommended or necessary for our data.

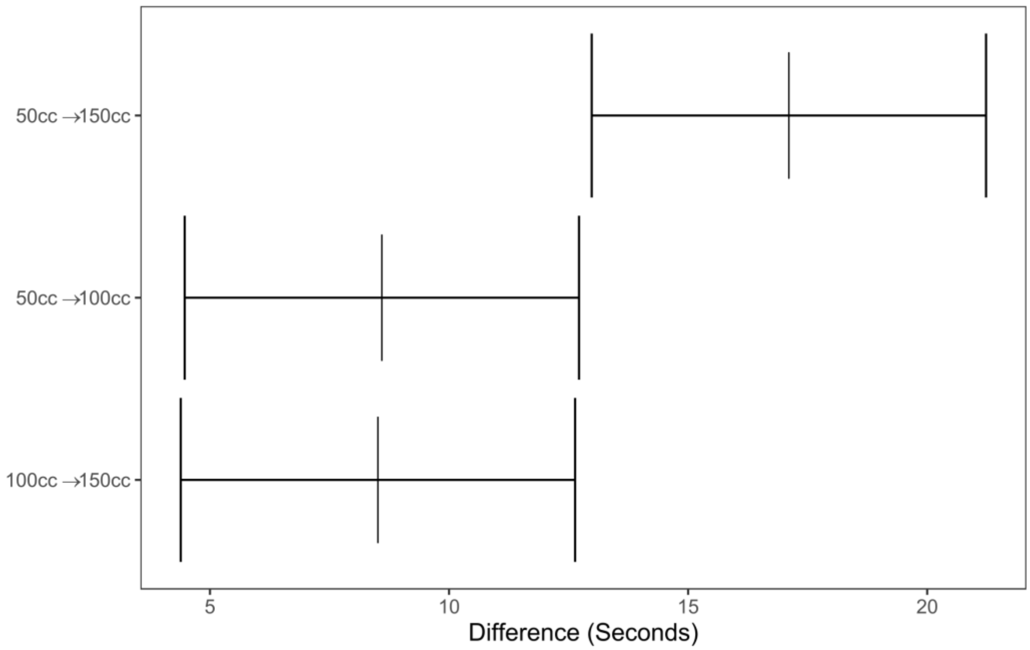



## 2.4 Results

Our only significant treatment factor is the difficulty of the game which, as stated in our final proposal, was expected because as the difficulty is increased, the speed of the karts increases, decreasing the time it takes to complete a race. To check whether our intuition is correct, we will be doing both pairwise Tukey and polynomial contrasts, keeping a familywise $\alpha$ of 0.05. While polynomial contrasts are not normally associated with categorical variables, we have learned that this variable can also be numeric if one belongs to the modding community. Modding in the gaming community involves the practice of editing the game files to change an aspect of the game, in this case, the game's difficulty. Modders have found that they can edit the difficulty value to be anything above, below, and in between the levels of our difficulty treatment; therefore, we will be choosing to look at this factor with both points of view in mind and do pairwise Tukey comparisons for those without the knowledge of how to modify the game files in Mario Kart 8 Deluxe and do linear and quadratic, orthogonal, polynomial contrasts for those who do.

Below, we show the results of all pairwise Tukey comparisons for the difficulty treatment factor using a familywise $\alpha$ of 0.03. As we can see, all comparisons are significant with p-values less than 0.03. A better display of the results can be seen in the graph below where the middle lines are the differences, and the outer lines are the 95% confidence intervals. The difference in time to complete a race when going from 50cc to 100cc is very similar to the difference in time when going from 100cc to 150cc.

| | Difference | Lower CI | Upper CI | p-Value |
|---|---|---|---|---|
| **100cc-150cc** | 8.513 | 4.389 | 12.64 | 4.789e-06 |
| **50cc-150cc** | 17.11 | 12.98 | 21.23 | 0 |
| **50cc-100cc** | 8.595 | 4.471 | 12.72 | 3.98e-06 |

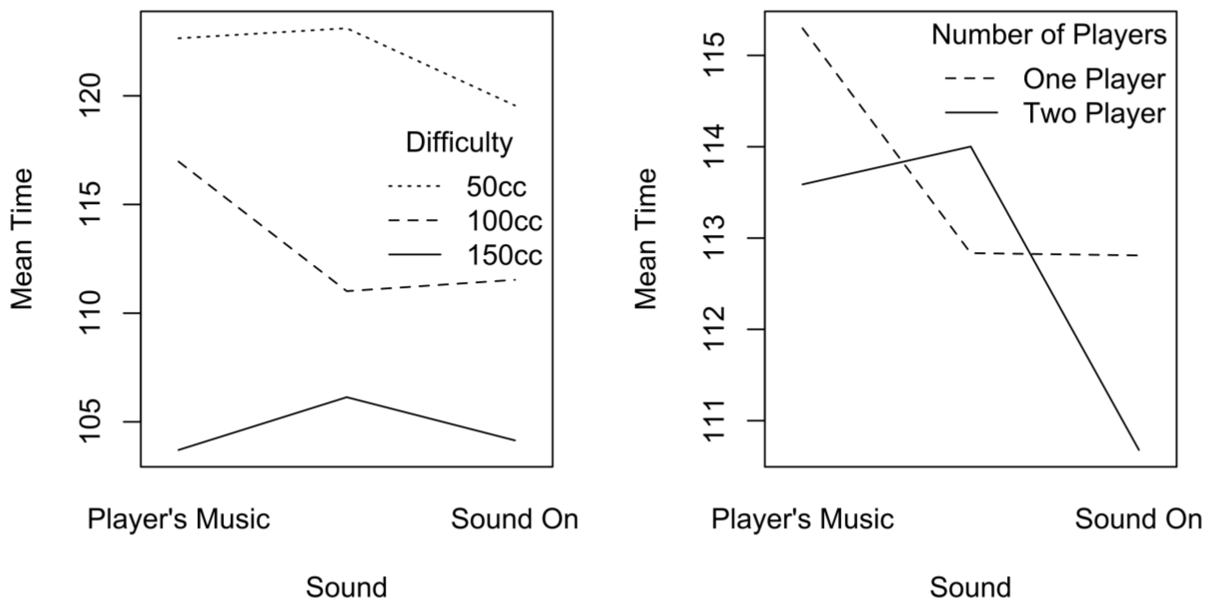



Below, we show the results of the polynomial contrasts where we can see that the confidence interval for the linear contrast does not include zero; therefore, there is a significant linear affect. We can also see that confidence interval for the quadratic contrast does include zero; therefore, difficulty does not have a quadratic effect.

| | Lower CI | Contrast | Upper CI |
|---|---|---|---|
| **Linear** | 2.558 | 17.11 | 31.66 |
| **Quadratic** | -14.47 | 0.08 | 14.63 |

### 2.4.1 Interactions

Our main factors of interest were the interactions between sound and difficulty and sound and number of players. We want to look at each of these interactions to see if there is a possibility of an interaction that we were not able to detect due to noise or error. We can see from the graphs below that the sound and difficulty may have an interaction but this may be due to error because of the insignificance of the interactions seen in section 2.2, and because there interactions are not very intuitive, for example, no sound changed from the best , to worst, to the best treatment as the difficulty increased. This is also the case for the interaction between sound and the number of players, as seen in the graph below.




