Analyzing Deep Sleep utilizing heart rate, heat index and light

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ABSTRACT
Sensors are becoming a more important aspect of our innovating and emerging society. In this report, the minutes of deep sleep and the quality of sleep are investigated. In the context of this study, it is hypothesized that as the wind chill, heart rate and light intensity decrease, there will be a corresponding increase in the duration of deep sleep. To analyze this hypothesis, insightful visualizations were made of different variables, and statistical tests have been conducted. The results show that there is a positive relationship between heat index and heart rate, but no significant evidence was found in our research for a relationship between light levels and heart rate.

CCS CONCEPT
• **Human-centered computing~Visualisation**; *Empirical studies in visualization;*

Author Keywords
Minutes of deep sleep, temperature, humidity, light, heat index, sleep activity, heart rate, linear regression model, data analyzing and visualizing.

INTRODUCTION
Sleep is one of the most important factors affecting human health and well-being, but it still seems hard for a lot of people to consistently get a good night's rest. Many factors influence sleep quality, such as temperature or light exposure. Measuring these factors and recognizing patterns that negatively affect sleep can be important in improving sleep quality

In this report, we present an approach to studying these factors. By measuring humidity, temperature and light during sleep and comparing these with heart rate data, we analyze the effects on deep sleep duration, the most physically restoring stage of sleep. Various sensors connected to an Arduino board were used in combination with the Xiaomi Mi Band to measure the sleep quality and sleep conditions of 5 participants over a time span of three weeks. After this, we processed, cleaned and visualized the data using Python and carefully analyzed the results. During the complete process, we constantly considered the ethical implications surrounding the gathering and doing research with sensitive real-life data.

Chapter 1 | Methods
To investigate our research question, we conducted a comprehensive study in which we measured heart rates using the MiBand, as well as temperature, humidity, and light intensity in the room where participants slept over a period of 21 days. Data was only collected during the hours when participants were sleeping, to ensure that our results accurately reflect the effects of these variables on deep sleep.

To account for potential outliers, each participant has kept a log to document any factors that may have influenced their data. This log includes information such as any unusual events or disruptions to the participant's sleep routine.

Data from the temperature/humidity sensor and the light sensor was collected and stored on an SD card for analysis. We used heart rate data as an indicator of deep sleep and calculated the minutes of deep sleep by analyzing changes in heart rate over the time the participants were sleeping.

Sensors
To measure temperature and humidity, we used a sensor (DHT111) that measures both variables in the area where the participants were sleeping. We included humidity measurements to calculate wind chill, which provides a

more accurate representation of perceived temperature. Wind chill takes into account not only the actual temperature but also the effect of wind speed on heat loss from the body. This is good to take into consideration since the YODL kit may not have been near the participants and it could have been colder due to any wind flow that wasn't near the sensor.

We also used a sensor (BH1750FVI) to measure light intensity in the room. Light exposure during sleep has been shown to affect sleep quality and latency [15], so we included this variable in our study. The sensor we chose can read any small changes in light intensity, which allows us to measure accurately the amount of light the participant was exposed to when he/she was in deep sleep.

To avoid potential data inconsistencies and make sure our results are accurate, we only used the MiBand to collect heart rate data and did not use its sleep score data. We discussed that calculating deep sleep duration using individual participant data would be more trustworthy than using the MiBand's sleep score, with which we experienced a continuation of sleep score when the participant was already awake.

Conceptual Design

To analyse the data collected from each participant, we used linear regression models and careful analysis of visualizations. Data from each sensor and the MiBand were entered into individual linear regression models for each participant. These models can then be examined over specific time periods to identify potential correlations between variables.

We used heart rate data to identify periods of deep sleep, during which blood pressure falls and heart rate slows to about 20% to 30% below resting levels [3]. We then compared this data with temperature and light intensity data from the same period to identify potential correlations.

Our goal was to determine whether factors such as light exposure (e.g., due to poorly closed curtains) or wind chill affect heart rate and, consequently, the minutes of deep sleep. We also examined the combined effects of these variables on sleep. For example, we may find that high levels of light exposure combined with low wind chill have a greater impact on deep sleep duration than either variable alone.

In addition to analysing the data collected from each participant, we also conducted group analyses to identify if there are any trends and patterns across participants. This allowed us to draw more general conclusions about the effects of our variables on deep sleep duration.

