DAB100 – MSOS final report

Daniël de Goederen
1847775
Best, Netherlands
d.x.d.goederen@student.tue.nl

Sem van Birgelen
1813862
Best, Netherlands
s.v.birgelen@student.tue.nl

Reijer Koudenburg
1794388
Eindhoven, Netherlands
r.j.koudenburg@student.tue.nl

Caleb Hyman
2023911
Eindhoven, Netherlands
c.b.hyman@student.tue.nl

Thijs Rexwinkel
1719653
Eindhoven, Netherlands
t.p.rexwinkel@student.tue.nl

ABSTRACT

This study investigates the relationship between humidity levels and sleep quality, aiming to determine the optimal humidity for a good night's sleep. While existing research suggests an optimal humidity range of 30-50% for sleep, the exact ideal humidity level and its variability among individuals remain unclear. Using MiFit bands and DHT11 sensors, we collected and analysed sleep and humidity data over four weeks.

Our findings indicate a weak correlation between higher humidity levels and lower heart rates during sleep, but this relationship was not statistically significant. Variations in individual responses and the limitations of the sensors used may have influenced the results. Despite these limitations, our research provides insights into how humidity levels might affect sleep, suggesting that personal comfort and other environmental factors play a significant role. Further studies with larger, more diverse participant groups and more accurate sensors are recommended to deepen the understanding of this relationship.

INTRODUCTION

Trying to get a good night's sleep in a stuffy and humid room is something that everyone has struggled with at some points in their lives. Despite this, some people chose to sleep with a humidifier in their room, as there is some evidence to suggest this helps with certain issues caused by dry, indoor air [10]. Others chose to use dehumidifiers as there is evidence to suggest that this helps to reduce respiratory and allergen-related issues caused in humid rooms [11]. Although existing research [9] suggests that the optimal humidity for sleep quality is between 30% and 50%, it does not specify what humidity exactly is the best and also not how much this differs per person. This makes it interesting to investigate the relationship between humidity and quality of sleep in order to gain insights into what humidity exactly is best for a good night's sleep (high, low, or moderate humidity). This raises the following research question: What level of humidity (high, low, or moderate) is associated with the best quality of sleep?

Accordingly, we can create a null hypothesis (H_0) stating that *there is no difference in the quality of sleep relating to a difference in humidity levels*. Consequently, the alternative hypothesis (H_1) states that *the quality of sleep differs based on different humidity levels*.

FAIR PRINCIPLES & ETHICS

In order to optimise the re-use of our data the FAIR principles will be endorsed. To do so, our data will not be publicly published so it will not be findable by anyone outside of the research group unless they have authority from members of the group itself. In that case the data will be shared with them privately. In terms of accessibility, all data will be stored on the TU/e OneDrive. External people can acquire the data by contacting one of the team members after they have permission from their research board. Also, for interoperability, usually programs like google collab are used to share datasets between devices optimally. However, with security in mind, the TU/e One Drive and only the TU/e One Drive only will be used. The data will be well documented in a structured way so that other people can reuse it. Information and labelling of the data will be done so that outsiders can have a complete understanding.

Since the only participants of the research are the researchers themselves. Since we ourselves know that the data will be shared only with a certain group of people and how it will be analysed, there are no ethical dilemmas. To further ensure data safety, we will check with all group members that they are okay with sharing the data.

RESERCH SETUP & SENSOR SELECTION

For our research we decided on gathering data through the MiFit band and the Arduino paired with a humidity sensor and a temperature sensor that served as a backup when the humidity recording would fail, see figure 1. The sensor (DHT11) would be placed somewhere in the bedroom where it could gather the humidity data. The MiFit band would be worn by each group member when going to sleep as it measures the quality of sleep had each night. In total, data was recorded for 4 weeks to allow for any issues that might arise, resulting in 3 weeks of complete data.

Some of the group members had a humidifier in their room allowing for different humidity settings to create variations within the data. While others open or closed their windows to create small variations within the data so we could later analyse the effect different humidity levels had on our sleep quality.

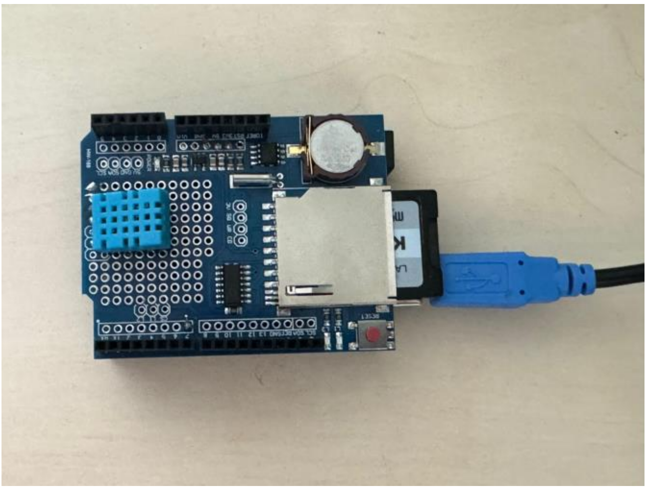

Figure 1, Arduino with data shield and DHT11 sensor

PROCESS

Stakeholder

The main stakeholder for our research is the general public. High sleep quality is something that is beneficial for everyone as it has many health benefits and is essential for optimal well-being (Harvard Health, n.d.). However a subgroup of the general public that would benefit in particular from this research would be people who struggle with their quality of sleep. A lack of quality sleep has an enormous negative impact as it is associated with distress, depression, confusion and generally lower life satisfaction [1]. Next to that it can cause mild to potentially life-threatening consequences from weight gain to sudden heart-attacks (Harvard Health, n.d.). Bettering sleep quality is beneficial for the entire general public and especially for individuals who struggle with getting quality sleep. Thus if certain humidity levels can make a contribution to better sleep quality that information is incredibly valuable to this main stakeholder.

Home humidity control companies, like for example Dyson, Philips and Duux [3,4,7] can also benefit from this research. Integrating knowledge about the optimal humidity in the design of their products would allow them to create more value for their customers and help optimize their health. For example humidifiers or dehumidifiers could add features that recommend users certain humidity settings for optimized sleep.

Acquisition

We collected the data using the sensors mentioned previously. For the MiFit band we had to connect it with our phone and sync the data so that we could transfer it to our computers. We had to create an account for ZeppLife and then download the data from our computers. We could then select the data we wanted to export; in our case we choose for the heartrate. Leaving us with a raw data csv file with timestamps and heartrate.

For the humidity and temperature all the data recorded over the weeks was saved on an SD card, the data was then easily extracted by inserting the SD card into our laptop and uploading the csv files filled with timestamps, humidity and

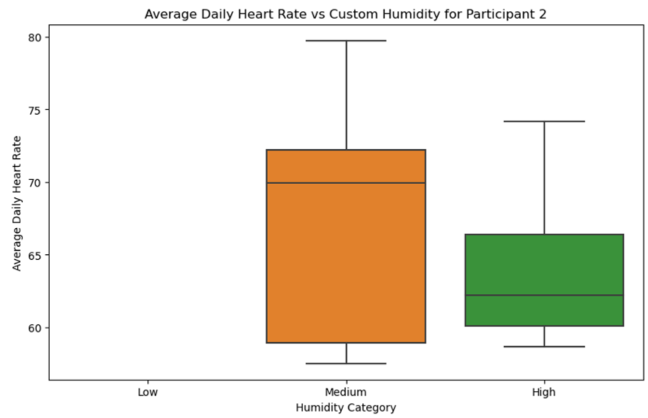

Figure 2, box plot of average daily heartrate vs custom humidity for participant 1

temperature values.

In order to make the data accessible to all the team members, a secure folder was made on the TU/e OneDrive which contained all the RAW data per participant.

Processing

We uploaded all the raw data csv files to Jupyter notebook in order to cleanse and organize our data. We started by creating data tables from the csv files. These datasets were quite messy, and they consisted of many NaN values and rows with headings as we had to reset the YODL kit situationally. First to get rid of the title resets, by filtering out all rows that did not include values but rather text. Then we combined our heartrate and humidity data by gathering the average humidity per minute. This was because heartrate data was only recorded each minute whilst humidity was done every 10 seconds. Doing this allowed us to combine both csv files into one raw dataframe. However, we still had NaN data points for some timestamps for both the YODL and MiFit data, due to technical errors. We code simply remove these with a line of codes that just drops all the rows that were missing values.

In addition, when aggregating the data all into one data set (for each participant) we had periods of time in which there was only data for one source and not the other. For example, times when we wore the MiBand but did not have our YODL activated and vice versa. Therefore, we removed all rows in which we did not have complete data for both sources, to leave only full rows.

Something we decided not to remove is outliers from the data. This is because are datasets were so large that the few outliers, we had were not significant to our final averages.

After the data was finally organized, we decided on the graphs that we would create.

Visualizing

The first and most accurate depiction of our data is the boxplot we created, see Figure 2. For this graph we computed the quartiles and divided the humidity amongst low, medium and high depending on each person's humidity data. Initially we took a different approach by using the same threshold for Low, Medium and High humidity for each, but this proved as humidity data varied greatly between participants resulting in some participants with only one box plot. So instead, we calculated the Low, Medium and High threshold for humidity based on the variation that each participant had. The main reason the box plot was so effective was that it uses median values instead of mean, removing the influence of outliers on main data. Below is one of the box plots, more can be found in Appendix A.

Another graph we incorporated was the violin plot which can be seen in Figure 3, which was mainly just the box plot but to add an extra dimension to our data. The density of the graphs just shows the amount of data points we had for each average heartrate.

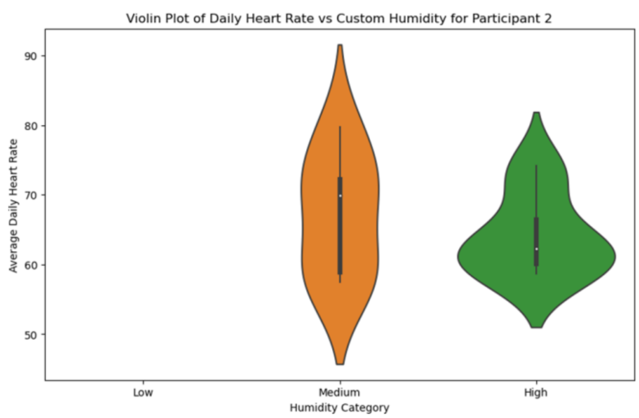

Figure 3, violin plot of daily heartrate vs custom humidity for participant 2

For the scatter plot we took each person's resting heart rate (given by the MiFit band), which would be our threshold, and then calculated the percentage of time for that day that the heartrate of the participant is below the resting heart rate (see Figure 4). Then we put that into a scatter plot comparing it against the average humidity of that day.

