Factorial Experimental Analysis on Running and Heart Rate

Stephen Shannon

April 12, 2021

I Description

Having a low resting heart rate is associated with lower risk of cardiovascular disease and other clinical outcomes(1). Those with healthy hearts pump blood more effeciently, and thus require less beats as opposed to other people. One of the most common ways that people have lower resting heart rates is by engaging in excercise(2) which pushes the heart to 50% to 85% of its capacity(3). For 20 year olds, this is about 100-170 BPM (beats per minute). During the on-going pandemic it has become tough to regularly excercise and to maintain a healthy heart due to frequent lockdowns. Thus it is important to understand what factors can lower or raise ones heart rate while excercising to achieve a heartrate within the recommended target zones. I devised a (2ˆ2) factorial experiment which sought to understand the effects of two popular conditions and their effect on heart rate. Namely, whether listening to music while running and whether stretching before a run would increase heart rate. Listening to music has been shown to have a positive impact on heart health because listning to music speeds up ones heart rate and increases breathing (4), and the effect becomes more pronounced as the speed of the song increases (4). Additionally, stretching has been shown to increase heart rate and heart rate variability within individuals (5). For this experiment, I recruited three friends to undertake 4 trials. Each trial consisted of running 500 meters than immediately taking the test subjects pulse for 10 seconds, i.e. Counting the number of beats ones heart makes in 10 seconds. Before any of the trials subjects took their resting heart rate for 10 seconds 5 times to calculate their average resting heart rate. In between each trial, to control for the impact of completing one trial on the other, subjects were made to rest for 10 minutes between each trial, allowing for a washout period to let their heart rates return to their baseline values before beginning the next trial. Each replication was done on seperate days.

Picture: Experimental unit completing a 500m run trial.

Trial 1 was the null trial, no stretching or music. In trial 2, all subjects participated in the same 10 minute stretching routine before carrying out the 500 meter run. In trial 3, all subjects were instructed to listen to music while they ran the 500 meters. In order to control for songs with different BPM (Beats per minute), the same song was used for during each trial with music. Darude - Sandstorm (https://www.youtube.com/watch?v=y6120QOlsfU). In trial 4, subjects were given the same streching routine in trial 2 and also instructed to listen to Darude - Sandstorm during their run. Once the four trials were completed, subjects left the site and came back the next day to complete a replication of the four trials. With the data having been collected, the response was the difference between the active heart rate and the resting heart rate in an attempt to control for differing base heart rates and active heart rates.

II Data Analysis

Seeking to understand the effects of stretching before running, listening to music while running, and potential interactions between these two factors on heart rate, we began our data analysis. Since each participant has a different baseline heart rate and active heart rate was different for each subject, I decided to model with the response variable being the increase from the baseline heart rate after running to try and minimize variation across subjects. baseline heart rate however still remains a random effect within our experiment that can not be controlled for.

Table 1: Table with all 24 entries for three experimental subjects. Showing each subject, their baseline heartrate for 10 seconds, and the difference from their baseline heart rate with respect to each trial and replication.

subject	baseline_bpm	run	rep	diff_from_baseline
1	10.4	1	1	19.6
1	10.4	2	1	18.6
1	10.4	3	1	19.6
1	10.4	4	1	19.6
1	10.4	1	2	19.6
1	10.4	2	2	19.6
1	10.4	3	2	20.6
1	10.4	4	2	19.6
2	11.4	1	1	17.6
2	11.4	2	1	18.6
2	11.4	3	1	17.6
2	11.4	4	1	17.6
2	11.4	1	2	16.6
2	11.4	2	2	17.6
2	11.4	3	2	17.6
2	11.4	4	2	16.6
3	10.2	1	1	20.8
3	10.2	2	1	21.8
3	10.2	3	1	22.8
3	10.2	4	1	21.8
3	10.2	1	2	19.8
3	10.2	2	2	20.8
3	10.2	3	2	20.8
3	10.2	4	2	21.8