### 2.5 Sources of error

We were not able to say that Our effects of interest were significant so we would like to explore possible sources of error that could have buried our results.

#### 2.5.1 Accuracy of our $\hat{\sigma}^2$

As shown in section 5.2.3 we estimated $\hat{\sigma}^2$ to be 33.14 using data from our pre-trial and the variation in the experiment was found to be 29.56. Using the same methods used in section 5.2.3 we found that our experiment results in a power of 0.9791, which is larger than our predicted power of 0.9640. Even though we underpredicted power, leading to a smaller type II error, we still want to test whether our estimated variance is statistically similar to the variance we got from our experiment using a F-test with an α = 0.05: $H_0: \sigma_1^2 = \sigma_2^2$ vs. $H_1: \sigma_1^2 > \sigma_2^2$, where $\sigma_1^2$ represents our estimated pre-trial variance and $\sigma_2^2$ represents the variance from our experiment. Our F-statistic is about $1.12 \sim F_{19, 54}$ resulting in a p-value of about 0.358 > α = 0.05; therefore, we fail to reject our null hypothesis and can state that our variance estimated from our pre-trial was a good estimate of the variance in our experiment.

#### 2.5.2 Blocking Efficiency

The question of whether we should have blocked or not can be answered simply by looking at the relatively large amount of variance explained by our blocking factor in section 2.2. We can also quantify this by calculating the relative efficiency of our randomized block design to our completely randomized design using the equation;

$$RE = cf\,\frac{\hat{\sigma}^2_{CRD}}{\hat{\sigma}^2_{RBD}}.$$

$cf$ stands for correction factor and represents the equation;

$$cf = \frac{(dfe_{RBD} + 1)(dfe_{CRD} + 3)}{(dfe_{RBD} + 3)(dfe_{CRD} + 1)},$$

where $dfe_{RBD}$ are the error degrees of freedom in our experiment and $dfe_{CRD}$ are the error degrees of freedom if we were to run our experiment using a completely randomized design. $dfe_{CRD}$ is calculated as $a(b-1)$ , where $a$ represents the number of treatments, and $b$ represents the number of blocks. $\hat{\sigma}^2_{RBD}$ is our experiment variance estimated by the mean square error (MSE) and $\hat{\sigma}^2_{CRD}$ is our variance if we were to run our experiment with a completely randomized design and is estimated by;

$$\hat{\sigma}^2_{CRD} = \frac{(b-1)MS_{block} + b(a-1)SE}{(ab-1)},$$

where $MS_{block}$ is the estimated variance explained by our blocking factor. We calculated our relative efficiency to be 5055.452 meaning that using the same universe of factors, we would have needed to increase our sample size by a factor of 5055.425 to achieve the same power as we did under the randomized block design. This means that there is not an unreasonable amount of error resulting from the use of blocking.

### 2.5.3 Data Collection

Out of all our sources of error, this may be the most significant. In our proposal we allowed the participants to have casual conversation and did not put any restrictions on the type of conversation. Some of our participants' competitive nature took over and the friendly banter may have created pressure to perform well which we did not account for. Another possible source of error in the data collection was the measurement error caused by inconsistent timing. A common complaint during the experiment came from the timers who found it difficult to pay attention to when they needed start and stop the stopwatches as the treatments within each block progressed. While any treatment that had a botched start or end time was scrapped and redone, we cannot rule out the possibility that some stopwatch operators may have been caught off guard by the beginning or end of the race and added or subtracted a few seconds to participants' time and not notify anyone.

# 3 Conclusions and Summary

Details: "Describe what you found from your experiment. Was it what you expected to find? What would you do differently if you were to do it again?"

The goal of our experiment was to check whether the main effect of sound and the interaction between sound and the number of players and the interaction between sound and difficulty, influenced the time it took to complete a seven-lap race on the Baby Park circuit in Mario Kart 8 Deluxe. After running our experiment, we discovered that the main factor and the two interactions we were interested in did not have a significant effect on a participant's race time; however, we did find that difficulty had a significant effect, but this was expected as the level of difficulty is increased, the speed of the karts in the game gets faster, reducing the length of time required to complete one seven-lap race. We explored the possibility that there was an interaction between sound and difficulty, and sound and the number of players buried beneath the error in our experiment. We cannot confirm or deny the possibility of an interaction effect between our factors of interest but we do have evidence that points towards the possibility that the effect of sound and it's interaction with difficulty and the number of players is less than what we were able to detect with our number of blocks as outline in our proposal in section 5.2.3.

## 3.1 Recommendations for Future Studies

Over the course of this study, we have come up with a few suggestions for future repeat studies. Our first suggestion is to increase the number of blocks from 4 to 35 to be able to detect a difference of 2 seconds with a power of about 0.93039 as we believe the effect of sound to be much lower than we anticipated. The code we used to calculate this power can be found in the code section of our appendix. We also recommend that future studies find a more consistent way to time the races as this can become quite taxing on the individual who is given this task. One last recommendation is to limit the participants communication with each other. We believe that these recommendations will reduce the error and give clearer results.

# 4 Learning Experience

This experiment was a great learning experience. Working on this project provided clarity and gave us a much better understanding of the material that was taught in class. The opportunity to complete a project of this magnitude, from start to finish, is an experience that we will be able to carry into the near future as we seek employment in industry. This project also provided us an opportunity to network with our fellow classmates. Some interesting discoveries made during this project were Olusegun's extraordinary Mario Kart game skills, Daniel's awful taste in music, Austin being a real-life zombie who does not need sleep, Nigeria's extraordinary jollof rice, and Daniel's fear of cats.

# 5 Proposals

## 5.1 Original Proposal

The Effect of Sound on Player Performance in Mario Kart 8 Deluxe

Group 6

Austin Hadamuscin, Olusegun Omotunde, Daniel Sasu

Very well thought out and great detail! Just describe the “other player” better as requested below and describe more clearly how the pilot study was done.

### 5.1.1 Goal

Our goal is to see if the sound and music of Mario Kart 8 Deluxe influence the performance of a player.