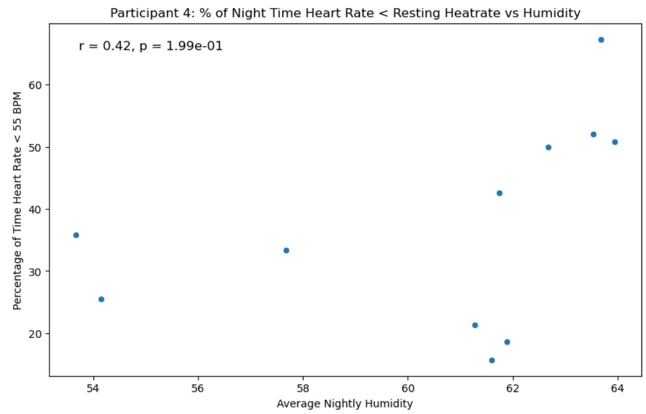

Figure 4, scatter plot of percentage of time night heartrate is below resting heartrate vs humidity per night for participant 4

Additionally, we created a line graph (see Figure 5) with normalized heart rate and normalized humidity data. This was done so we could compare them together in one graph and see the impact of a spike in humidity on the heartrate data. The formula we used for normalizing the data is as follows:

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}}$$

X = The original value from the dataset.

X_{min} = The minimum value of the feature in the dataset.

X_{max} = The maximum value of the feature in the dataset.

X′ = The normalized value after applying the Min-Max normalization formula.

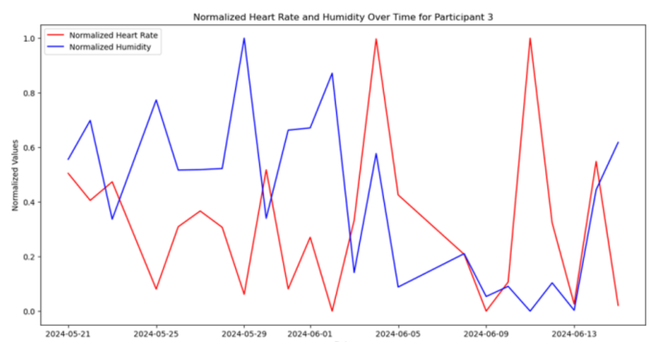

Figure 5, normalized line graph of normalized heartrate and humidity over time for participant 3

Analysis

From the boxplots in appendix A, we could tell that for all but one participant (Participant 1), the median heartrate was on average higher when the humidity was lower, and the heartrate decreased as humidity increased. The outliers can still be observed as they are the furthest points on the boxplot, but these are not as interesting to us for the research.

The violin plots as seen in appendix B, shows that the most amount of data points lie around the median and only a very small amount is at the top which were the outliers talked about previously. This suggest that the box plots are an accurate depiction of our data.

From our scatterplots shown in appendix C, a similar pattern was derived as we observed that as humidity increases along the x-axis there is a somewhat linear correspondence with the heartrate percentage on the y-axis also slightly increasing. Since the heartrate percentage was the value for the amount of time our heartrate was below our resting heartrate it showcases a slight trend between higher humidity leads to lower heartrate.

As can be seen in appendix D, we also added regression lines to the scatter plots to show the trend of our data points. However, these are once again too inconsistent to draw a certain conclusion from. Participant 1 for example shows a negative trend, while participant 4 once again shows a strong positive correlation. This is made clearer when looking at the graph with all participants data.

From our normalized line graph in appendix E, it is a bit more difficult to draw a pattern. However, if we look at figure 4 certain spikes for example on 2024-05-29, show that when the average normalized value of humidity drastically increases, the heartrate once again does as well. Although this matches our expectations it is not clear enough from this graph that our hypothesis can be proven this is because just before 2024-06-05 for example we see both the humidity and heartrate spike contradicting our previous finding. The data is this graph is too unpredictable to make a clear statement.

Overall, most of our results show a small positive correlation between the humidity in the room and the heartrate of the participant. A final visualization (figure 6) we made to view our data is a scatter plot of all the data points where we compare the percentage of time of a day that the participants heartrate was lower than their resting heart rate to the humidity. This trendline shows that there is a small negative correlation also supported by the correlation coefficient of -0.15 suggests a very weak relationship. And the p-value of

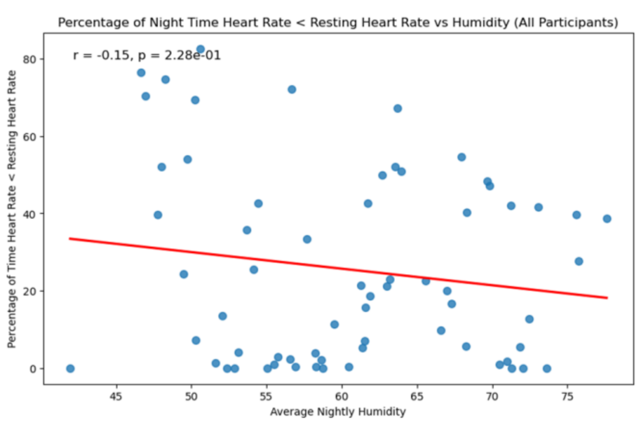

Figure 6, scatter regression plot of percentage of time night heartrate is below resting heartrate vs humidity of all participants

0.228 indicates that this weak relationship is not statistically significant. So, from our results we were unfortunately unable to find a pattern or conclusion. Meaning that there is not enough correlation to support our hypothesis namely that humidity has an impact on heartrate.

Documentation

The personal data collected and stored, along with other documents related to this research project, will be kept on the shared OneDrive of group 30, accessible to all team members. The raw and processed research data will be retained for 21 days. After this period, the data will either be deleted or anonymized so that it can no longer be linked to any individual. If necessary (e.g., for a scientific integrity check), the research data may be shared with individuals outside the research group, but only in an anonymous form.

DISCUSSION

Reliability & validity

Our three-week analysis about the relationship between humidity and the quality of sleep failed to find definitive patterns or conclusions. However, when you ignore the weak p-value, the results show a very small negative correlation between percentage of time of a day that the participants heartrate was lower than their resting heart rate to the humidity.

It is important to note that this research has its limitations. First of all, it should be taken into account that this research was done with a relatively low number of participants with a low diversity. Secondly, the analysis is based on collected data from the MiBand and the DHT11 sensor that both have their inaccuracies. For the MiBand a better alternative would for example be a research-grade sensor like the Bittium Faros [2]. The Bittium would be more accurate and on top of that would solve the loosening problem faced with the MiBand. The Bittium Faros uses ECG rather than optical heart rate monitoring, which measures the electrical signals of the heart and has superior accuracy. During measurements participants would roll in their sleep causing the MiBand to loosen impacting accuracy negatively and sometimes resulting in having to delete the entire data from that day. The DHT 11 also has its flaws in accuracy as it measures humidity with an accuracy of ±5% RH [12]. A better option for the DHT11 sensor is HDC1080 [5], as it is claimed to be a more accurate humidity detector (±2%). The downside to both these alternatives is that they are more expensive.

Another important thing to be aware of is that we express sleep quality by calculating the amount of deep sleep (time that the heartrate of the participant is below the resting heart). This however does not capture sleep quality in its entirety as that depends on many other things as well. For example, polysomnography, the gold standard of sleep studies, takes records of brain waves, oxygen levels in blood, breathing and eye and leg movements into account as well [8].

Additionally, we did not take 'special' events into account that might have influenced our quality of sleep (changing sleeping environment, alcohol consumption, deadline stress etc.). Also, we cannot ensure that the changes in the quality of sleep are a direct causation of the changes in humidity. When an AC was being used to dehumidify, the temperature was also cooled down. Using a dehumidifier would be a better option since it has no effect on temperature. Also, humidity itself is inversely proportional to temperature, so the real reason for changes in sleep quality could also be caused by a change in temperature or something else.

While this research gave us insights in the relationship between humidity and sleep, future work could seek to include additional controls. Also, a bigger group of participants with a diverse background using more accurate sensors could improve the overall accuracy of the research and provide a better, deeper understanding of the relationship between humidity and sleep.

Comparison with existing literature

Existing research on the correlation between humidity and sleep quality states that a humidity level between 30 and 50 percent is optimal for sleep quality [9]. Humidity below this bound can cause dry skin, itchy eyes, and respiratory problems which impact sleep quality negatively. Excessive humidity on the other hand can lead to “discomfort, and the growth of allergens, difficulty breathing and disrupting sleep patterns” [9].

There is also a study that goes more in depth in the mechanisms behind the sleep quality [6]. It states that there is still a gap of scientific knowledge in the mechanisms for peripheral humidity detection and that for people the perceived humidity level is highly subjective. The research also states that one of the reasons there is a correlation between humidity and sleep quality is that it has an impact on the rate of heat transfer because it influences evaporation which in turn disturbs temperature dynamics within the skin and body.

If we compare these insights to the results of our own research, there are a few things that stand out. First of all, according to the existing research, there should be a correlation. Results that would be expected according to the existing research is a decrease in sleep quality outside the 30% to 50% humidity bounds. The very small correlation of our own research somewhat aligns with this. Although our own research cannot say a lot about the lower than 30% bound since our measurements did not reach humidity below that level, a lot of data was gathered for humidity over 50%. Especially in the scatter plots you can see a lot of the data points above the 50 percent humidity mark. The percent of nighttime heart rate below resting heart rate decreases above this mark although we do not have enough measurements below the 50% humidity to determine whether here the sleep quality would remain constant. Secondly if results per person are compared there is a large level of variance. This might be because of the fact that perceived humidity is very subjective (Manzar et al., 2012) and for some participants a certain threshold for humidity levels beneficial for sleep might have been exceeded while for others this was not the case.

CONCLUSION

In conclusion, our research did not find sufficient evidence to support our hypothesis. However, we gained valuable insights into the relationship between humidity and heart rate during sleep.

When analysing the correlation between the percentage of time our heart rates were below resting levels and the average humidity per night, we observed that while some individual members showed correlation, there was no consistent correlation across all participants. Consequently, we reject the alternative hypothesis and uphold the null hypothesis (that there is no relationship between humidity and the quality of sleep). This is because our research does not provide enough evidence to suggest that a correlation or relationship exists.

Despite this, our research revealed intriguing patterns. Using boxplots, we observed that higher humidity generally corresponded with lower heart rates for all participants except one. This anomaly likely resulted from a lack of humidity variation for that participant. For the others, the data consistently showed a trend contrary to existing research, suggesting that other factors unrelated to humidity might be at play.

In summary, our study uncovered interesting trends, though none with sufficient evidence for definitive conclusions. Further research is needed to explore these findings in greater detail.