From this table it is obvious for each subject there is no substantial change with respect to each run, and the only difference among subjects is accounted for by their baseline heart rate. The above data is summarized below in the following boxplot graph

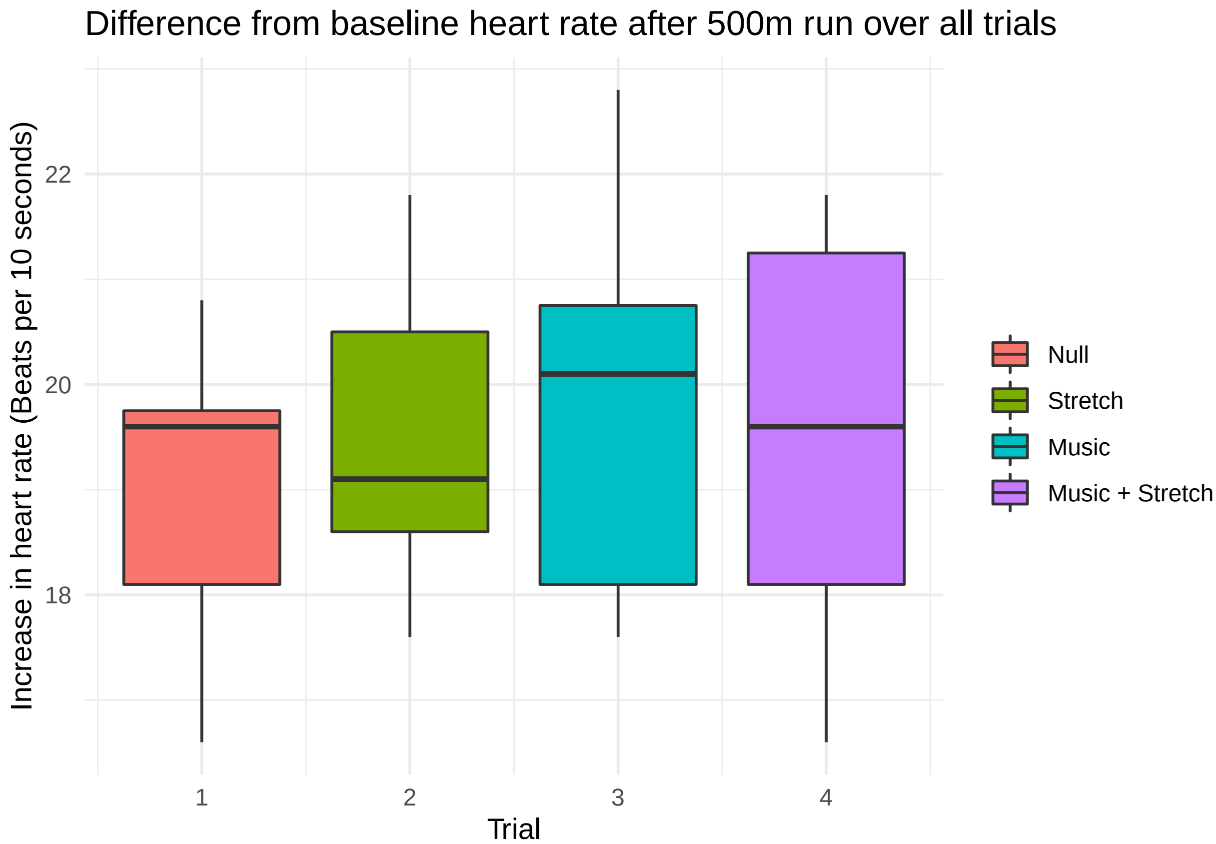

Figure 1: Boxplot representing the IQR and the Median of the results. It appears that there is not much of a difference between each of the trials. However, across all subjects, it appears that listening to music has the highest median increase in heart rate, as well as having the highest observed value in heart rate increase. Perhaps music may be an signifigant effect?