### 5.1.2 Response

Time (seconds) to complete a seven-lap race on the Baby Park track.

| Factor | Levels | Description |
|---|---|---|
| Difficulty | 3 ~~Factors~~levels<br>- 50cc<br>- 100cc<br>- 150cc | These levels reference engine displacement in cubic centimeters of real-life engines. Generally, the larger the displacement of a vehicle's engine is, the faster the vehicle can go. In Mario Kart, as a player increases the difficulty, the racing becomes faster and the CPUs (A.K.A. Computers) become more competent competitors. We believe that as the speeds increases, it may be harder to detect obstacles or items that are thrown due to the increased concentration it takes to race at faster speeds. |
| Sound | 3 ~~Factors~~levels<br>- Game Sound On<br>- Game Sound Off<br>- Player's Own Music | This is the focus of our study. Mario Kart has excellent sound design that allows players to detect when other players are near, when obstacles on the course will spin them out, or when an item is about to hit them. We suspect that the absence of sound may affect how a player reacts to objects being used on them or their in-game environment. We are including a player's own music as a level because if there is a change in race times from when the game sound is on versus when it is off, we wanted to see whether that change was due to the absence of game music, or sound in general. |
| Number of Players | 2 ~~Factors~~levels<br>- One Player against all CPUs<br>- One Player against another player and CPUs on local split-screen | This factor was chosen because playing against all CPUs vs playing against CPUs and one other person may change the way players choose to use their items. Instead of targeting a CPU with a red shell, one may choose to save it until they can hit their friend/real-life opponent. Additionally, when playing locally with another player, the screen is split vertically. This dramatically reduces the amount of track the players can see, making it harder to detect incoming obstacles or items, especially with the sound turned off. |
| Participants | Blocking Factor | Each participant will have a different skill level that we are not trying to detect; therefore, we will |

| | | |
|---|---|---|
| | | be blocking by the participants to account for this source of variance. |

### 5.1.3 Narrative

Nintendo are masters of sound design when it comes to their own intellectual property and Mario Kart 8 Deluxe is no exception. The race used in this experiment, Baby Park, is a hectic, seven-lap, short oval race accompanied by a soundtrack that becomes incrementally more frantic as each lap is complete. Due to these characteristics, we suspect that the absence of sound while racing on this track will affect players' race times. We included three levels of sound: game sound on, game sound off, and player's choice of music. For the first two levels, we will be turning the speaker amplifier on and off, respectively to control the sound. For the third level of sound, a player's choice of music, participants will be instructed to play music from their personal headphones in both ears, at a level of their choosing. The genre of music will be determined by each participant, but the genre must stay consistent throughout the entire experiment. General conversation among participants and spectators will be permitted while any level of sound is being conducted.

The complications that arise when measuring a continuous response variable, race time in seconds, are compounded by the fact that Mario Kart 8 Deluxe does not provide race times for races other than time trials; therefore, will be using the stopwatches on our phones to time our races. Time will start at *GO!* (see image 1 in the index) and stop at *FINISH!* (see image 2 in the index). We are blocking by the participants, so the individual operating the stopwatch does not have to be consistent throughout the entire experiment but will need to be consistent throughout an entire block. If there is an error in the measurement caused by the stopwatch operator forgetting to start or stop the stopwatch, a glitch in the game or stopwatch, or any other unforeseen circumstance, the observation for that treatment be aborted and redone if found immediately after, or during the observation. If the error is caught after one or several treatments have been complete, we will assess the severity of the error and weigh if it is worth redoing the entire block.

There will be two levels for the number of players: one- and two-player. Each block must have a consistent opponent for the two-player level and local multiplayer must be used, not online multiplayer. The online multiplayer is not free so this choice will make the expected budget of the experiment $0 since Austin already owns the console, game, and tv. An opponent may be another participant in the experiment or someone from outside the experiment.

Mario Kart 8 Deluxe, comes with 41 characters, 23 karts, 18 wheels, and 12 gliders, each with a unique set of stats that can drastically affect gameplay so, we have decided to keep these choices consistent for the entire experiment. Each participant will need to use the character Mario, the kart Streetle, the wheel Roller, and the glider Waddle Wing (see images 3-6 in the index respectively). This combination was chosen because of its high traction and acceleration (see image 7 in the index), which will make the tight corners of Baby Park easier for newcomers. Also as a way to help newcomers get used to the game, every participant, regardless of skill level or experience, will complete three single-player, 50cc, practice races, with the game sound on, on any track(s) to get used to the controls and mechanics of the game. No in game assists, such as Smart Steering and Auto Acceleration will be used. These settings are found by pressing + or – on the Joy-Con controller during kart selection. If a participant decides to use tilt steering rather than joy-stick steering, they may do so, but they cannot switch between the two. Participants will be using one Joy-Con controller (either the red or the blue) rather than both and they must remain with one color as the button layout for each Joy-Con is slightly different. The race mode we will be using is called VS Race. This mode will allow us to race on Baby Park, with both one and two players, and with CPUs without having to play through an entire four circuit cup like we would in Grand Prix mode. Both the order of blocks and the order of treatments have been randomized. The code that accomplished the random ordering, as well as the randomized data table itself can be found at the end of this section.

From a pre-trial experiment we ran on one treatment of one block (single player, 100cc, game sound on), we expect each observation to take anywhere from 90-120 seconds, so we are planning for 30 to 45 minutes per block which includes setup time in between treatments. There will be 4 participants (Austin, Olusegun, Daniel, Jill), so we are planning on data collection to take anywhere from 2 to 3 hours. We plan to conduct all blocks of our experiment on Saturday, April 2nd, 2022 at 1:00 PM at Austin's apartment, given that our proposal has been approved. Otherwise, we will postpone the experiment until the next Saturday, April 9th, 2022 at 1:00 PM at the same location.

We want to be able to detect a difference in means, $D$, of 7 seconds over an entire race, or 1 second per lap. This is not to say that we expect participants to lose 1 second per lap, this is more to give context to our desired detectable difference. Using the data from our pre-trial, we estimated $\sigma^2$ as 33.1427. The factors "difficulty" and "sound" have 3 levels of treatment and the factor "number of players" has 2 levels of treatments. So, using this information, the non-centrality parameter for difficulty and sound will be $\lambda = \frac{nB(2)(3)(10^2)}{2(33.1427)} \approx 3.39nB$ and the non-centrality parameter for number of players will be $\lambda = \frac{nB(3)(3)(10^2)}{2(33.1427)} \approx 2.26nB$, where $nB$ represents the number of blocks desired. We used the first non-centrality parameter, $\lambda \approx 2.26nB,$ for block estimation because it will result in a lower power, giving us a conservative estimate of the number of blocks needed to reach our desired power for any test in question. With 4 blocks, our lambda is about 13.57, giving us a critical value of around 3.179 from an $F_{2,51}$ distribution. This F-value results in a power of about 0.964, showing that the . The R code for these calculations can be found below.