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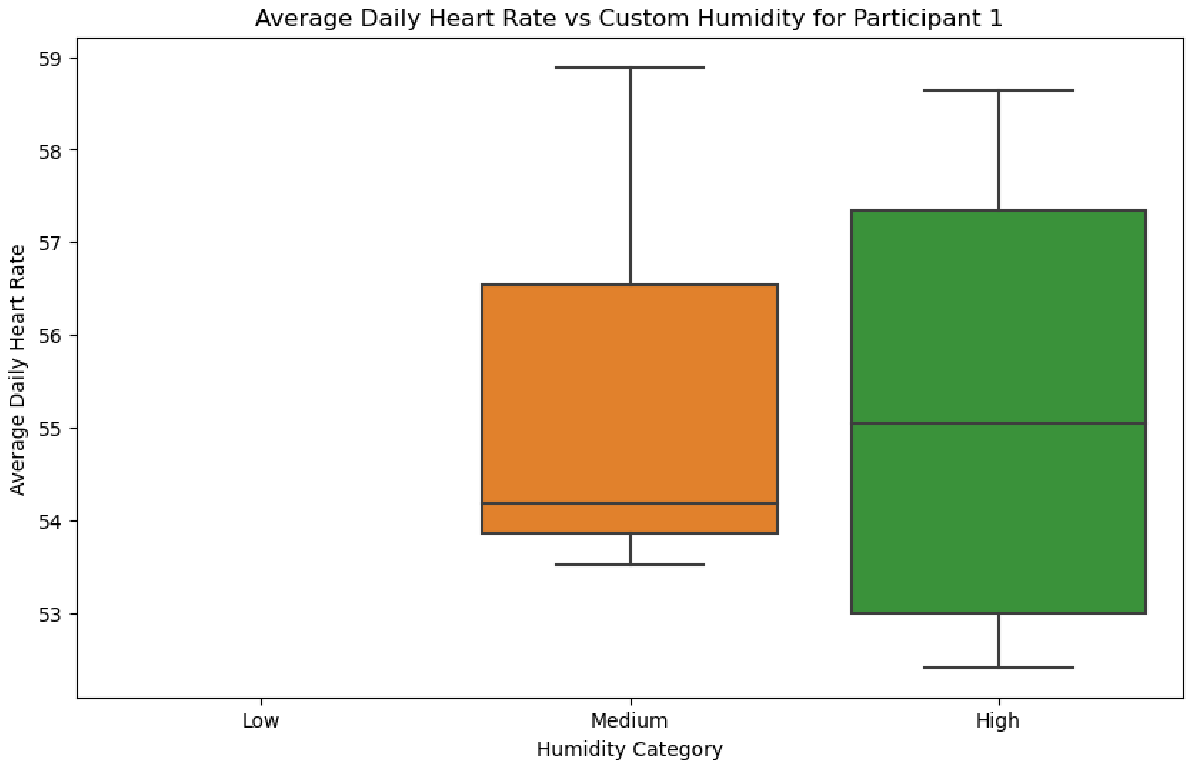
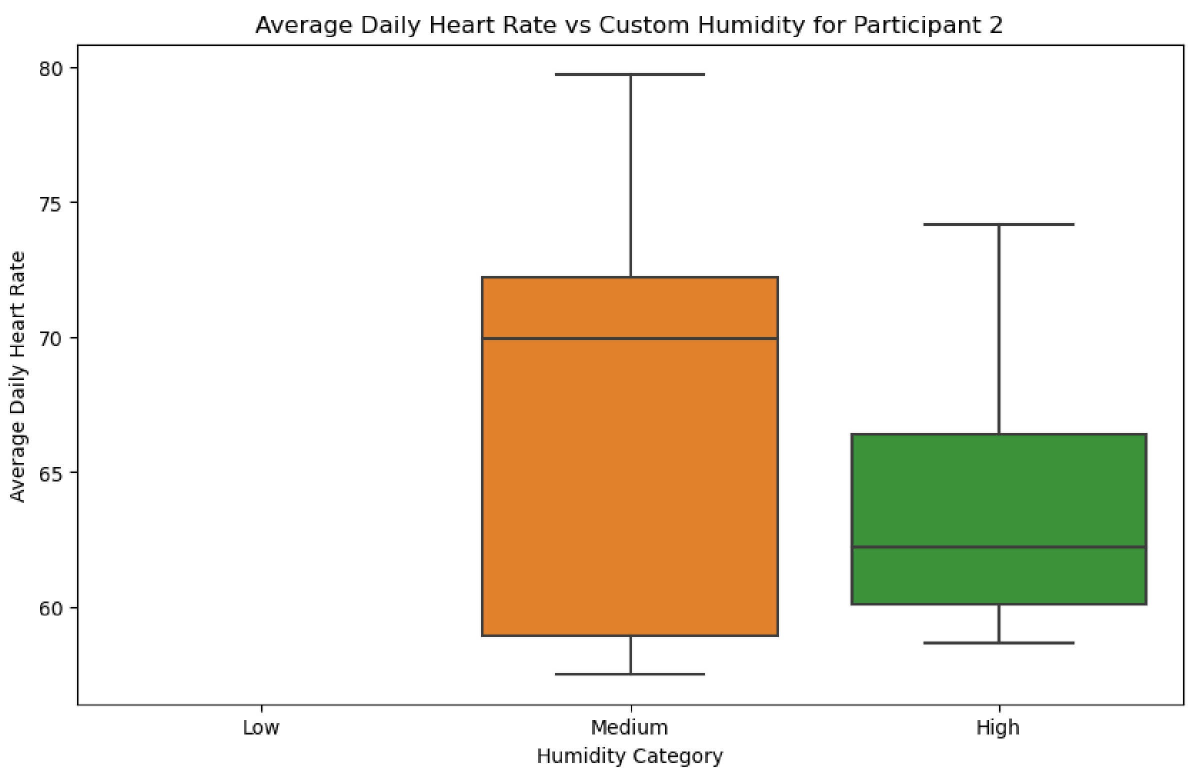
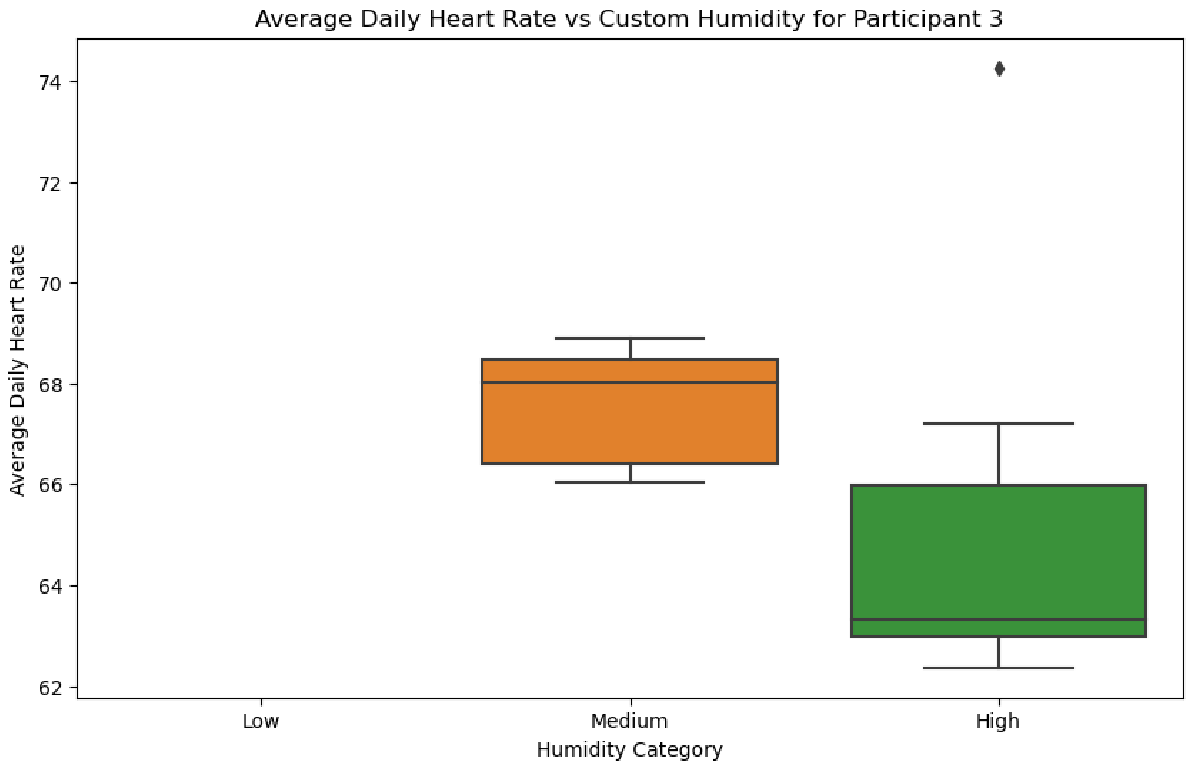
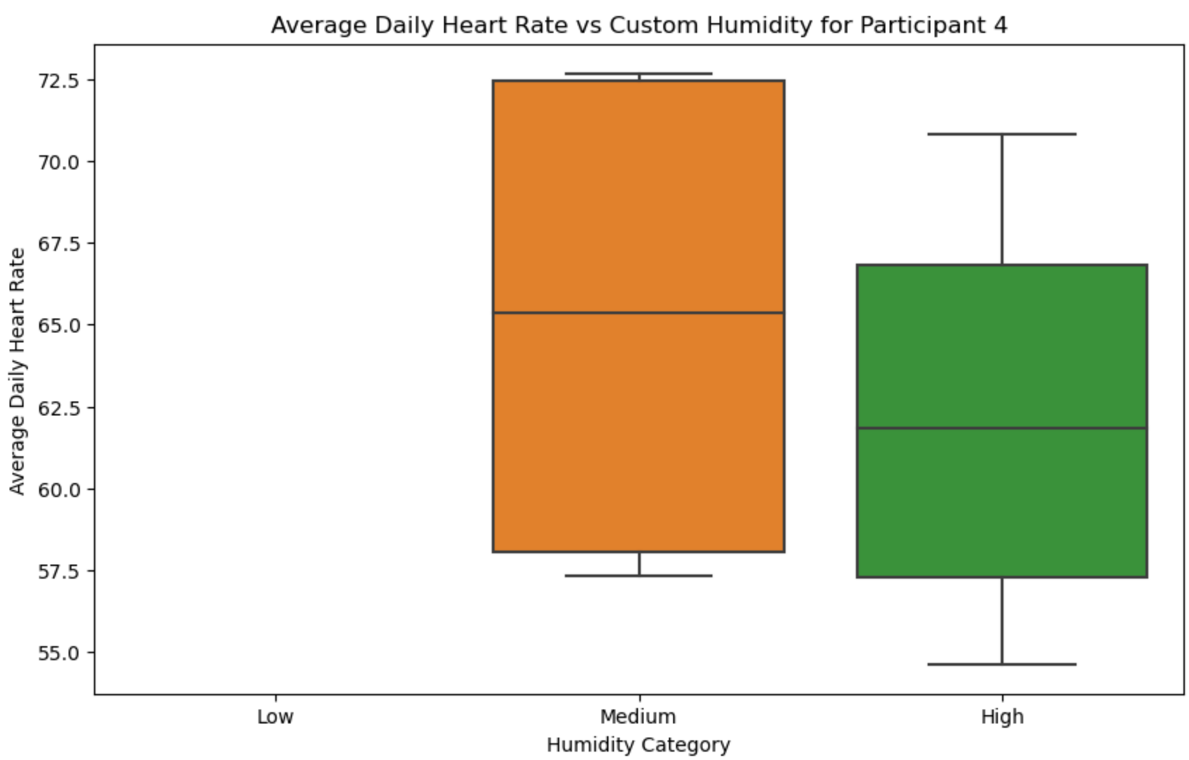
APPENDIX