Overall, our concept for the study was designed to provide insights into the factors that influence minutes of deep sleep. By carefully controlling for potential confounding factors and using linear regression models to analyse our data, we hoped to contribute to a better understanding of how environmental factors affect sleep.

Chapter 2 | Datasets (Fair Principles) and ethical considerations

FAIR Principles

In our data collection and usage, we adhere to the FAIR principles [15] to ensure that our data is Findable, Accessible, Interoperable, and Reusable. To make our data findable, we provide detailed metadata that describes the characteristics of the data we have collected. Our data is stored on a shared drive, where all participants of our research can access and download it.

To ensure interoperability, we stored our data in a standardized file format (CSV) that can be easily integrated with other datasets. We use data mining techniques to combine and analyse our data, and we generate visualizations to facilitate the interpretation of the results.

In addition, we provide documentation to support the reuse of our data for other research purposes. This documentation includes information about the methods we used to collect and analyse our data, as well as any relevant contextual information.

Ethical Considerations

We also incorporate ethical considerations into our research by obtaining informed consent from all participants (see appendix). This is a requirement for conducting ethical research and helps to ensure that our study is transparent and trustworthy. Furthermore, we store participant data on a secure drive (SURFdrive) to prevent data leaks and protect the privacy of our participants.

Chapter 3 | Process

During this course, several steps were taken, starting with formulating a plan and its comprehensive setup. The first step was formulating a research question which involved finding shared interests of group members and research confirming the possibilities of these shared interests. To conclude this first step we formed a hypothesis, which would later change multiple times. This first hypothesis resulted in a No Go. This was caused by a lack of explanation regarding our analyzing methods and misinterpreting the possibilities within the course. After explaining, which factors were to be compared and used in the linear regression model, a Go was received.

The second phase was collecting data to see if the findings and hypothesis could be substantiated. Collecting data had its complications. The position of the YODL kit, wiring and creating a rhythm for the collecting of data took some time. Finalizing the data collection, a goal was set to collect 3 weeks of data from every group member to make sure that if problems occurred, there would be sufficient data to move forward in the process. During these 3 weeks, weekly checks were made to supervise the collected data and if the setup worked as intended.

Thirdly, we had to clean and transport the data, to acquire any insights regarding the research question. Cleaning the data entailed interpolating, clustering, aggregation and filtering. Interpolating and filtering made sure outliers were removed and possible erroneous measurements were highlighted. Clustering and aggregation showed relations between data points, which was used in grouping data into structured hours and ensured that data was presented orderly.

The next step was processing and visualizing the data. The aforementioned structured data was imported into Jupyter Notebook, where the pandas and numpy libraries helped create data frames, which is a necessity if we wanted to adapt the different cleaning methods. In addition, we used basic Python libraries such as SNS Seaborn, Matplotlib, Statsmodels and Matic to further process and most importantly visualize the data. Visualizing the data was done in two phases. Phase one included using SNS Seaborn to create boxplots, kernel density plots and histograms trying the visualize the cleaned data. In addition, the first phase highlighted salient data and showed group members' data. Keeping the ethical considerations in mind, we personally addressed informed consent forms. Moreover, each group member kept daily track of their bedtime routine and if any specialities could influence the data. See Figure 1. These highlighted differences showed if further data cleaning was needed. The second phase was implementing a linear regression model, which showed the relation between independent and dependent variables. In this case for example the relation between the heart rate and heat index. With this model, we could easily find relations between the different measured factors.

Day	Sleeping situation	Speciality
25/May	togheter not at home	
26/May	alone at home	no data
27/May	alone at home	defect light sensor
28/May	togheter at home	
29/May	togheter not at home	functioning light sensor
30/May	alone at home	
31/May	alone at home	
01/Jun	togheter not at home	
02/Jun	togheter not at home	MiBand did not update data
03/Jun	alone at home	MiBand registered unmeasured heart rate (not worn) and erroneous amount of sleep
04/Jun	togheter not at home	closed curtains from now on
05/Jun	alone at home	Again measured heart rate without wearing and exceptional room temperature (hot)
06/Jun	alone at home	
07/Jun	togheter not at home	
08/Jun	togheter not at home	
09/Jun	togheter not at home	
10/Jun	alone at home	
11/Jun	togheter not at home	
12/Jun	alone at home	
13/Jun	alone at home	
14/Jun	alone at home	
15/Jun	togheter at home	

Figure 1. Documentation of bedtime routine and specialities.