5.1.4 R Code that Randomizes the Experiment

```
rand_dat <- list(4)
it = 1

for(i in sample(c("Austin", "Olusegun", "Daniel", "Jill"))){

  dat <- expand.grid(Participant = i,
                    `Number of Players` = c("One Player","Two Players"),
                    Difficulty = c("50cc","100cc","150cc"),
                    Sound = c("Sound On", "Sound Off", "Player's Music"))

  rand_dat[[it]] <- dat[sample(1:nrow(dat)),]
```

```
  it <- it + 1

}

rand_dat <- do.call(rbind, rand_dat)
```

5.1.5 R Code that Calculates the Number of Blocks

```
time_obs <- c(116.73,116.99,100.20,108.60,
              103.77,  97.55,110.00,107.92,
              107.79,108.19,110.96,102.94,
              116.48,109.17,108.16,105.30,
              109.99,  98.52,116.21,105.95)

#the following code is used to find the samples size needed for Two-Way ANOVA
alpha=.05
a=3     #number of levels of A
b=3     #number of levels of B
c=2 #number of levels of C
sigsq=var(time_obs)  # our estimate of sigma^2 from the pretrial

n=4                  #number of blocks
DA=7  #desired diff (in seconds) in means to detect with prob 1-beta
Fcrit=qf(1-alpha,a-1,(a*b*c-1)*(n-1))        #value at which we reject H0
lam=n*b*c*(DA^2)/(2*sigsq)         #non-centrality parameter (ncp)
beta=pf(Fcrit,a-1,(a*b*c-1)*(n-1),ncp=lam)
power=1-beta
nforA=cbind(n,Fcrit,beta,power)    #output for A
nforA

     n   Fcrit        beta           power
[1,]  4   3.178799   0.03597092   0.9640291
```

5.1.6 Data Table

| Participant | Number of Players | Difficulty | Sound | Time (seconds) |
|---|---|---|---|---|
| Jill | Two Players | 150cc | Sound On | |
| Jill | Two Players | 100cc | Sound On | |
| Jill | Two Players | 150cc | Sound Off | |
| Jill | Two Players | 50cc | Player's Music | |
| Jill | Two Players | 100cc | Sound Off | |
| Jill | One Player | 100cc | Sound On | |
| Jill | One Player | 100cc | Sound Off | |
| Jill | One Player | 150cc | Sound Off | |
| Jill | One Player | 150cc | Sound On | |
| Jill | One Player | 50cc | Sound Off | |
| Jill | One Player | 100cc | Player's Music | |

| | | | | |
|---|---|---|---|---|
| Jill | Two Players | 100cc | Player's Music | |
| Jill | Two Players | 150cc | Player's Music | |
| Jill | One Player | 50cc | Player's Music | |
| Jill | One Player | 150cc | Player's Music | |
| Jill | One Player | 50cc | Sound On | |
| Jill | Two Players | 50cc | Sound Off | |
| Jill | Two Players | 50cc | Sound On | |
| Daniel | Two Players | 100cc | Player's Music | |
| Daniel | One Player | 50cc | Sound Off | |
| Daniel | Two Players | 100cc | Sound On | |
| Daniel | One Player | 150cc | Sound On | |
| Daniel | Two Players | 50cc | Sound On | |
| Daniel | Two Players | 150cc | Player's Music | |
| Daniel | One Player | 100cc | Sound On | |
| Daniel | One Player | 50cc | Sound On | |
| Daniel | Two Players | 150cc | Sound Off | |
| Daniel | Two Players | 150cc | Sound On | |
| Daniel | Two Players | 50cc | Sound Off | |
| Daniel | Two Players | 50cc | Player's Music | |
| Daniel | One Player | 50cc | Player's Music | |
| Daniel | One Player | 150cc | Sound Off | |
| Daniel | Two Players | 100cc | Sound Off | |
| Daniel | One Player | 100cc | Sound Off | |
| Daniel | One Player | 150cc | Player's Music | |
| Daniel | One Player | 100cc | Player's Music | |
| Olusegun | Two Players | 150cc | Sound Off | |
| Olusegun | One Player | 100cc | Sound On | |
| Olusegun | One Player | 50cc | Player's Music | |
| Olusegun | Two Players | 50cc | Player's Music | |
| Olusegun | Two Players | 50cc | Sound On | |
| Olusegun | One Player | 50cc | Sound Off | |
| Olusegun | Two Players | 100cc | Player's Music | |
| Olusegun | Two Players | 100cc | Sound On | |
| Olusegun | One Player | 100cc | Player's Music | |
| Olusegun | Two Players | 50cc | Sound Off | |
| Olusegun | Two Players | 150cc | Player's Music | |
| Olusegun | One Player | 50cc | Sound On | |
| Olusegun | One Player | 150cc | Sound On | |
| Olusegun | One Player | 150cc | Sound Off | |
| Olusegun | One Player | 150cc | Player's Music | |
| Olusegun | Two Players | 150cc | Sound On | |
| Olusegun | Two Players | 100cc | Sound Off | |
| Olusegun | One Player | 100cc | Sound Off | |
| Austin | Two Players | 150cc | Sound On | |
| Austin | Two Players | 150cc | Sound Off | |

| | | | | |
|---|---|---|---|---|
| Austin | One Player | 100cc | Sound On | |
| Austin | One Player | 50cc | Player's Music | |
| Austin | Two Players | 150cc | Player's Music | |
| Austin | One Player | 150cc | Sound Off | |
| Austin | One Player | 50cc | Sound On | |
| Austin | One Player | 150cc | Sound On | |
| Austin | Two Players | 100cc | Sound Off | |
| Austin | One Player | 100cc | Player's Music | |
| Austin | Two Players | 50cc | Sound Off | |
| Austin | Two Players | 100cc | Sound On | |
| Austin | One Player | 100cc | Sound Off | |
| Austin | Two Players | 50cc | Player's Music | |
| Austin | One Player | 50cc | Sound Off | |
| Austin | One Player | 150cc | Player's Music | |
| Austin | Two Players | 100cc | Player's Music | |
| Austin | Two Players | 50cc | Sound On | |

5.1.7 Index

Image 1: The *GO!* that indicates when to start the stopwatch. (GamerJGB, 2017)


Image 2: The *FINISH!* that indicates when to stop the stopwatch. (GamerJGB, 2017)

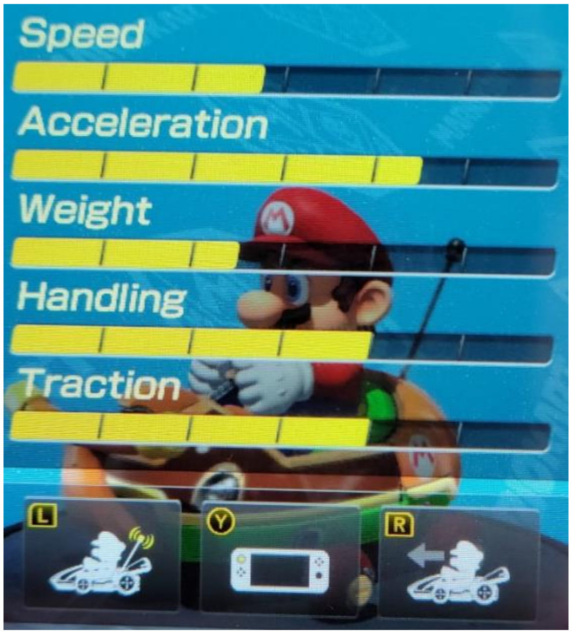

Image 3: Mario ("Mario Kart 8 Deluxe in-game statistics", 2022)

Image 4: Streetle kart ("Mario Kart 8 Deluxe in-game statistics", 2022)

Image 5: Roller wheel ("Mario Kart 8 Deluxe in-game statistics", 2022)

Image 6: Waddle Wing glider ("Mario Kart 8 Deluxe in-game statistics", 2022)

Image 7: Kart Statistics




### 5.1.8 References

GamerJGB. (2017, June 7). *Mario Kart 8 Deluxe: GCN Baby Park [1080 HD]* [Video]. YouTube. https://www.youtube.com/watch?v=RgfGIju16M0

Mario Kart 8 Deluxe in-game statistics. (2022, March 30). In *Super Mario Wiki*.