Appendix A: box plot of average daily heartrate vs custom humidity

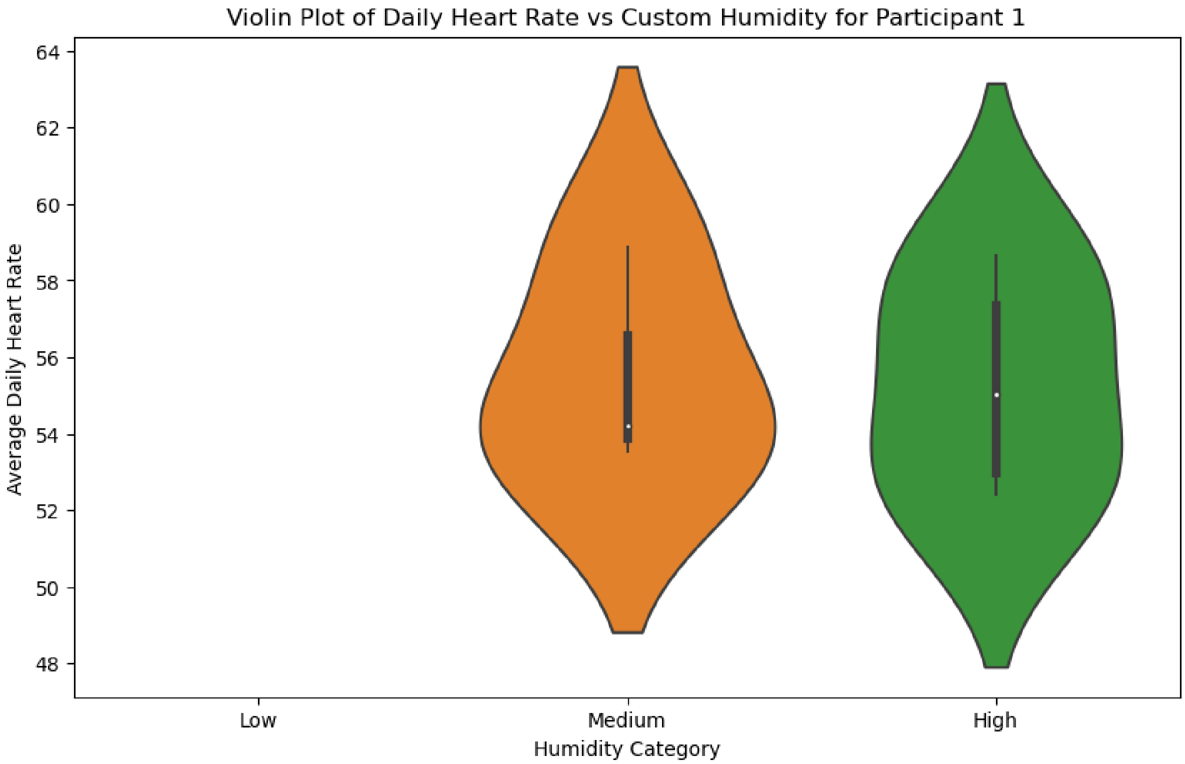


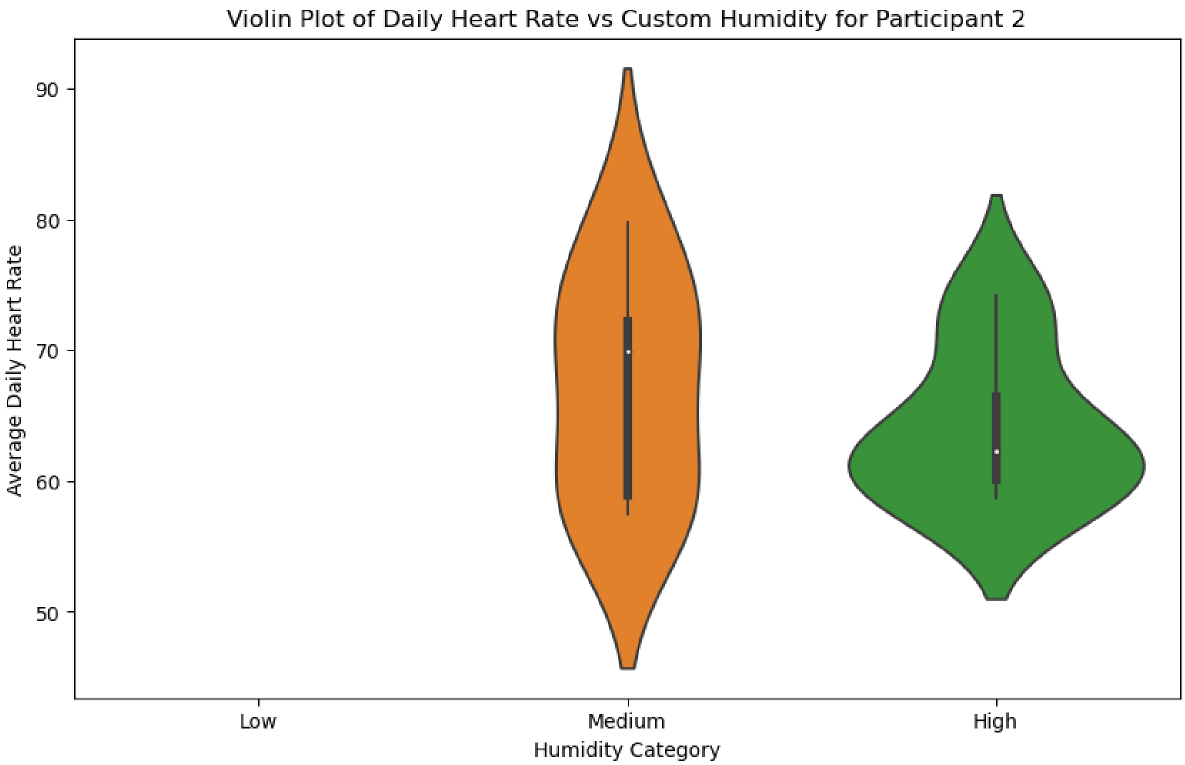


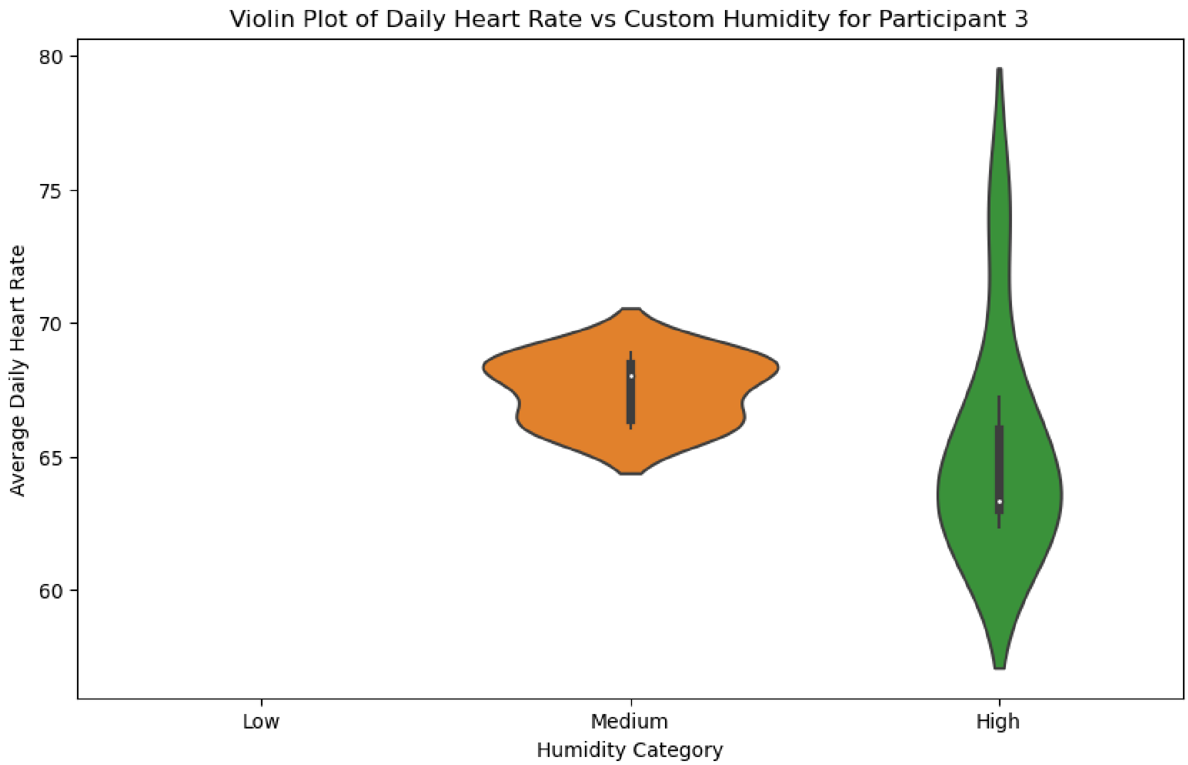

Average Daily Heart Rate vs Custom Humidity for Participant 3
74
72
70
68
66
64
62
Average Daily Heart Rate
Low
Medium
High
Humidity Category

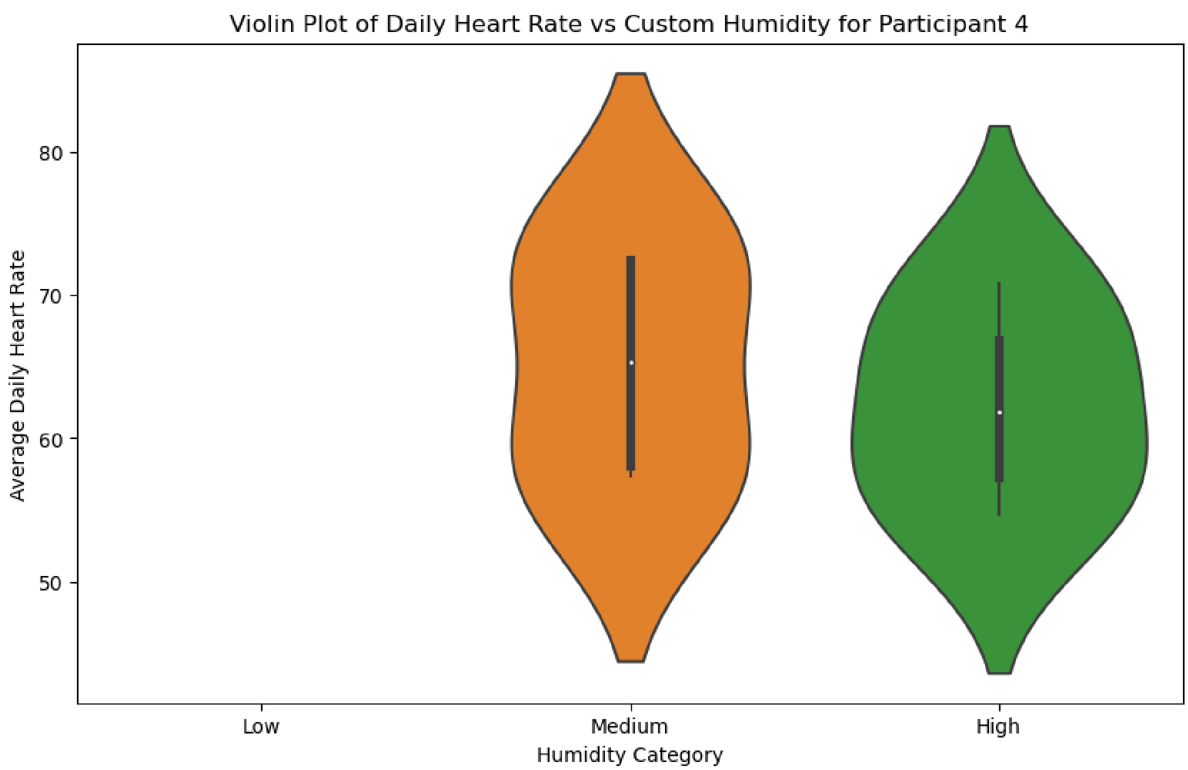

Average Daily Heart Rate vs Custom Humidity for Participant 4
72.5
70.0
67.5
65.0
62.5
60.0
57.5
55.0
Average Daily Heart Rate
Low
Medium
High
Humidity Category