Turning now to the analysis of the factors in this experiment, we can estimate the effect of a specifc condition by comparing the mean response of all other conditions when that particular condition is not involved. This is called the main effect of the variable because it is an average taken over all the other factor levels. Specifically, it is the cast that the main effect of stretching is 0.085, and the main effect of listening to music is 0.41. The effect of the interaction between stretching and music is -0.41.

To further analyze the interaction effect, I used an interaction plot to see the effect of music on stretching.

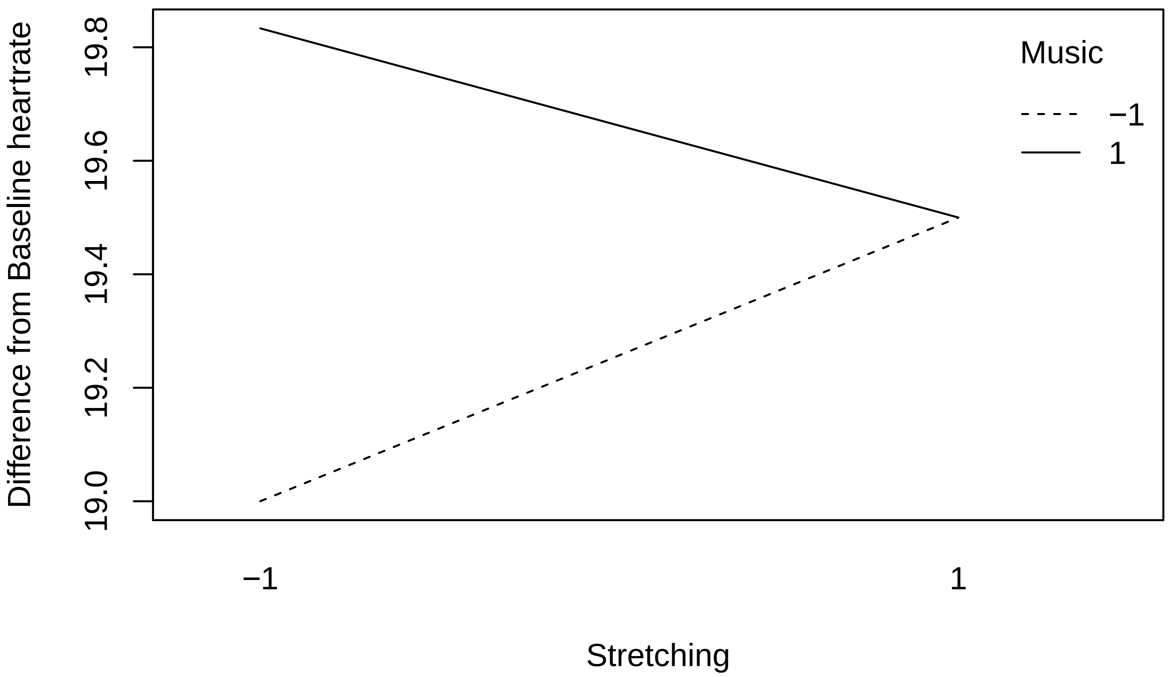

Figure 2: Interaction plot of music and stretching.

Since the slopes appear to be orthogonal to each other, this suggests an interaction between Stretching and listening to music. Music slightly raises heart rate, and stretching slightly lowers it. It is not surprising then, that when both factors are included it seems to "cancel out" the other factor and has the same effect as if there was neither stretching or music, the same conditions in the null trial. Listening to music seems to have the largest impact on heartrate out of all the other factors, raising heart rate on average by 0.415 beats over 10 seconds. Later, we will investigate whether this effect is signifigant.

Having done a replication for the experiment, it was possible to calculate the error variance of the effects (stretching, listening to music) from the replicated runs. In this case we found that the error variance is 0.076, which is a very small amount. This is because there simply is not much variation in the data across each subjects replications.