## 5.2 Revised Proposal

### 5.2.1 Goal

Our goal is to see if the sound and music of Mario Kart 8 Deluxe influence the performance of a player.

### 5.2.2 Response

Time (seconds) to complete a seven-lap race on the Baby Park track.

| Factor | Levels | Description |
|---|---|---|
| Difficulty | <u>3 Levels</u><br>- 50cc<br>- 100cc<br>- 150cc | These levels reference engine displacement in cubic centimeters of real-life engines. Generally, the larger the displacement of a vehicle's engine is, the faster the vehicle can go. In Mario Kart, as a player increases the difficulty, the racing becomes faster and the CPUs (A.K.A. Computers) become more competent competitors. We believe that as the speeds increases, it may be harder to detect obstacles or items that are thrown due to the increased concentration it takes to race at faster speeds. |
| Sound | <u>3 Levels</u><br>- Game Sound On<br>- Game Sound Off<br>- Player's Own Music | This is the focus of our study. Mario Kart has excellent sound design that allows players to detect when other players are near, when obstacles on the course will spin them out, or when an item is about to hit them. We suspect that the absence of sound may affect how a player reacts to objects being used on them or their in-game environment. We are including a player's own music as a level because if there is a change in race times from when the game sound is on versus when it is off, we wanted to see whether that change was due to the absence of game music, or sound in general. |
| Number of Players | <u>2 Levels</u><br>- One Player against all CPUs<br>- One Player against another player and CPUs on local split-screen | This factor was chosen because playing against all CPUs vs playing against CPUs and one other person may change the way players choose to use their items. Instead of targeting a CPU with a red shell, one may choose to save it until they can hit their friend/real-life opponent. Additionally, when playing locally with another player, the screen is split vertically. This dramatically reduces the amount of track the players can see, making it harder to detect incoming obstacles or items, especially with the sound turned off. |

| | | |
|---|---|---|
| Participants | Blocking Factor | Each participant will have a different skill level that we are not trying to detect; therefore, we will be blocking by the participants to account for this source of variance. |

### 5.2.3 Narrative

Nintendo are masters of sound design when it comes to their own intellectual property and Mario Kart 8 Deluxe is no exception. The race used in this experiment, Baby Park, is a hectic, seven-lap, short oval race accompanied by a soundtrack that becomes incrementally more frantic as each lap is complete. Due to these characteristics, we suspect that the absence of sound while racing on this track will affect players' race times. We included three levels of sound: game sound on, game sound off, and player's choice of music. For the first two levels, we will be turning the speaker amplifier on and off, respectively to control the sound. For the third level of sound, a player's choice of music, participants will be instructed to play music from their personal headphones in both ears, at a level of their choosing. The genre of music will be determined by each participant, but the genre must stay consistent throughout the entire experiment. General conversation among participants and spectators will be permitted while any level of sound is being conducted.

The complications that arise when measuring a continuous response variable, race time in seconds, are compounded by the fact that Mario Kart 8 Deluxe does not provide race times for races other than time trials; therefore, will be using the stopwatches on our phones to time our races. Time will start at *GO!* (see image 1 in the index) and stop at *FINISH!* (see image 2 in the index). We are blocking by the participants, so the individual operating the stopwatch does not have to be consistent throughout the entire experiment but will need to be consistent throughout an entire block. If there is an error in the measurement caused by the stopwatch operator forgetting to start or stop the stopwatch, a glitch in the game or stopwatch, or any other unforeseen circumstance, the observation for that treatment be aborted and redone if found immediately after, or during the observation. If the error is caught after one or several treatments have been complete, we will assess the severity of the error and weigh if it is worth redoing the entire block.

There will be two levels for the number of players: one- and two-player. Each block must have a consistent opponent for the two-player level and local multiplayer must be used, not online multiplayer. The online multiplayer is not free so this choice will make the expected budget of the experiment $0 since Austin already owns the console, game, and tv. Also, when playing online, participants will be able to see the entire screen, as opposed to sharing half the screen when playing local multiplayer. An opponent may be another participant in the experiment or someone from outside the experiment. We decided on this because, due to the nature of the game, we believe that the skill of a player does not impact the performance of his or her opponent nearly as much as the performance lost from missing half of the screen, as mentioned in the table on the previous page.

Mario Kart 8 Deluxe, comes with 41 characters, 23 karts, 18 wheels, and 12 gliders, each with a unique set of stats that can drastically affect gameplay so, we have decided to keep these choices consistent for the entire experiment. Each participant will need to use the character Mario, the kart Streetle, the wheel Roller, and the glider Waddle Wing (see images 3-6 in the index respectively). This combination was chosen because of its high traction and acceleration (see image 7 in the index), which will make the tight corners of Baby Park easier for newcomers. Also as a way to help newcomers get used to the game, every participant, regardless of skill level or experience, will complete three single-player, 50cc, practice races, with the game sound on, on any track(s) to get used to the controls and mechanics of the game. No in-game assists, such as Smart Steering and Auto Acceleration will be used. These settings are found by pressing + or – on the Joy-Con controller during kart selection. If a participant decides to use tilt steering rather than joy-stick steering, they may do so, but they cannot switch between the two. Participants will be using one Joy-Con controller (either the red or the blue) rather than both and they must remain with one color as the button layout for each  Joy-Con is slightly different. The race mode we will be using is called VS Race. This mode will allow us to race on Baby Park, with both one and two players, and with CPUs without having to play through an entire four circuit cup like we would in Grand Prix mode. Both the order of blocks and the order of treatments have been randomized. The code that accomplished the random ordering, as well as the randomized data table itself can be found at the end of this section.

Austin conducted a pre-trial at his home on Thursday, March 24, 2022. He gathered 20 observations from one treatment of our experiment (single player, 100cc, game sound on). Austin's girlfriend, Jill, timed his races. The gathered data can be seen in our R code located at the end of this section, where we calculated an estimate for our number of blocks.

From the pre-trial experiment, we expect each observation to take anywhere from 90-120 seconds, so we are planning for 30 to 45 minutes per block which includes setup time in between treatments. There will be  4 participants (Austin, Olusegun, Daniel, Jill), so we are planning on data collection to take anywhere from 2 to 3 hours. We plan to conduct all blocks of our experiment on Saturday, April 2$^{nd}$, 2022 at 1:00 PM at Austin's apartment, given that our proposal has been approved. Otherwise, we will postpone the experiment until the next Saturday, April 9$^{th}$, 2022 at 1:00 PM at the same location.