Parallel to collecting, cleaning, transporting and visualizing data, we dived into the course material. Trying to generalize the data operations and theory, making it adaptable to our research question. The literature in the study guide generated extra depth in working with (on-body) sensors and how to measure vitality. This was implemented together with for example knowledge about different kinds of noise (learning about different kinds of outliers).

After expanding the needed Python skills and gathering knowledge about the course material, the data could be analyzed. Because the data was made interoperable [11], it helped us form a communication language, that every team member understood, which made results and visualizations easier to communicate. Analyzing the data was done in two ways. Firstly, we compared the graphs we made in the aforementioned phase 1 and 2. This showed possible relations. Secondly, to confirm our hypothesis by verifying these possible relations, we conducted several statistical tests such as a Pearson correlation test, Anderson-Darling test and finally t-tests. The Pearson correlation test measured the correlation between two variables, the Anderson-Darling test showed if these variables followed a normal distribution and a t-test was used to see if the hypothesis or relations could be confirmed.

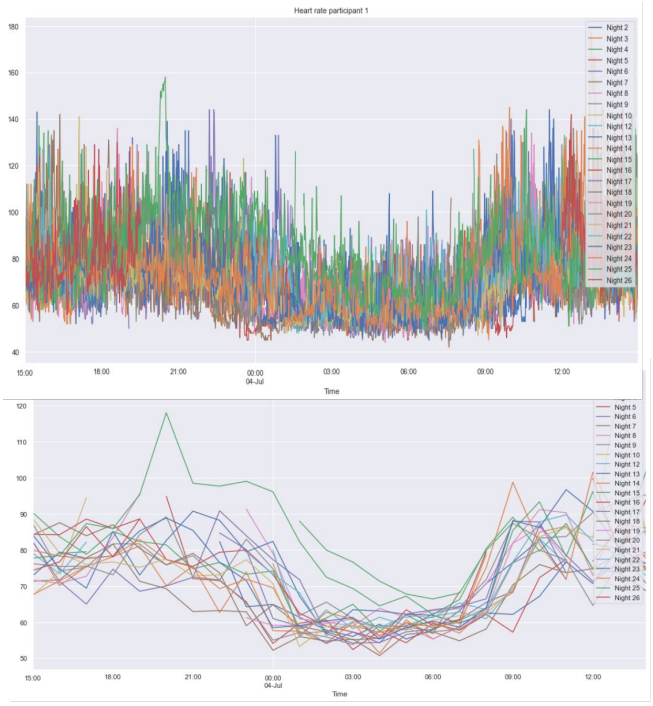
Finally, the end of our process is the documentation of our overall results, making visualizations and deriving a conclusion.

Chapter 4 | Visualizations

The process of visualizing the data yielded intriguing and unexpected findings. However, it was not always straightforward, as we often had to filter out large amounts of data to focus on the relevant information.

Defining sleep

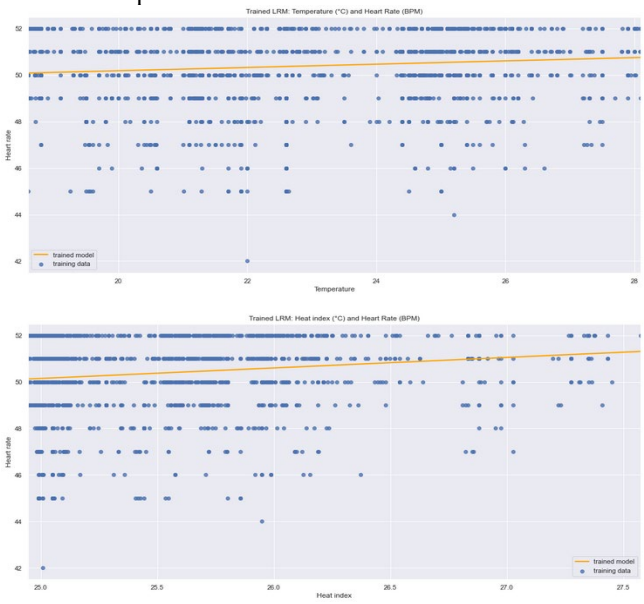
To define the periods of deep sleep, we had to determine when the participant was asleep or awake. To accomplish this, we initially plotted the heart rate over time for each night. This visualization revealed a noticeable decrease in heart rate (measured in beats per minute) during the sleeping hours. To enhance clarity, we calculated the average heart rate over one-hour intervals and incorporated it into the graphs. This approach significantly improved the readability of the graphs and provided further confirmation of the observed drop in heart rate during sleep



Figures 1a & 3b. Line diagrams showing the heart rate changing during the day. 3a is the heart rate data per minute, and 3b is the heart rate data per hour.

