Group 15 members: Jackelin Hernandez, Ngoc Nguyen,
Isabelle Tandradinata, Sam Reade, Mingye Wang,
Katelyn Soulman

# STATS 101B Final Report
## Which type of exercise is the most effective at reducing cortisol (stress) levels?


## Abstract

This study examines how varying physical exercise intensities (no exercise, walking outdoors, yoga, swimming, strength training, running outdoors) affect immediate stress responses by measuring salivary cortisol levels. Our research question is: What type of exercise is the most effective at reducing cortisol levels? Participants will provide preliminary saliva samples, engage in exercises ranging from low to high intensity, and then provide subsequent saliva samples once again. We have six treatment levels (types of exercise) and block our data by age (6 levels) to reduce variability from factors such as energy and stress levels changing as people age. We construct an ANOVA summary table; however, our data indicates that none of the exercises contributed to lowering or increasing the cortisol levels of our participants. Despite this, we conducted post hoc data analysis to assess potentially significant pairs and found that walking has the potential to have a significant effect on stress levels in comparison to doing nothing. We additionally performed residual analysis and concluded that our model's assumptions are valid. This means our data collection is accurate, but other nuisance factors we did not control for might have influenced our results.


## Introduction

In recent years, growing research has been directed toward the role of physical activity in mental health, particularly in managing stress (American Psychological Association, 2020). Understanding the causal relationship between exercise and stress could help prevent or treat stress-induced illnesses by simply promoting physical activity (Sharon-David & Tenenbaum, 2017). As college students, we were also particularly interested in exploring this research topic because stress is something many students deal with on a regular basis, and we hope to find practical ways to alleviate this barrier to academic success.

In this project, we aim to design an experiment that statistically explains the immediate effects of exercise intensity on salivary cortisol levels using 'The Islands' virtual simulation. Our population of interest is individuals aged 12+, as Islanders under this threshold are unable to perform certain exercises. We conducted this study using a randomized complete block design to analyze how five treatment exercises (brisk walking outdoors, yoga, freestyle swimming, strength training, and running outdoors) influence salivary cortisol compared to the control group (no exercise) and with one another. We will then perform data analysis, residual analysis, and a power test using R to determine which variables were significant, if any, and ensure our model assumptions are valid. Once we fit a final population model, we will conclude by discussing experiment limitations and real-world implications.

## Design of the experiment

We use a complete randomized block design. We have six levels for the treatment factor: yoga, swimming, strength training, running outdoors, walking outdoors, and doing nothing (as a control group). We also block the participants by age into six categories: 12-19, 20-29, 30-39, 40-49, 50-59, 60-99. This is justified because energy and stress levels change as people age, and blocking reduces the variability of the effect of age on the treatment.

We decided on a total of 90 participants, with 30 selected from each of the islands. There were 90 replicates (six treatments, each with 15 participants), resulting in 180 observations (cortisol levels before and after exercise). We used R to randomly sample cities within each island with replacement. Then we randomly sampled the houses without replacement to avoid confounding variables such as housing situation. If more than one person lived in the house, we would randomly pick one of them, using R, to participate in the experiment.

If a person refused to be a participant in the study, withdrew, or passed away, we resampled from houses in the same city to find a replacement. For each island, we used a random number generator to assign a number to each participant and then sorted them randomly based on this number. We then listed the treatments and used R to randomly generate a treatment order. Every five participants were assigned the treatment based on that order for each island.

The initial experiment was only blocked by island, so when we switched to blocking by age, we had to resample because the blocks ended up unbalanced, with some blocks having zero participants for a certain treatment (**Figure A2**). The blocks were still unbalanced, but every block had at least one participant for each treatment after resampling (**Figure A3**). We decided to resample instead of adding more participants because we had equal variances in our treatment groups. According to Karen Grace-Martin, if we have an unequal sample size, this can be remedied by having equal variances in our groups. While this isn't ideal, this supports the idea that since we have equal variance, as evident in **Figure 4**, we just made sure all the age groups were not empty (Grace-Martin, K., 2023).