We want to be able to detect a difference in means, $D$, of 7 seconds over an entire race, or 1 second per lap. This is not to say that we expect participants to lose 1 second per lap, this is more to give context to our desired detectable difference. Using the data from our pre-trial, we estimated $\sigma^2$ as 33.1427. The factors "difficulty" and "sound" have 3 levels of treatment and the factor "number of players" has 2 levels of treatments. So, using this information, the non-centrality parameter for difficulty and sound will be $\lambda = \frac{nB(2)(3)(7^2)}{2(33.1427)} \approx 4.44nB$ and the non-centrality parameter for number of players will be $\lambda = \frac{nB(3)(3)(7^2)}{2(33.1427)} \approx 6.65nB$, where $nB$ represents the number of blocks desired. We used the first non-centrality parameter, $\lambda \approx 4.44nB,$ for block estimation because it will result in a lower power, giving us a conservative estimate of the number of blocks needed to reach our desired power for any test in question. With 4 blocks, our lambda is about 13.57, giving us a critical value of around 3.179 from an $F_{2,51}$ distribution. This F-value results in a power of about 0.964, showing that we have enough blocks to detect our desired difference. The R code for these calculations can be found below.

5.2.4 R Code that Randomizes the Experiment

```
rand_dat <- list(4)
it = 1
```

```
for(i in sample(c("Austin", "Olusegun", "Daniel", "Jill"))){

  dat <- expand.grid(Participant = i,
                  `Number of Players` = c("One Player","Two Players"),
                   Difficulty = c("50cc","100cc","150cc"),
                   Sound = c("Sound On", "Sound Off", "Player's Music"))

  rand_dat[[it]] <- dat[sample(1:nrow(dat)),]

  it <- it + 1

}

rand_dat <- do.call(rbind, rand_dat)
```

5.2.5 R Code that Calculates the Number of Blocks

```
time_obs <- c(116.73,116.99,100.20,108.60,
                     103.77,  97.55,110.00,107.92,
                     107.79,108.19,110.96,102.94,
                     116.48,109.17,108.16,105.30,
                     109.99,  98.52,116.21,105.95)

#the following code is used to find the samples size needed for Two-Way ANOVA
alpha=.05
a=3     #number of levels of A
b=3     #number of levels of B
c=2    #number of levels of C
sigsq=var(time_obs)  # our estimate of sigma^2 from the pretrial

n=4                #number of blocks
DA=7  #desired diff (in seconds) in means to detect with prob 1-beta
Fcrit=qf(1-alpha,a-1,(a*b*c-1)*(n-1))        #value at which we reject H0
lam=n*b*c*(DA^2)/(2*sigsq)         #non-centrality parameter (ncp)
beta=pf(Fcrit,a-1,(a*b*c-1)*(n-1),ncp=lam)
power=1-beta
nforA=cbind(n,Fcrit,beta,power)    #output for A
nforA

      n    Fcrit         beta              power
[1,]  4    3.178799    0.03597092    0.9640291
```

5.2.6 Data Table

| Participant | Number of Players | Difficulty | Sound | Time (seconds) |
|---|---|---|---|---|
| Jill | Two Players | 150cc | Sound On | |
| Jill | Two Players | 100cc | Sound On | |
| Jill | Two Players | 150cc | Sound Off | |
| Jill | Two Players | 50cc | Player's Music | |
| Jill | Two Players | 100cc | Sound Off | |
| Jill | One Player | 100cc | Sound On | |
| Jill | One Player | 100cc | Sound Off | |
| Jill | One Player | 150cc | Sound Off | |
| Jill | One Player | 150cc | Sound On | |
| Jill | One Player | 50cc | Sound Off | |
| Jill | One Player | 100cc | Player's Music | |
| Jill | Two Players | 100cc | Player's Music | |
| Jill | Two Players | 150cc | Player's Music | |
| Jill | One Player | 50cc | Player's Music | |
| Jill | One Player | 150cc | Player's Music | |
| Jill | One Player | 50cc | Sound On | |
| Jill | Two Players | 50cc | Sound Off | |
| Jill | Two Players | 50cc | Sound On | |
| Daniel | Two Players | 100cc | Player's Music | |
| Daniel | One Player | 50cc | Sound Off | |
| Daniel | Two Players | 100cc | Sound On | |
| Daniel | One Player | 150cc | Sound On | |
| Daniel | Two Players | 50cc | Sound On | |
| Daniel | Two Players | 150cc | Player's Music | |
| Daniel | One Player | 100cc | Sound On | |
| Daniel | One Player | 50cc | Sound On | |
| Daniel | Two Players | 150cc | Sound Off | |
| Daniel | Two Players | 150cc | Sound On | |
| Daniel | Two Players | 50cc | Sound Off | |
| Daniel | Two Players | 50cc | Player's Music | |
| Daniel | One Player | 50cc | Player's Music | |
| Daniel | One Player | 150cc | Sound Off | |
| Daniel | Two Players | 100cc | Sound Off | |
| Daniel | One Player | 100cc | Sound Off | |
| Daniel | One Player | 150cc | Player's Music | |
| Daniel | One Player | 100cc | Player's Music | |
| Olusegun | Two Players | 150cc | Sound Off | |
| Olusegun | One Player | 100cc | Sound On | |
| Olusegun | One Player | 50cc | Player's Music | |
| Olusegun | Two Players | 50cc | Player's Music | |
| Olusegun | Two Players | 50cc | Sound On | |
| Olusegun | One Player | 50cc | Sound Off | |
| Olusegun | Two Players | 100cc | Player's Music | |

| | | | | |
|---|---|---|---|---|
| Olusegun | Two Players | 100cc | Sound On | |
| Olusegun | One Player | 100cc | Player's Music | |
| Olusegun | Two Players | 50cc | Sound Off | |
| Olusegun | Two Players | 150cc | Player's Music | |
| Olusegun | One Player | 50cc | Sound On | |
| Olusegun | One Player | 150cc | Sound On | |
| Olusegun | One Player | 150cc | Sound Off | |
| Olusegun | One Player | 150cc | Player's Music | |
| Olusegun | Two Players | 150cc | Sound On | |
| Olusegun | Two Players | 100cc | Sound Off | |
| Olusegun | One Player | 100cc | Sound Off | |
| Austin | Two Players | 150cc | Sound On | |
| Austin | Two Players | 150cc | Sound Off | |
| Austin | One Player | 100cc | Sound On | |
| Austin | One Player | 50cc | Player's Music | |
| Austin | Two Players | 150cc | Player's Music | |
| Austin | One Player | 150cc | Sound Off | |
| Austin | One Player | 50cc | Sound On | |
| Austin | One Player | 150cc | Sound On | |
| Austin | Two Players | 100cc | Sound Off | |
| Austin | One Player | 100cc | Player's Music | |
| Austin | Two Players | 50cc | Sound Off | |
| Austin | Two Players | 100cc | Sound On | |
| Austin | One Player | 100cc | Sound Off | |
| Austin | Two Players | 50cc | Player's Music | |
| Austin | One Player | 50cc | Sound Off | |
| Austin | One Player | 150cc | Player's Music | |
| Austin | Two Players | 100cc | Player's Music | |
| Austin | Two Players | 50cc | Sound On | |