Finally, before constructing a linear model, it is necessary to check if the response variable, the difference in heart rate is normally distributed.

```
qqnorm(table_main$diff_from_baseline);qqline(table_main$diff_from_baseline)
```

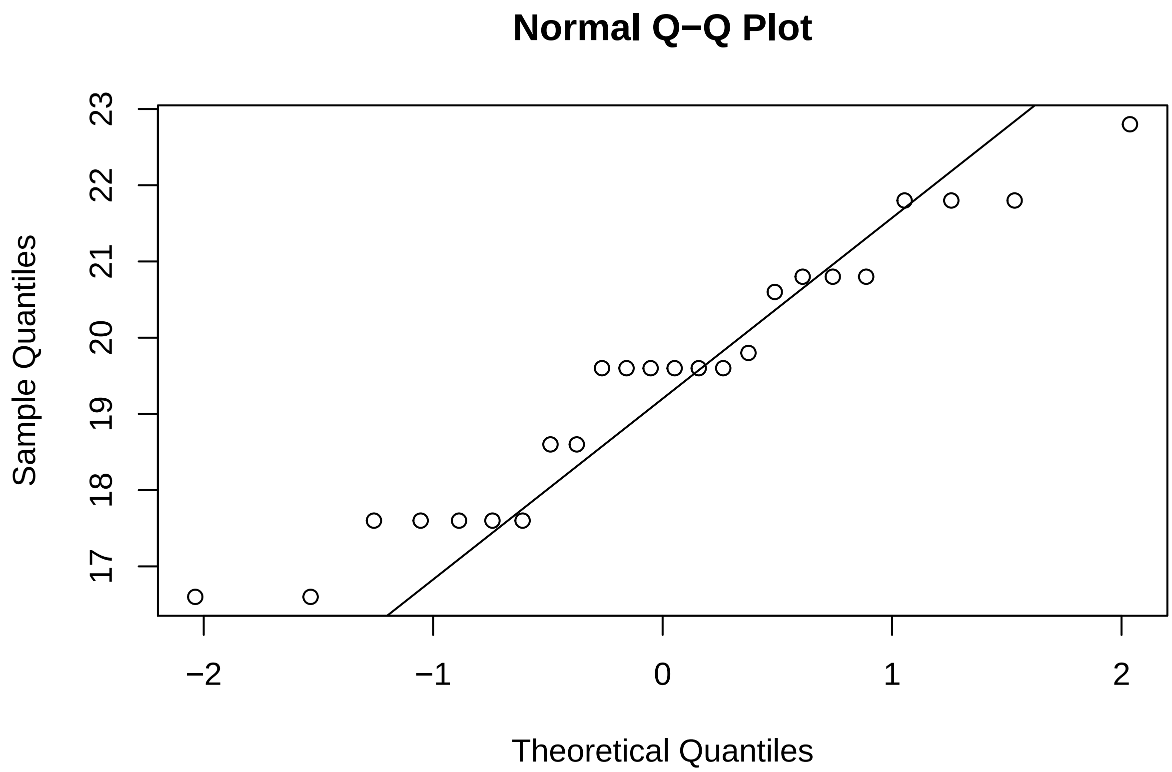

Figure 3: Q-Q plot of the response variable, Difference from baseline heart rate. Since our data points adhere to the line, it is safe to say that the response is normally distributed.

Understanding effects, the interactions and variance introduced from errors, and validating that our response is gaussian, we can now construct a linear model to fit to our data and capture the small imapct of our factors on running. Our first model will be fit with all factors.

$y = \beta_0 + \beta_1 x_1 + \beta 2 x_2 + \beta_3 x_3 + \epsilon$

Where β_0 is the intercept, β_1 is the parameter for stretching, β_2 is the parameter for listening to music, and β_3 is the parameter for the interaction between stretching and listening to music.