Appendix B: violin plots of daily heartrate vs custom humidity

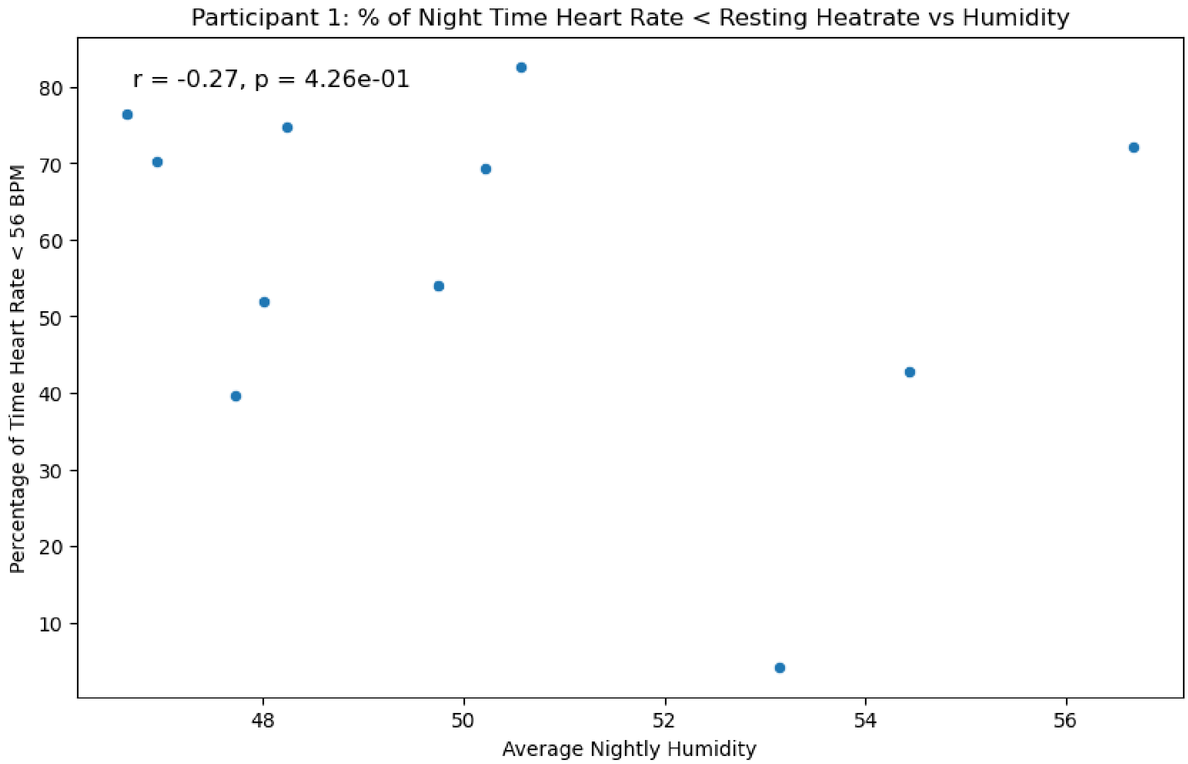


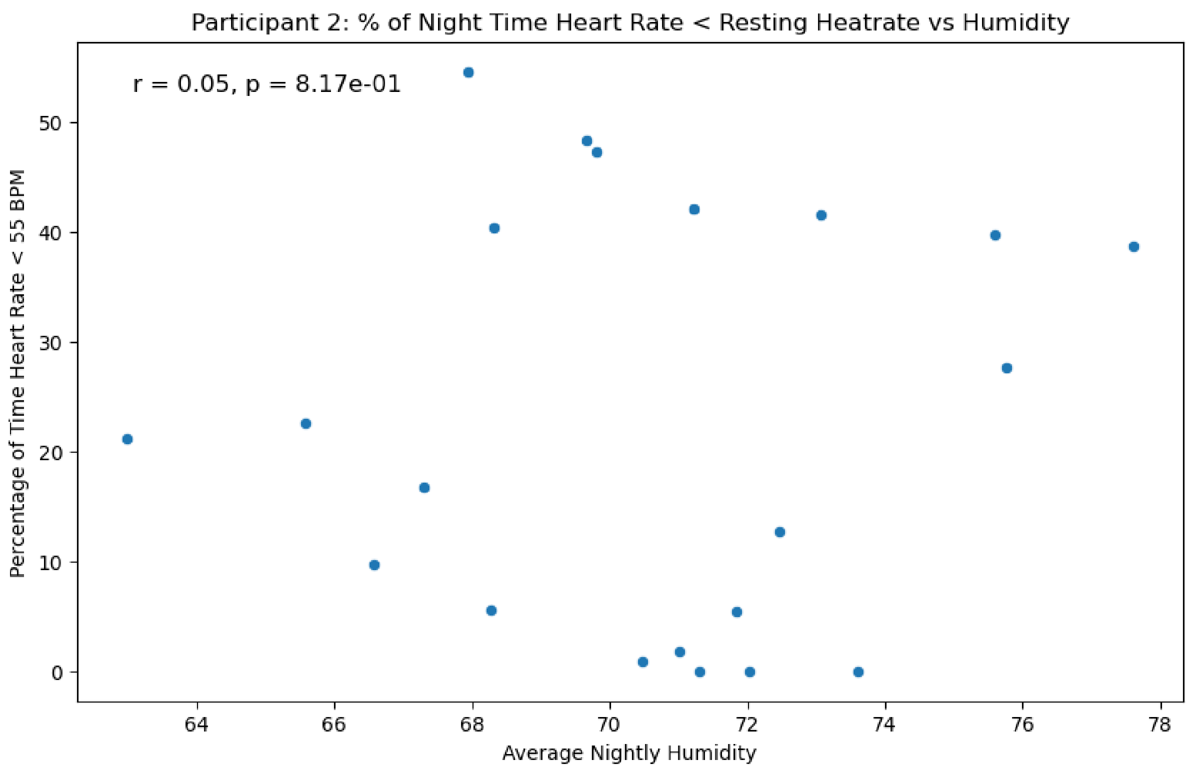


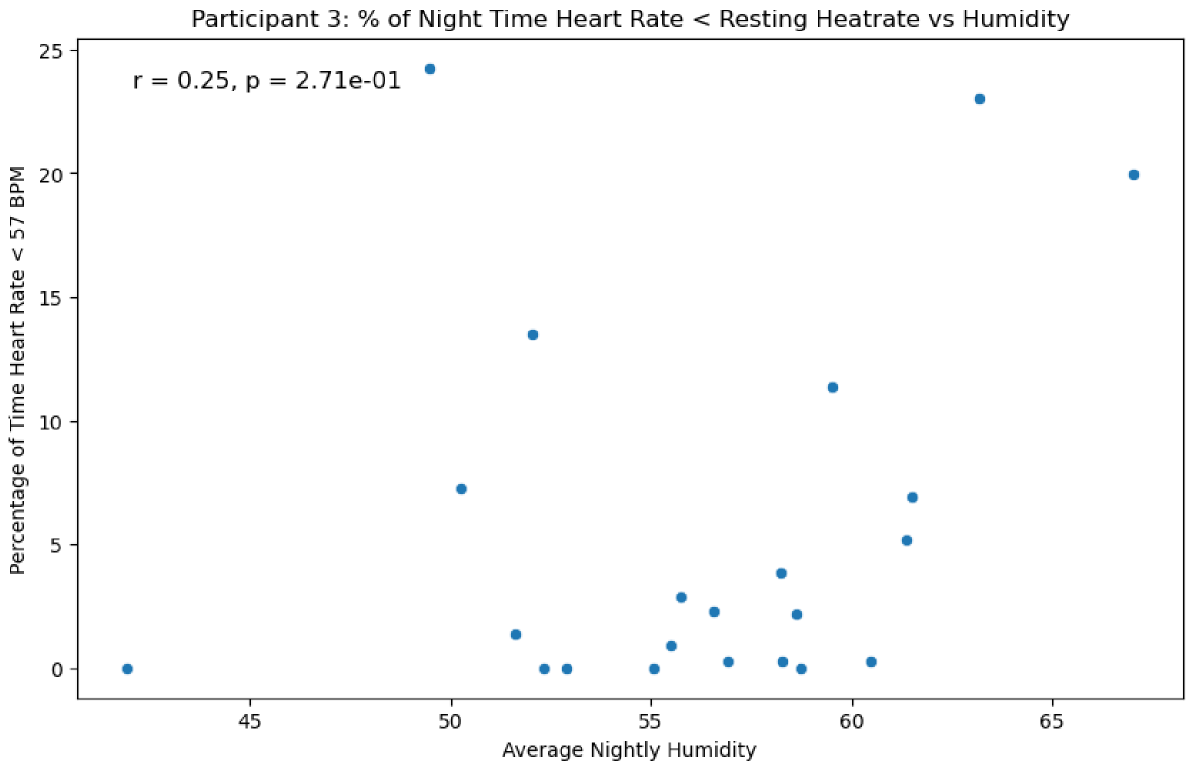

Violin Plot of Daily Heart Rate vs Custom Humidity for Participant 3
Average Daily Heart Rate
80
75
70
65
60
Low
Medium
High
Humidity Category


Violin Plot of Daily Heart Rate vs Custom Humidity for Participant 4
Average Daily Heart Rate
80
70
60
50
Low
Medium
High
Humidity Category