## Results and interpretation

After we finished collecting data, we started performing ANOVA to determine whether the exercises have a significant effect on the islanders' cortisol levels while blocking age. We decided to block by age as we are only interested in seeing the change in cortisol levels without the effect of age variability.

| | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| treatment | 5 | 0.00604 | 0.0012078 | 1.853 | 0.112 |
| age | 5 | 0.00273 | 0.0005466 | 0.839 | 0.526 |
| Residuals | 79 | 0.05148 | 0.0006517 | | |

*Figure 1. ANOVA Model with Block Factor Age*

From our ANOVA model in **Figure 1**, we see that the exercises are not significant in affecting the islanders' cortisol level, for the p-value is 0.112, which is greater than the significance level of 0.05. Based on this result, we conclude that there is no statistically significant difference in cortisol level changes among different exercises with the blocking of age.

Besides age, there is another potential blocking factor that we do not want to study in this experiment, and that is gender. We conducted another ANOVA model that uses gender as the blocking factor to see if we can receive a lower p-value for treatment. However, Figure A1 in Appendix A shows that gender gives a higher p-value for treatment than age. Even though the p-value for gender is lower than that for age, we only care about the p-value for treatment. Thus, blocking by age would be more ideal.

Although our ANOVA model indicates that there is no significance, we still wanted to narrow down which exercises could still affect cortisol levels. To do this, we utilized **post-hoc analysis**, in which we applied Tukey's method to compare different combinations of exercises and see which group means for exercises are significantly different from one another.

```
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = change ~ treatment + age)

$treatment
                        diff         lwr         upr     p adj
run-nothing      -0.0216666667 -0.04889320 0.005559869 0.1967478
strength-nothing -0.0207333333 -0.04795987 0.006493203 0.2385188
swim-nothing     -0.0133333333 -0.04055987 0.013893203 0.7085561
walk-nothing     -0.0252000000 -0.05242654 0.002026536 0.0859005
yoga-nothing     -0.0154000000 -0.04262654 0.011826536 0.5670926
strength-run      0.0009333333 -0.02629320 0.028159869 0.9999985
swim-run          0.0083333333 -0.01889320 0.035559869 0.9468743
walk-run         -0.0035333333 -0.03075987 0.023693203 0.9989448
yoga-run          0.0062666667 -0.02095987 0.033493203 0.9844902
swim-strength     0.0074000000 -0.01982654 0.034626536 0.9677876
walk-strength    -0.0044666667 -0.03169320 0.022759869 0.9967591
yoga-strength     0.0053333333 -0.02189320 0.032559869 0.9925650
walk-swim        -0.0118666667 -0.03909320 0.015359869 0.7986697
yoga-swim        -0.0020666667 -0.02929320 0.025159869 0.9999236
yoga-walk         0.0098000000 -0.01742654 0.037026536 0.8987773
```

*Figure 2. Tukey's Method*

Based on Tukey's Method in **Figure 2**, we can see that walk-nothing is the combination of exercises that has the lowest p-value of around 0.086. Although the p-value is not less than 0.05 to reject the null hypothesis and conclude that one of the exercises is significant over the others, it still provides us with the insight that, between walking and doing nothing, walking has the greatest potential to reduce cortisol levels compared to doing nothing.

To perform the **power ANOVA test**, the means of each treatment group needed to be calculated. The standard deviation within each group also needed to be found. From these metrics, the F-value for the test is calculated, which would be used for the power ANOVA test. The test was utilized to give us insight into how many participants we would need in each treatment group for a desired significance level and power of 0.05 and 0.9, respectively. The group means for control, brisk walk outdoors, run outdoors, strength training, swim freestyle, and yoga were calculated to be about -0.0096, 0.0156, 0.0121, 0.01113, 0.00373, 0.0058, respectively. The standard deviation within groups was calculated to be about 0.0254, and with these values, the F-value was found to be about 0.32454. The power ANOVA test, the results of which are visualized to the left, reports that we should have approximately 27 participants assigned to each treatment. However, due to time constraints, we were only able to achieve 15 participants for each treatment, which would become a limitation in our study.

```
     Balanced one-way analysis of variance power calculation

              k = 6
              n = 27.00035
              f = 0.3245381
      sig.level = 0.05
          power = 0.9

NOTE: n is number in each group
```