With this model setup, it is now possible to begin hypothesis testing. Referring back to the original research questions, whether stretching, listening to music and the interaction between stretching and listening to music has an impact on heart rate, I will setup three hypothesis tests to determine whether or not the parameters for these factors are significant or not. The tests are as follows

Test1: H0: The coeffecient estimate for stretching $\beta 1$ is not significant, that is, $\beta_1 = 0$. HA: The coeffecient estimate for stretching $\beta 1$ is significant, that is, β_1 is NOT equal to 0. P-val = 0.913

Test2: H0: The coeffecient estimate for music $\beta 2$ is not significant, that is, $\beta_2 = 0$. HA: The coeffecient estimate for music $\beta 2$ is significant, that is, β_2 is NOT equal to 0. P-val = 0.585

Test3: H0: The coeffecient estimate for the interaction between music and stretching $\beta 3$ is not significant, that is, $\beta_3 = 0$. HA: The coeffecient estimate for interaction between music and stretching $\beta 3$ is significant, that is, β_3 is NOT equal to 0. P-val = 0.585

In this instance, the P-value for all three tests were above 0.05, which indicates that the probability of observing the T-values associated with our coeffecient estimates does not meet the threshold of significance, and that we fail to reject the null hypotheses in all three tests.

In fact, the only parameter which does have a significant P-value, is the intercept parameter β_0. Thus, a better linear model for this experiment would be an intercept only model.

$y = \beta_0$

This makes sense since, the response changed very little over the course of the factorial trials, and this variation can not be accurately measured as a change arising from natural error, or actual change resulting from the factorial conditions. Running stepwise regression on the fullmodel with backward selection AIC, confirms that the the lowest AIC value of 27.57 is obtained with the intercept only model as opposed to the full model with AIC 32.82.

Since we are left with an intercept only model, it makes sense that since each experimental unit varied with respect to their baseline heart rates, that we create a linear mixed effect model, which will fit a random intercept associated with each experimental unit.

Letting our intercept parameter vary for each subject presents the best model as we allow more flexibility to our intrecept parameter for better generalization if we were to encounter another dataset for our model to make predictions about.

$y_i = (\beta_0 + Z_{subject}) + \epsilon$

where, $Z_{subject} \sim N(0, \tau^2)$, where τ^2 is 1.106

III Conclusions

After conducting the experiment and analyzing the collected data, it is apparent that stretching and listening to music have very little to no effect on ones heartrate after running 500 meters. The effect of stretching and listening to music upon heart rate is minimal and can not be distinguished as a seperate effect or as nastural variation in the response. Furthermore, the interaction between stretching and listening to music was not significant and produced about the same results as the null trial did, that is, no music or no stretching. In terms of finding the "optimal" conditions, that is, the largest increase in heart rate, the highest observed difference from baseline heart rate was in trial 3 where participants listened to music. Trial 3 had the highest median value of an increase in heart rate. It was determined that the interaction between listening to music and stretching had a minimal decrease on heartrate, but this effect was determined to be not significant. In the end, the best generalized model that was discovered was an intercept only model. It is safe to conclude then that stretching, listening to music, and the their interaction have little to no impact upon heart rate after completing a 500m run.

IV Discussions and Limitations

This experiment had many limiting factors which impacted the data collection process. To begin with, measuring heart rate is not as easy a task as it seems. Since heart rate decreases as time passes since 500 meter run, it is not possible to count every pulse the heart generates within a minute. Measurements would be different each time the measurement is taken, and if the experimental unit makes a mistake while counting, the measurement is lost. To account for this, I measured heart rate for only 10 seconds, which is a small enough time frame that heart rate would not change through the measurement period. However, this reduced the amount of variation present in the response variables, which made it more difficult to detect differeneces during different conditional runs, for instance if a factor had an impact that reduced or added 3 BPM (beats per minute) to heart rate over 60 seconds, then in 10 seconds we would expect that factor to reduce or add 0.5 beats in 10 seconds, which is difficult to seperate from natural noise and measurement error. A device that is able to accurately gauge a subjects BPM within a short time frame would be an excellent tool to use if this experiment were to be repeated in the future. Furthermore, after the completion of one trial, while heart rate does decrease over time, and subjects were given 10 minute breaks to allow for a return to resting heart rate, fatigue and exhaustion from previous trials grows with every increasing trial. This was not accounted for, controlled or even measured in anyway during the experiment.