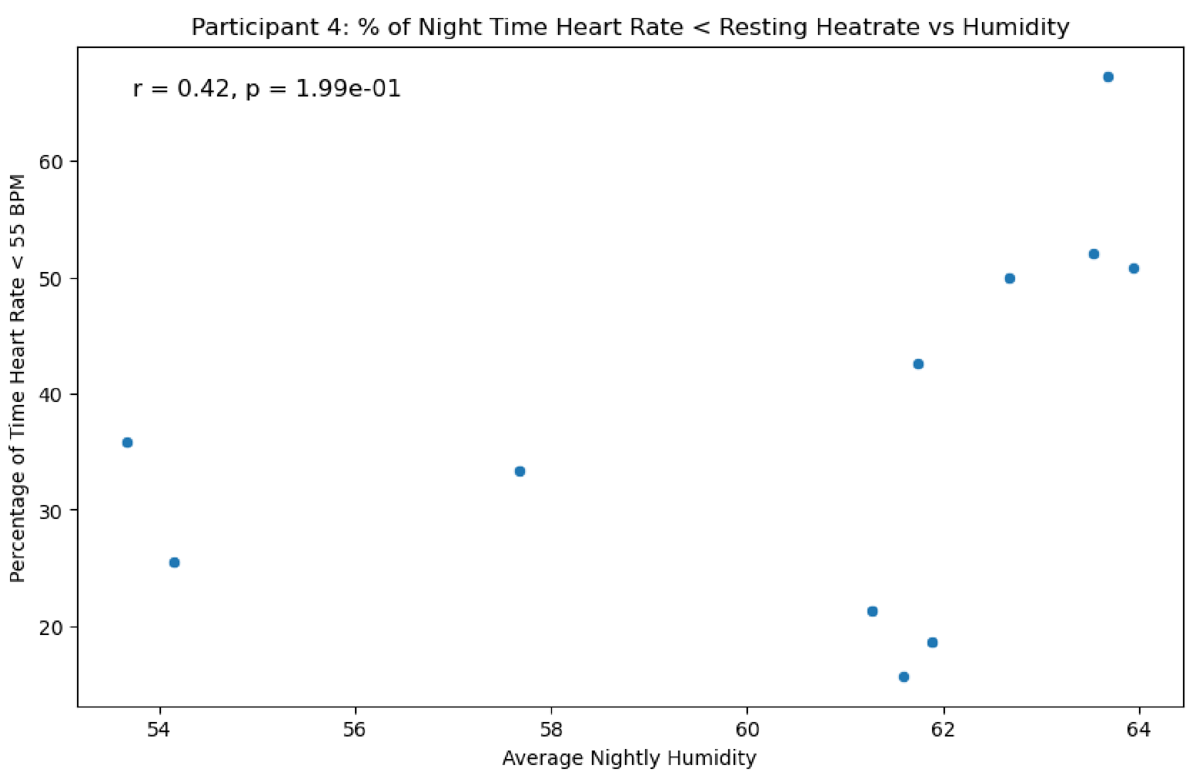
Appendix C: scatter plot of percentage of time night heartrate is below resting heartrate vs humidity per night





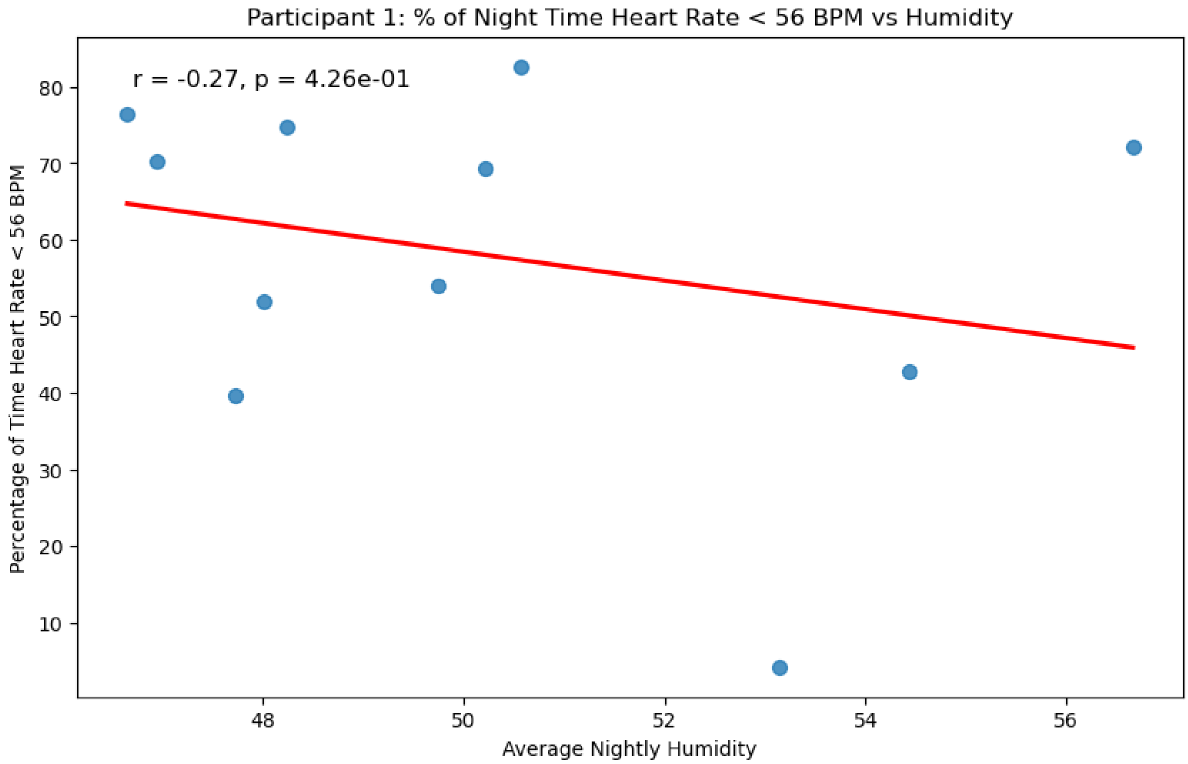


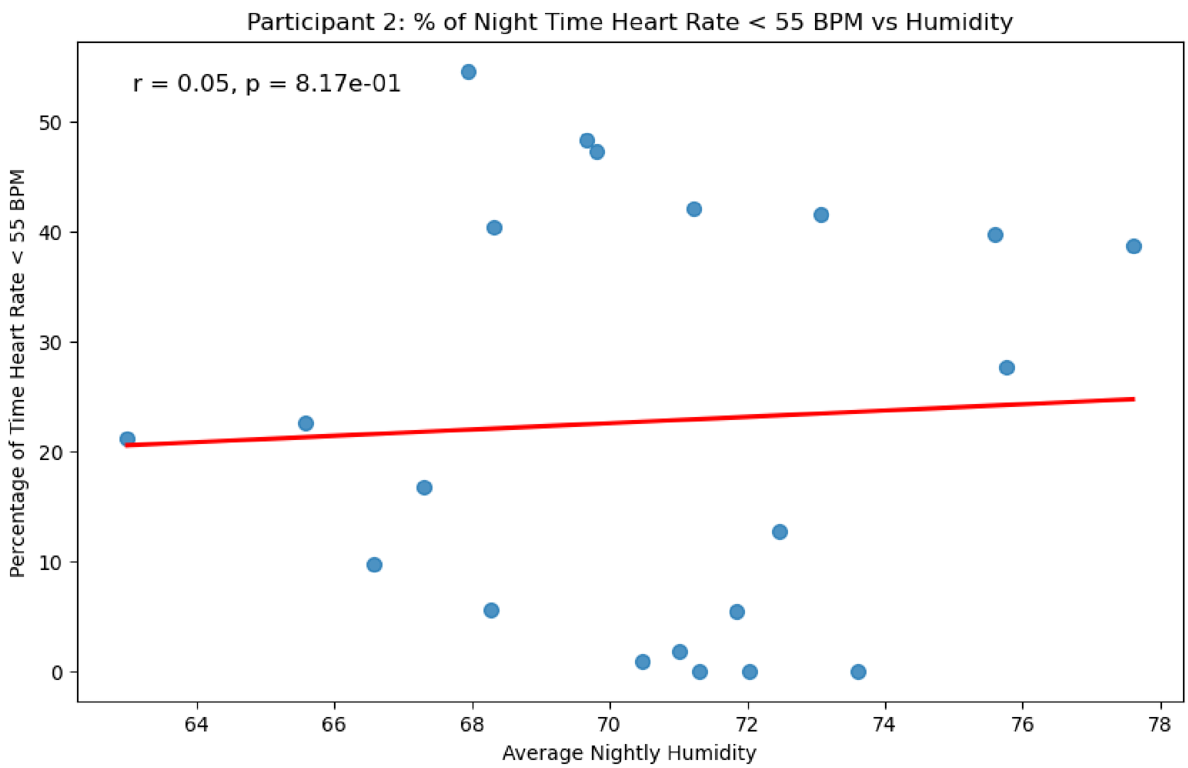
Participant 3: % of Night Time Heart Rate < Resting Heatrate vs Humidity
r = 0.25, p = 2.71e-01
Percentage of Time Heart Rate < 57 BPM
Average Nightly Humidity
0
5
10
15
20
25
45
50
55
60
65