### 5.2.7 Index

Image 1: The *GO!* that indicates when to start the stopwatch. (GamerJGB, 2017)


Image 2: The *FINISH!* that indicates when to stop the stopwatch. (GamerJGB, 2017)


Image 3: Mario ("Mario Kart 8 Deluxe in-game statistics", 2022)

Image 4: Streetle kart ("Mario Kart 8 Deluxe in-game statistics", 2022)

Image 5: Roller wheel (“Mario Kart 8 Deluxe in-game statistics”, 2022)

Image 6: Waddle Wing glider (“Mario Kart 8 Deluxe in-game statistics”, 2022)

Image 7: Kart Statistics

### 5.2.8 References

GamerJGB. (2017, June 7). *Mario Kart 8 Deluxe: GCN Baby Park [1080 HD]* [Video]. YouTube. https://www.youtube.com/watch?v=RgfGIju16M0

Mario Kart 8 Deluxe in-game statistics. (2022, March 30). In *Super Mario Wiki*.

# 6 Appendix

## 6.1 Data

| Participant | Number of Players | Difficulty | Sound | Time (seconds) |
|---|---|---|---|---|
| Jill | Two Players | 150cc | Sound On | 105.38 |
| Jill | Two Players | 100cc | Sound On | 107.87 |
| Jill | Two Players | 150cc | Sound Off | 107.59 |
| Jill | Two Players | 50cc | Player's Music | 128.25 |
| Jill | Two Players | 100cc | Sound Off | 112.23 |
| Jill | One Player | 100cc | Sound On | 105.51 |
| Jill | One Player | 100cc | Sound Off | 112.08 |
| Jill | One Player | 150cc | Sound Off | 101.71 |
| Jill | One Player | 150cc | Sound On | 107.84 |
| Jill | One Player | 50cc | Sound Off | 124.18 |
| Jill | One Player | 100cc | Player's Music | 106.38 |
| Jill | Two Players | 100cc | Player's Music | 108.59 |
| Jill | Two Players | 150cc | Player's Music | 105.81 |
| Jill | One Player | 50cc | Player's Music | 123.35 |
| Jill | One Player | 150cc | Player's Music | 97.87 |
| Jill | One Player | 50cc | Sound On | 118.51 |
| Jill | Two Players | 50cc | Sound Off | 123.56 |
| Jill | Two Players | 50cc | Sound On | 112.08 |
| Daniel | Two Players | 100cc | Player's Music | 116.55 |
| Daniel | One Player | 50cc | Sound Off | 125.86 |
| Daniel | Two Players | 100cc | Sound On | 120.1 |
| Daniel | One Player | 150cc | Sound On | 114.96 |
| Daniel | Two Players | 50cc | Sound On | 123.94 |
| Daniel | Two Players | 150cc | Player's Music | 112.9 |
| Daniel | One Player | 100cc | Sound On | 130.38 |
| Daniel | One Player | 50cc | Sound On | 127.21 |
| Daniel | Two Players | 150cc | Sound Off | 116.69 |
| Daniel | Two Players | 150cc | Sound On | 110.83 |
| Daniel | Two Players | 50cc | Sound Off | 130.19 |
| Daniel | Two Players | 50cc | Player's Music | 120.7 |
| Daniel | One Player | 50cc | Player's Music | 126.27 |
| Daniel | One Player | 150cc | Sound Off | 120.09 |
| Daniel | Two Players | 100cc | Sound Off | 119.4 |
| Daniel | One Player | 100cc | Sound Off | 119.65 |
| Daniel | One Player | 150cc | Player's Music | 114.43 |
| Daniel | One Player | 100cc | Player's Music | 123.04 |
| Olusegun | Two Players | 150cc | Sound Off | 103.91 |

| | | | | |
|---|---|---|---|---|
| Olusegun | One Player | 100cc | Sound On | 117.92 |
| Olusegun | One Player | 50cc | Player's Music | 123.06 |
| Olusegun | Two Players | 50cc | Player's Music | 118.32 |
| Olusegun | Two Players | 50cc | Sound On | 122.15 |
| Olusegun | One Player | 50cc | Sound Off | 122 |
| Olusegun | Two Players | 100cc | Player's Music | 118.96 |
| Olusegun | Two Players | 100cc | Sound On | 108.9 |
| Olusegun | One Player | 100cc | Player's Music | 126.57 |
| Olusegun | Two Players | 50cc | Sound Off | 125.05 |
| Olusegun | Two Players | 150cc | Player's Music | 103.69 |
| Olusegun | One Player | 50cc | Sound On | 122.47 |
| Olusegun | One Player | 150cc | Sound On | 102.42 |
| Olusegun | One Player | 150cc | Sound Off | 98.32 |
| Olusegun | One Player | 150cc | Player's Music | 104.23 |
| Olusegun | Two Players | 150cc | Sound On | 102.54 |
| Olusegun | Two Players | 100cc | Sound Off | 109.29 |
| Olusegun | One Player | 100cc | Sound Off | 104.45 |
| Austin | Two Players | 150cc | Sound On | 96.88 |
| Austin | Two Players | 150cc | Sound Off | 92.32 |
| Austin | One Player | 100cc | Sound On | 97.9 |
| Austin | One Player | 50cc | Player's Music | 121.35 |
| Austin | Two Players | 150cc | Player's Music | 100.89 |
| Austin | One Player | 150cc | Sound Off | 108.45 |
| Austin | One Player | 50cc | Sound On | 116.28 |
| Austin | One Player | 150cc | Sound On | 92.32 |
| Austin | Two Players | 100cc | Sound Off | 111.67 |
| Austin | One Player | 100cc | Player's Music | 127.2 |
| Austin | Two Players | 50cc | Sound Off | 116.13 |
| Austin | Two Players | 100cc | Sound On | 103.69 |
| Austin | One Player | 100cc | Sound Off | 99.34 |
| Austin | Two Players | 50cc | Player's Music | 119.87 |
| Austin | One Player | 50cc | Sound Off | 117.89 |
| Austin | One Player | 150cc | Player's Music | 89.82 |
| Austin | Two Players | 100cc | Player's Music | 108.52 |
| Austin | Two Players | 50cc | Sound On | 113.79 |

## 6.2 Code

### 6.2.1 Packages used

```
library(tidyverse)
library(pander)
library(MASS)
```

### 6.2.2 Import the above data

```
dat <- read.csv("data.csv", stringsAsFactors = T,fileEncoding = 'UTF-
8-BOM')
dat$difficulty <- relevel(dat$difficulty, "50cc")
```

### 6.2.3 ANOVA Table

```
aov_out <- aov(formula = time ~ numPlayers*difficulty*sound +
participant,
               data = dat)
(aovSum <- summary(aov_out)[[1]])
```