*Figure 3. Power ANOVA test*

All relevant **model assumptions** in **Figure 4** were evaluated and found to be satisfied. The normality of residuals was assessed using a Q-Q plot, which indicated that the residuals were approximately normally distributed. The vast majority of the data points lie along the diagonal line with very small deviations. Homogeneity of variances, homoscedasticity, was confirmed using the Scale-Location plot, which showed no significant difference in variances across groups. The data points appear randomly scattered and show no clear pattern. Independence of observations was ensured by the study design, with data collected from unrelated subjects randomly. Inspection of the Residuals vs. Fitted and Residuals vs. Leverage plots also showed no patterns. This further supports the assumptions of normality and equal variance, essential to the study. Therefore, the ANOVA results can be considered valid and interpretable under the model assumptions.

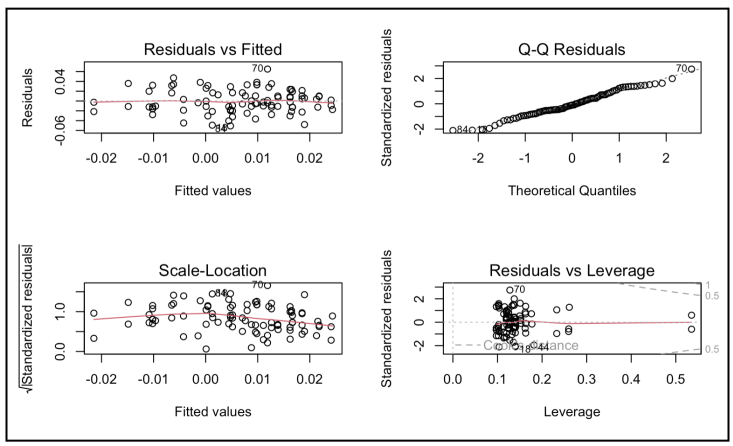


*Figure 4. Checking Model Assumptions*

**Discussion**

Our study aimed to investigate the effects of various types of physical exercise on cortisol levels. Despite our analysis being unable to show any statistically significant differences in cortisol levels among the six exercise treatments at the 0.05 level, blocking by age resulted in a slightly reduced p-value, suggesting that age influenced the effect of exercise on our response variable and that blocking this decreased our model's total variability. Ultimately, we concluded that none of the tested exercises had a statistically significant effect on salivary cortisol levels. Despite this overall insignificance among our findings, a post-hoc analysis revealed that brisk walking outdoors versus no physical activity yielded the smallest p-value, 0.0859, among all exercise comparisons, suggesting that walking may potentially be beneficial for managing stress levels.

These observations are consistent with real-world recommendations that encourage physical activity for overall well-being, including managing stress. As students, we were particularly interested in practical ways to reduce stress, given how commonly it manifests in academic environments. Walking is a convenient and accessible way to exercise and can easily be implemented into daily routines. Since walking shows the most potential among all other exercises, it reinforces the idea that even light physical activity can be effective in aiding in stress reduction.

The outcome of our study aligns with the existing research, such as "*The effects of exercise intensity on the cortisol response to a subsequent acute psychosocial stressor"* (Caplin et al., 2021), which found that the relationship between exercise and cortisol levels is not always linear or significant across different exercise intensities. Their study specifically showed that exercise has the ability to "buffer" cortisol response to specific stressors, but that the effectiveness is dependent on the type of exercise, intensity, and individual variability. Similarly, our results suggest that walking may have some effect on cortisol, but it is likely that the lack of control using simulated data may have led to an excess of variability and prevented us from obtaining any strong conclusions.