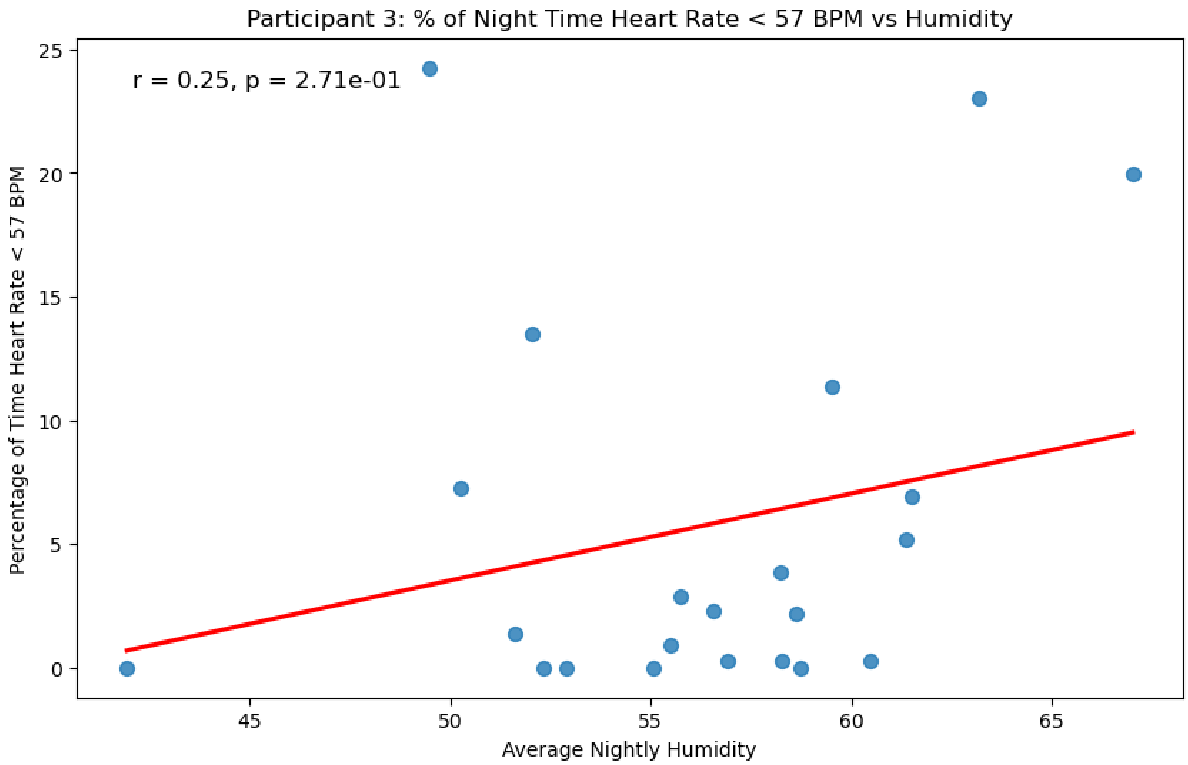


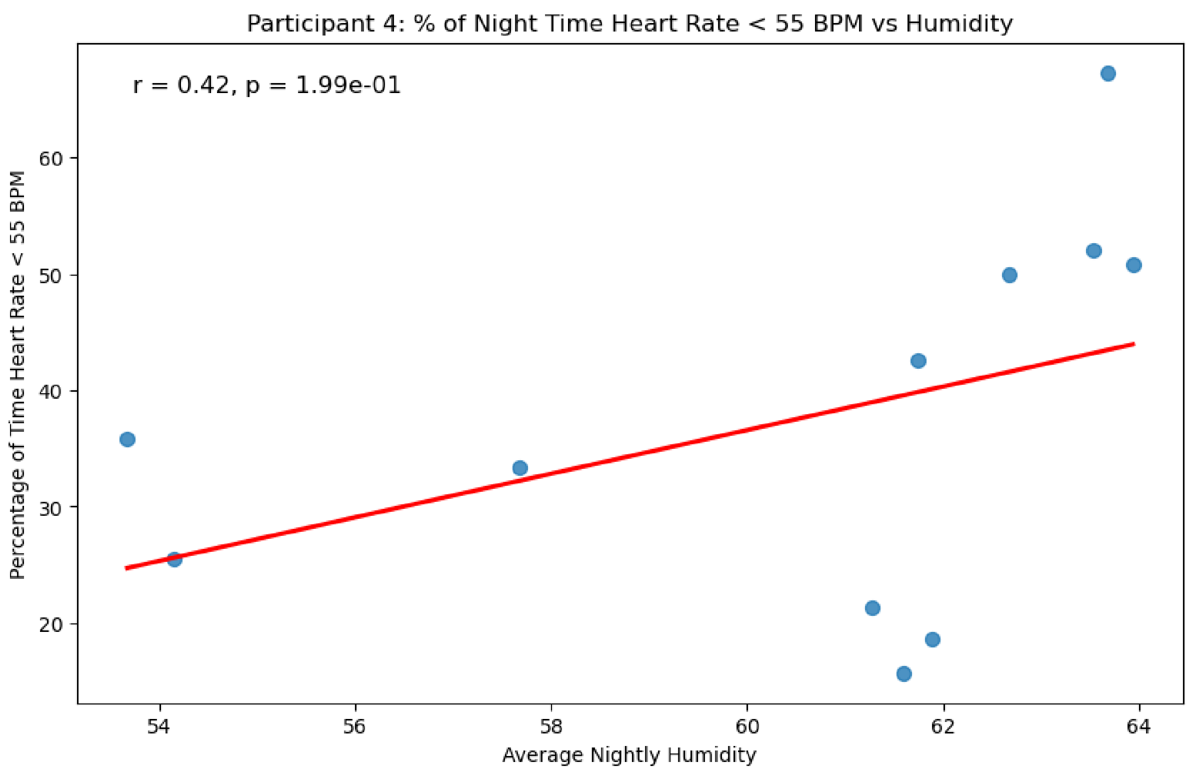
Participant 4: % of Night Time Heart Rate < Resting Heatrate vs Humidity
r = 0.42, p = 1.99e-01
Percentage of Time Heart Rate < 55 BPM
Average Nightly Humidity
20
30
40
50
60
54
56
58
60
62
64

Appendix D: scatter regression plot of percentage of time night heartrate is below resting heartrate vs humidity

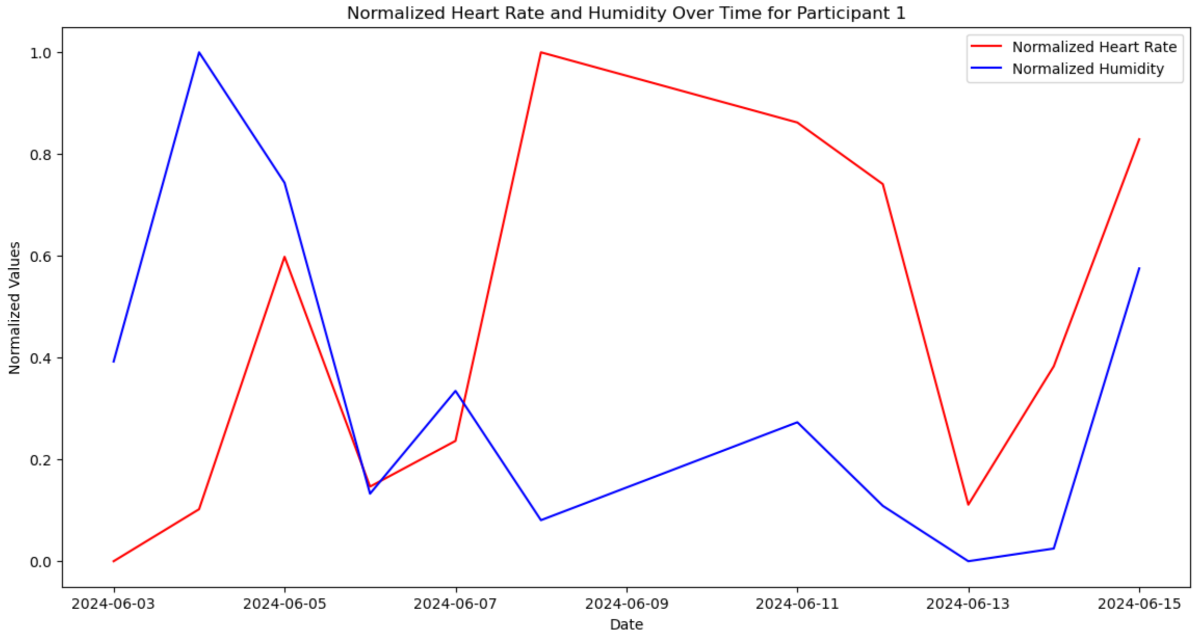


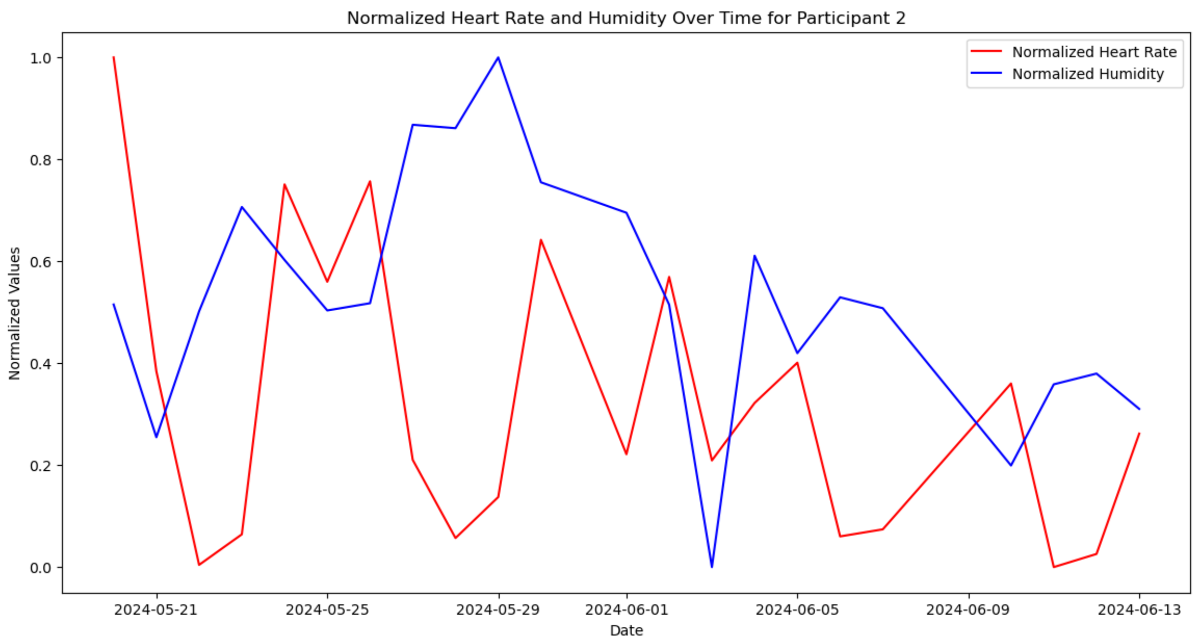


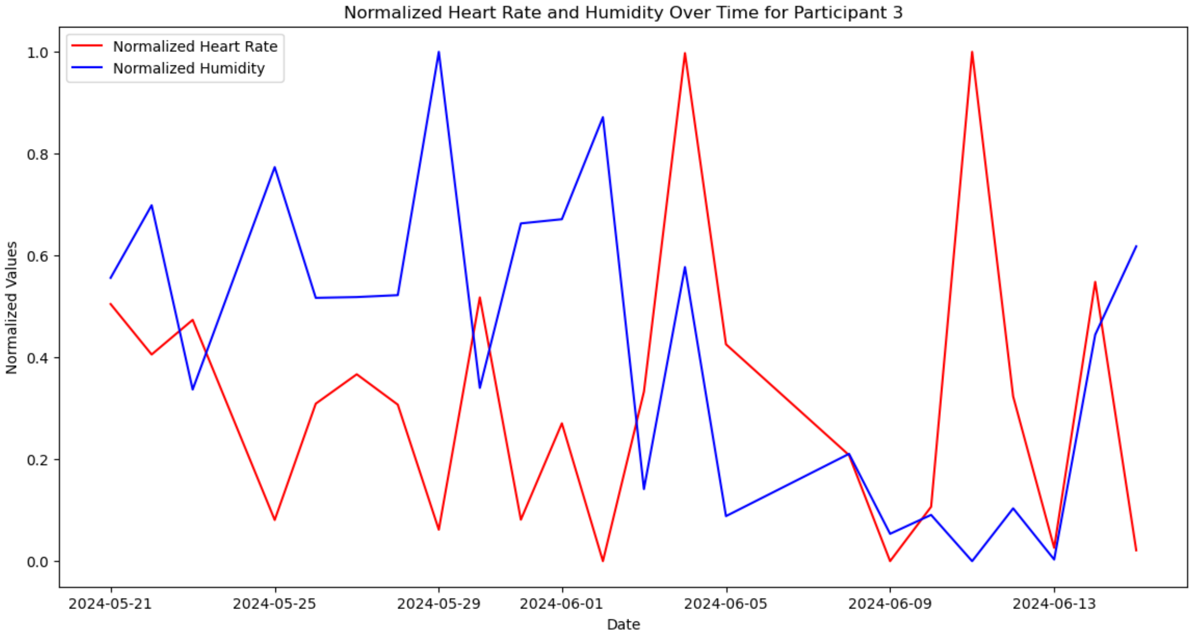

Participant 3: % of Night Time Heart Rate < 57 BPM vs Humidity
r = 0.25, p = 2.71e-01
Percentage of Time Heart Rate < 57 BPM
Average Nightly Humidity
0
5
10
15
20
25
45
50
55
60
65