### 6.2.4 Assumption Checking

```
qqnorm(aov_out$residuals)
qqline(aov_out$residuals)
par(mfrow = c(2,2),
    mar = c(2,0,0,0),
    mgp = c(0,.5,0),
    omi = c(0,.25,0,0))
plot(x = dat$numPlayers, y = aov_out$residuals,
     xlab = "", ylab = "Residuals")
plot(x = dat$difficulty, y = aov_out$residuals,
     xlab = "", ylab = "", yaxt = "n")
plot(x = dat$sound, y = aov_out$residuals,
     xlab = "", ylab = "Residuals")
plot(x = dat$participant, y = aov_out$residuals,
     xlab = "", ylab = "Residuals", yaxt = "n")
plot(aov_out$fitted.values,aov_out$residuals,xlab="Fitted Lap
Times",ylab="Residuals",
     main="Residuals vs. Fitted Lap Times")
abline(h=0)
plot(aov_out$residuals,ylab="Residuals",type="l",
     main="Residuals vs. Index", xlim = c(1,72))
res_ind_df <- data.frame(index = 1:length(aov_out$residuals),
                          res = aov_out$residuals)
res_ind_lm1 <- lm(res~index, res_ind_df[1:18,])
res_ind_lm2 <- lm(res~index, res_ind_df[(18+1):(18*2),])
res_ind_lm3 <- lm(res~index, res_ind_df[(18*2+1):(18*3),])
res_ind_lm4 <- lm(res~index, res_ind_df[(18*3+1):(18*4),])
plot(aov_out$residuals,ylab="Residuals",type="l",
     main="Residuals vs. Index", xlim = c(1,72))
abline(v= 18)
abline(v= 18*2)
abline(v= 18*3)
clip(1, 18, -100, 100)
abline(res_ind_lm1, xlim = 1:18)
clip(18, 18*2, -100, 100)
abline(res_ind_lm2, xlim = 1:18)
clip(18*2, 18*3, -100, 100)
abline(res_ind_lm3, xlim = 1:18)
clip(18*3, 18*4, -100, 100)
abline(res_ind_lm4, xlim = 1:18)
# outlier detection
```

```
which(abs(aov_out$residuals/aovSum$`Mean Sq`[9])>3)
boxcox(aov_out)
```

#### 6.2.5 F-test between the pre-trial variance and the experiment variance

```
Fstat <- var(time_obs)/aovSum$`Mean Sq`[9]
1-pf(Fstat, df1 = 19, df2 = 54)
```

#### 6.2.6 Interaction charts

```
Sound <- dat$sound
Difficulty <- dat$difficulty
`Number of Players` <- dat$numPlayers
par(mfrow = c(1,2))
interaction.plot(x.factor = Sound, trace.factor = Difficulty,
                 response = dat$time, xlab = "Sound", ylab = "Mean
Time",
                 legend = F)
legend(x = 2.1, y = 119, legend = c("50cc","100cc","150cc"), lty =
3:1,
       bty = "n", title = "Difficulty")
interaction.plot(x.factor = Sound, trace.factor = `Number of Players`,
                 response = dat$time, xlab = "Sound", ylab = "Mean
Time",
                 legend = F)
legend(x = 1.7, y = 115.5, legend = c("One Player","Two Player"), lty
= 2:1,
       bty = "n", title = "Number of Players")
```

#### 6.2.7 Tukey Comparisons

```
alphaTukey <- 0.03
TukeyHSD(aov_out, "difficulty",ordered = T,
         conf.level = 1-alphaTukey)$difficulty

tuk <- TukeyHSD(x = aov_out,which = "difficulty",
                 ordered = T, conf.level = 1-.03)$difficulty %>%
  apply(2,function(i) as.numeric(i)) %>% as.data.frame()

difficultyTukey <- cbind(comparison = c("100cc->150cc",
                                        "50cc->150cc",
                                        "50cc->100cc"),
                         tuk)
theme_set(theme_bw())
theme_update(text = element_text(size=12),
panel.grid.major = element_blank(),
panel.grid.minor = element_blank(),
strip.background = element_blank()
)
ggplot(data = difficultyTukey) +
  geom_point(mapping = aes(x =  comparison, y = diff),
             stat="identity", pch = 3, size = 20) +
  geom_errorbar(mapping = aes(x = comparison, ymin = lwr, ymax = upr))
+
  labs(x = "", y = "Difference (Seconds)") +
  scale_x_discrete(labels=c('50cc->150cc'= expression("50cc" %->%
"150cc"),
```

```
                            '50cc->100cc'= expression("50cc" %->%
"100cc"),
                            '100cc->150cc'= expression("100cc" %->%
"150cc"))) +
  coord_flip()
```

### 6.2.8 Polynomial comparisons

```
dat %>%
  group_by(difficulty) %>%
  summarise(mean(time),.groups = "drop") %>%
  select(-difficulty) %>%
  unlist() %>% unname() -> difficulty_means

alpha_poly <- 0.02

MSE <- aovSum$`Mean Sq`[9]

ci_lin <- c(1,0,-1)
ci_quad <- c(1,-2,1)

C_lin <- sum(ci_lin*difficulty_means)
C_quad <- sum(ci_quad*difficulty_means)

mult_poly <- qt(1-alpha_poly/(2*2), df = aovSum$Df[9])

lower_poly_CI_lin <- C_lin - mult_poly*sqrt(MSE)
lower_poly_CI_quad <- C_quad - mult_poly*sqrt(MSE)
upper_poly_CI_lin <- C_lin + mult_poly*sqrt(MSE)
upper_poly_CI_quad <- C_quad + mult_poly*sqrt(MSE)

cbind(`Lower CI` = c(lower_poly_CI_lin, lower_poly_CI_quad),
      `Contrast` = c(C_lin, C_quad),
      `Upper CI` = c(upper_poly_CI_lin, upper_poly_CI_quad)) ->
polyout

rownames(polyout) <- c("Linear", "Quadratic")
pander::pander(polyout)
```

### 6.2.9 Relative Efficiency

```
a <- 3
b <- 4
MSblock <-aovSum$`Mean Sq`[4]

sigma2CRD <- ((b-1)*MSblock + b*(a-1)*MSE)/(a*b-1)

dfe_RBD <- (a-1)*(b-1)
dfe_CRD <- a*(b-1)

cf <- ((dfe_RBD+1)+(dfe_CRD+3))/((dfe_RBD+3)+(dfe_CRD+1))

cf*sigma2CRD*MSE
```

6.2.10 Power for future studies

```
alpha=.05
a=3  # number of levels of A
b=3  # number of levels of B
c=2     # number of levels of C
sigsq = 29.56 # The sigma squared from the experiment
n=35 #number of blocks
DA=2 #desired diff (in seconds) in means to detect with prob 1-beta
Fcrit=qf(1-alpha,a-1,(a*b*c-1)*(n-1)) #value at which we reject H0
lam=n*b*c*(DA^2)/(2*sigsq) #non-centrality parameter (ncp)
beta=pf(Fcrit,a-1,(a*b*c-1)*(n-1),ncp=lam)
power=1-beta
nforA=cbind(n,Fcrit,beta,power)  #output for A
nforA
```

# 7 Citations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