While heartrate was fairly constant over each trial, subjects reported becoming more tired throughout the experiment with each increasing trial. In the future, the ability to quantify the fatigue of a subject after every trial may be a useful piece of data to collect. The 500m course setup for the subjects to run was the circle road around King's college at the University of Toronto St. George Campus, while participants all ran the same course, it is possible due to the curvature of the circle that participants may have ran slightly different lengths, while it is unlikely that running an extra +/- 1 meter would have a noticeable impact on heartrate, in the future this experiment should be done on a straight course. Finally, there is the natural variation within the subjects themselves, since each participants increased heartrate after running 500m was essentially the same after each trial, the only variation in the data was the natural variation that existed within the participants. This opens up an entire range of factors that could potentially influence a participants baseline heart rate or their elevated heart rate. For instance, how many hours of sleep a participant had the night of the experiment, how much food and how long ago they had consumed prior to the experiment, how physically active the participant is in their day to day life, etc. Completing a replication trial on a different day to allow for a full nights rest, then was an optimal solution to attempt to control for this, as some of the factors relating to the variability of each subjects heart rate are not kept the same from day to day, for instance, getting 6 hours of sleep before replication 1, and getting 9 hours of sleep before replication 2. Fortunately, the second replication did not reveal a deviation from the first replication. Then there are the factors themselves, stretching is recommended to be done before any physical activity as it gets the blood moving and provides a mental signal to prepare for excercise.

Picture: Experimental units conducting the stretching routine prior to the stretching trial.

Perhaps if the stretching period was longer than it may have had a more noticeable effect on heart rate. Listening to music has been shown to affect heart rate, by leading the heart to "sync up" with the songs BPM and it is fairly popular to listen to music while running. In order to control for natural variation of a song's BPM participants were made to listen to only one specific song, Darude Sandstorm. Darude

Sandstorm has a BPM of 136, which is lower than the participants elevated heart rates which range from (174 BPM to 192 BPM). It is possible then that if a song has a lower BPM than the elevated heart rate that listening to music would in fact lower heart rate. In the data analysis it was discovered that, though insignificant, heart rate does increase on average by 0.45 beats per 10 seconds, which is a confounding result. Perhaps an experiment what had participants subject to different treatment songs with different BPM could be done to further study the interaction between listening to music and the impact on heart rate.

References

(1) Arnold, J. M., Fitchett, D. H., Howlett, J. G., Lonn, E. M., & Tardif, J. C. (2008). Resting heart rate: a modifiable prognostic indicator of cardiovascular risk and outcomes?. The Canadian journal of cardiology, 24 Suppl A(Suppl A), 3A–8A. https://doi.org/10.1016/s0828-282x(08)71019-5

(2) All about heart rate (pulse). (n.d.). https://www.heart.org/en/health-topics/high-blood-pressure/the-facts-about-high-blood-pressure/all-about-heart-rate-pulse.

(3) Understanding Your Target Heart Rate. Johns Hopkins Medicine. (n.d.). https://www.hopkinsmedicine.org/health/wellness-and-prevention/understanding-your-target-heart-rate.

(4) Music Boosts Heart Health. CardioSmart. (n.d.). https://www.cardiosmart.org/news/2015/10/music-boosts-heart-health.

(5) Publishing, H. H. (n.d.). Exercise 101: Don't skip the warm-up or cool-down. https://www.health.harvard.edu/staying-healthy/exercise-101-dont-skip-the-warm-up-or-cool-down.