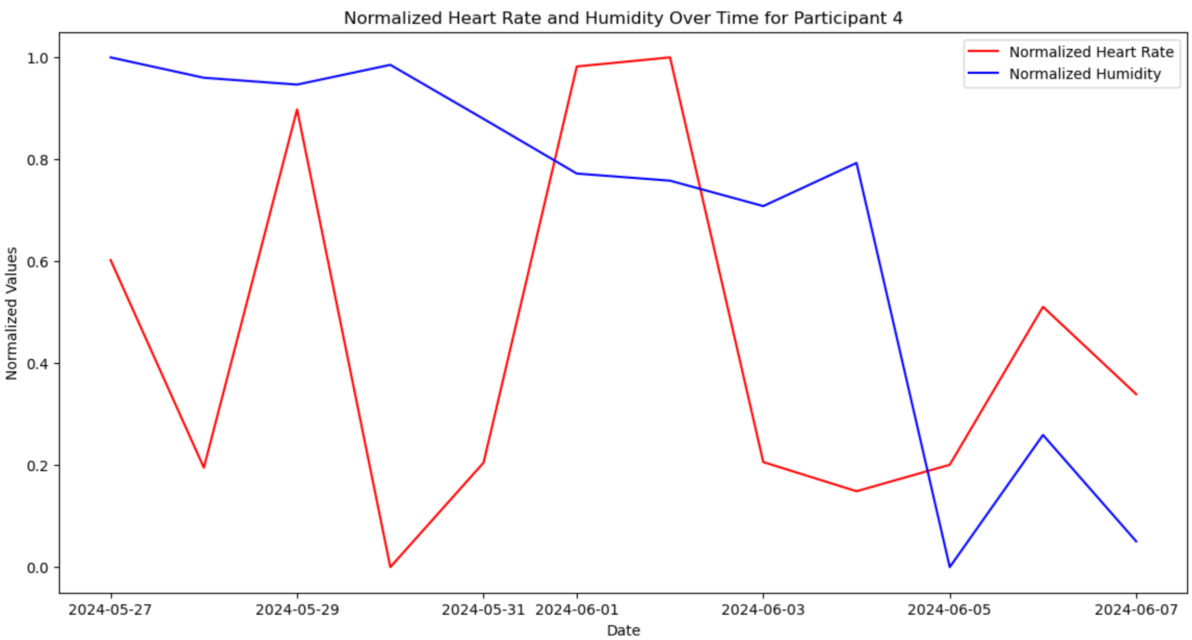

Participant 4: % of Night Time Heart Rate < 55 BPM vs Humidity
r = 0.42, p = 1.99e-01
Percentage of Time Heart Rate < 55 BPM
Average Nightly Humidity
20
30
40
50
60
54
56
58
60
62
64

Appendix E: normalized line graph of normalized heartrate and humidity over time

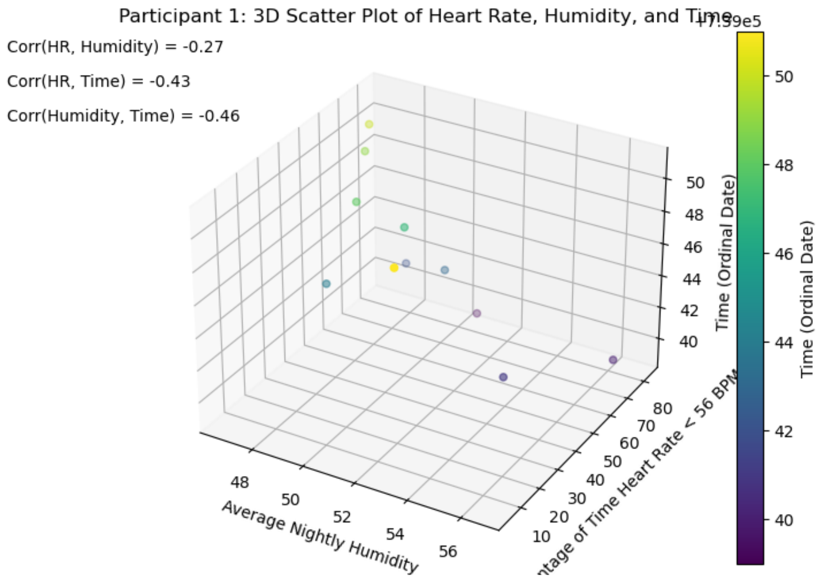


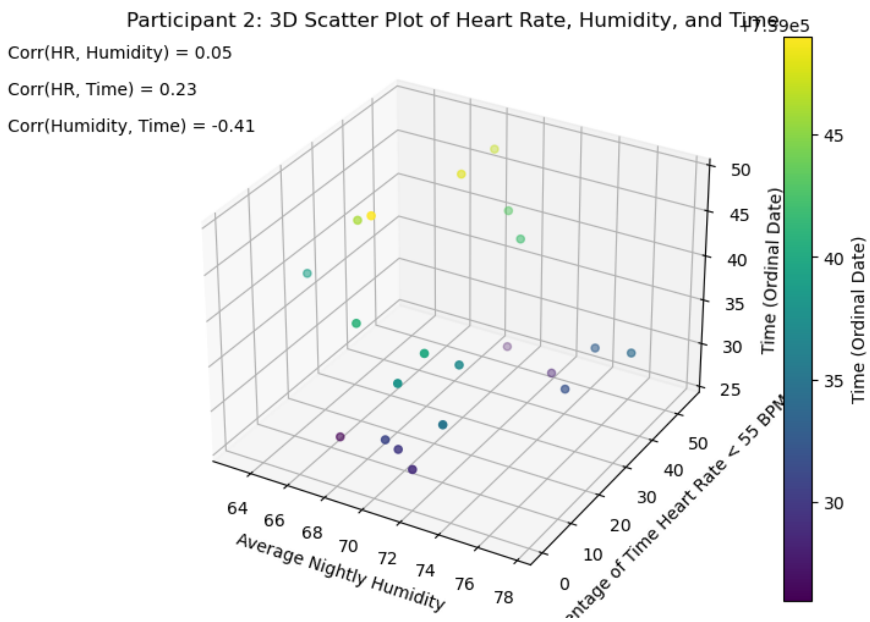


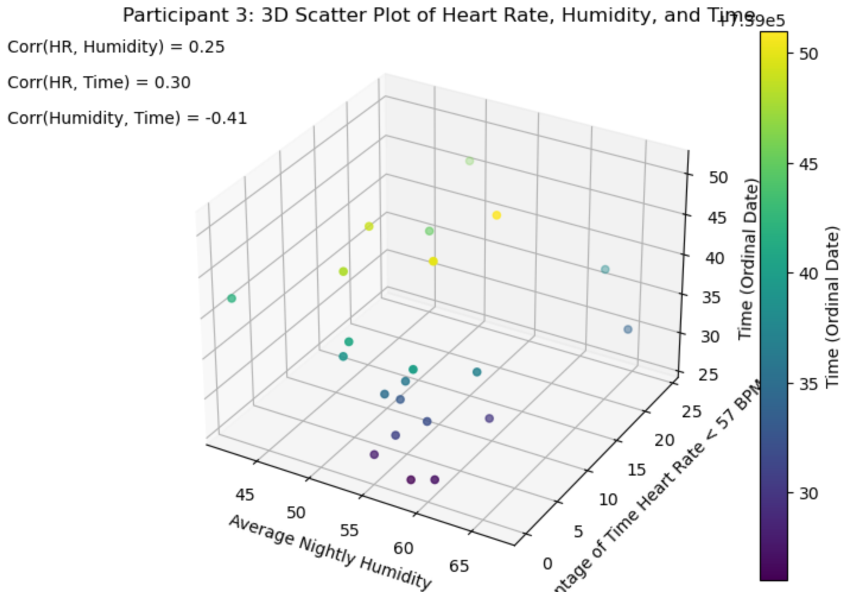

Normalized Heart Rate and Humidity Over Time for Participant 3
Normalized Heart Rate
Normalized Humidity
Normalized Values
1.0
0.8
0.6
0.4
0.2
0.0
2024-05-21
2024-05-25
2024-05-29
2024-06-01
2024-06-05
2024-06-09
2024-06-13
Date

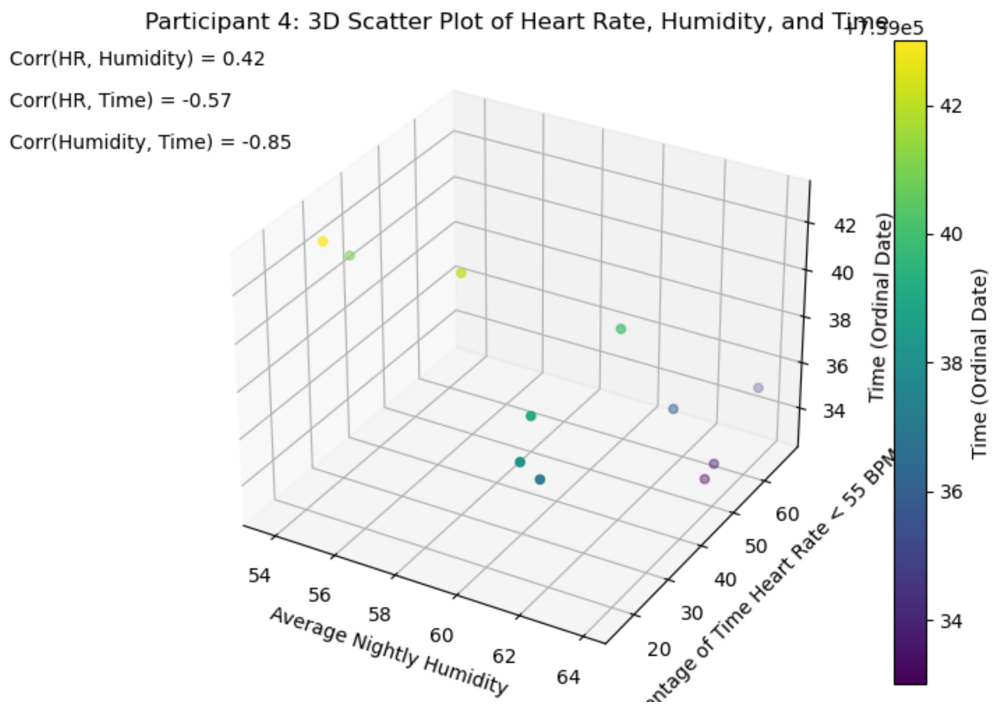

Normalized Heart Rate and Humidity Over Time for Participant 4
Normalized Heart Rate
Normalized Humidity
Normalized Values
1.0
0.8
0.6
0.4
0.2
0.0
2024-05-27
2024-05-29
2024-05-31
2024-06-01
2024-06-03
2024-06-05
2024-06-07
Date

APPENDIX F:


Participant 1: 3D Scatter Plot of Heart Rate, Humidity, and Time
Corr(HR, Humidity) = -0.27
Corr(HR, Time) = -0.43
Corr(Humidity, Time) = -0.46
Average Nightly Humidity
ntage of Time Heart Rate < 56 BPM
Time (Ordinal Date)
+7.39e5
Time (Ordinal Date)


Participant 2: 3D Scatter Plot of Heart Rate, Humidity, and Time
Corr(HR, Humidity) = 0.05
Corr(HR, Time) = 0.23
Corr(Humidity, Time) = -0.41
Average Nightly Humidity
ntage of Time Heart Rate < 55 BPM
Time (Ordinal Date)
+7.39e5
Time (Ordinal Date)


Participant 3: 3D Scatter Plot of Heart Rate, Humidity, and Time
Corr(HR, Humidity) = 0.25
Corr(HR, Time) = 0.30
Corr(Humidity, Time) = -0.41
Average Nightly Humidity
Time (Ordinal Date)
Time (Ordinal Date)
+7.39e5


Participant 4: 3D Scatter Plot of Heart Rate, Humidity, and Time
Corr(HR, Humidity) = 0.42
Corr(HR, Time) = -0.57
Corr(Humidity, Time) = -0.85
Average Nightly Humidity
Time (Ordinal Date)
Time (Ordinal Date)
+7.39e5