Several limitations should also be considered that may have contributed to the lack of statistical significance in our results. First, the use of simulated data may not fully reflect real-world variability in human behavior. Second, we could not control for important confounding factors, like the participants' sleep, diet, prior physical activity, or the exact time of salivary cortisol measurement, due to logistical constraints. Third, based on our power ANOVA test **(Figure 3)**, our sample size was too small to identify any small effects between the different treatments. Lastly, we initially went into the experiment blocking by island, not by age. As a result, we sampled with balanced blocks across islands, but once we found that blocking by age resulted in a smaller p-value, we were left with an unbalanced randomized block design. Because of time constraints, we could not redo our experiment with an even number of participants in each age level. However, we did our best to correctly follow the procedure in handling an unbalanced block based on further research. This still may have affected our results and our ability to identify any significant differences due to large within-block variability. The unbalanced block likely introduced more variability, weakening the estimates of the effects.

In spite of this, our study supports the idea that light to moderate intensity exercise, like walking, may be beneficial in regard to managing stress levels, especially when compared to doing no physical activity at all. While these findings don't exactly align with our original hypothesis, they highlight the need for further research, likely using real-world data, tightly controlled conditions, and a larger sample size to isolate the effects of different exercise types on cortisol levels more effectively.

## References

A. Caplin, F.S. Chen, M.R. Beauchamp, E. Puterman, The effects of exercise intensity on the cortisol response to a subsequent acute psychosocial stressor, Psychoneuroendocrinology, Volume 131, 2021, 105336, ISSN 0306-4530,https://doi.org/10.1016/j.psyneuen.2021.105336.

American Psychological Association. (2020). Working out boosts brain health. American Psychological Association. https://www.apa.org/topics/exercise-fitness/stress

Grace-Martin, K. (2023, August 9). When unequal sample sizes are and are NOT a problem in ANOVA. The Analysis Factor. https://www.theanalysisfactor.com/when-unequal-sample-sizes-are-and-are-not-a-problem-in-anova/

Sharon-David, H., & Tenenbaum, G. (2017). The Effectiveness of Exercise Interventions on Coping with Stress: Research Synthesis. *ResearchGate*. https://www.researchgate.net/publication/328286842_The_Effectiveness_of_Exercise_Interventions_on_Coping_with_Stress_Research_Synthesis

## Appendix A

### Tables

| | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|---|---|---|---|---|---|
| treatment | 5 | 0.00584 | 0.0011677 | 1.823 | 0.117 |
| gender | 1 | 0.00034 | 0.0003366 | 0.525 | 0.471 |
| Residuals | 83 | 0.05318 | 0.0006407 | | |

*Figure A1. ANOVA Model with Block Factor Gender*

```
table(data$Treatment, data$AgeRange)
```

| | 12-19 | 20-29 | 30-39 | 40-49 | 50-59 | 60-69 | 70-79 | 90-99 |
|---|---|---|---|---|---|---|---|---|
| Brisk Walk Outdoors | 2 | 6 | 1 | 4 | 0 | 1 | 1 | 0 |
| Nothing (Control) | 2 | 5 | 2 | 2 | 1 | 2 | 0 | 1 |
| Run Outdoors | 1 | 2 | 4 | 2 | 4 | 1 | 0 | 1 |
| Strength Training | 4 | 4 | 1 | 2 | 2 | 1 | 1 | 0 |
| Swim Freestyle | 2 | 2 | 4 | 0 | 3 | 2 | 2 | 0 |
| Yoga | 5 | 4 | 1 | 0 | 1 | 2 | 2 | 0 |

*Figure A2. Table showing the number of participants in a treatment for a certain age range.*

```
table(data$Treatment, data$AgeRange)
```

| | 12-19 | 20-29 | 30-39 | 40-49 | 50-59 | 60-99 |
|---|---|---|---|---|---|---|
| Brisk Walk Outdoors | 2 | 4 | 2 | 3 | 2 | 2 |
| Nothing (Control) | 2 | 5 | 2 | 2 | 1 | 3 |
| Run Outdoors | 1 | 2 | 4 | 2 | 4 | 2 |
| Strength Training | 4 | 4 | 1 | 2 | 2 | 2 |
| Swim Freestyle | 2 | 2 | 3 | 2 | 3 | 3 |
| Yoga | 3 | 4 | 1 | 2 | 1 | 4 |

*Figure A3. Table showing the number of participants in a treatment for the different age ranges after resampling.*