Deep sleep filtering

To differentiate deep sleep from regular sleep, we utilized heart rate as a key indicator. Typically, during deep sleep, the heart rate experiences a decline of around 20% to 30%. Drawing on this knowledge, we created a Boolean mask to isolate periods of deep sleep. This involved identifying the lowest recorded heart rate for each participant and excluding data points that exceeded this threshold by 25% or more, indicating non-deep sleep periods. Consequently, we employed this filtered dataset to develop linear regression models, aiming to explore potential connections between temperature or heat index and heart rate.



Figures 2a & 4b. Linear regression models. 4a temperature against heart rate, 4b heat index against heart rate.

Light

In addition to temperature and heat index, we also considered the impact of light in our analysis. Throughout the nights, the light remained relatively stable, with minor fluctuations occurring in the mornings corresponding to sunrise. During most of the night, the light levels remained at 0 lux. The significant spikes observed in the diagram can be attributed to turning a light source on or off.

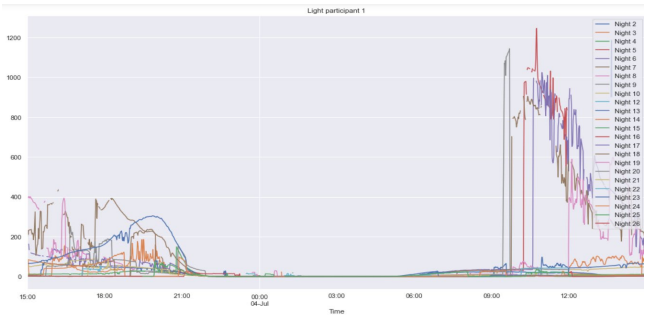


Figure 5. Line diagrams showing the light level changing during the day.

Chapter 5 | Results & Analyses

Carefully analyzing the data as well as visualization, we can conclude that a lower heat index can be related to a lower heart rate, but not that lower light levels can be related to a lower heart rate. Before considering an analysis of statistical tests and visualizations, we will discuss the derivation of the heat index.

Heat index

As said before, we do not only use temperature but also heat index. We calculated the heat index with the use of temperature and humidity. We did this to give a better representation of what the temperature felt to the participants. We used the following formula, rewritten to work with degrees Celsius [12]. $Heat\ index = c_1 + c_2T + c_3R + c_4TR + c_5T^2 + c_6R^2 + c_7T^2R + c_8TR^2 + c_9T^2R^2$

$$c_1 = -8.78469475556$$
$$c_2 = 1.61139411$$
$$c_3 = 2.33854883889$$
$$c_4 = -0.14611605$$
$$c_5 = -0.012308094$$
$$c_6 = -0.0164248277778$$
$$c_7 = 2.21173210 \times 10^{-3}$$
$$c_8 = 7.2546 \times 10^{-4}$$
$$c_9 = -3.582 \times 10^{-6}$$

Statistical tests

When performing a Pearson correlation test, we found a weak positive Pearson correlation coefficient of 0.23 between heat index and heart rate, as well as a very weak positive Pearson correlation coefficient of 0.10 between light level and heart rate. Since the light sensor we used was quite insensitive to small changes in lower light levels, the effect of light on heart rate during sleep could be even larger. Since the correlations are clear but somewhat weak, we can statistically conclude other factors influence heart rate as well [14]. This is expected as sleep and heart rate can also be influenced by factors such as noise or general mental and physical health [8].

To support the claims made above, t-tests to test for the equality of means were conducted. Although the data is not likely of a normal distribution (which follows from Anderson-Darling tests), we can still use a t-test for the equality of means because we are using a large sample size. In the tests, it was hypothesized that colder perceived temperatures have lower average heart rates and that lower levels of light have lower average heart rates. While correlation does not mean causation, the t-test does find statistically significant relations between lower heart rates and low heat index, as well as low light levels.

Visualizations

Looking for further insights visually, we find in Figure 3b that, as was expected, heart rates drop significantly during the night. Here, we can still consider night individually, and find that not all nights follow the same pattern. We see, for

example, two nights (in green) that start with a much higher heart rate. This can be related to the late-night activities of this particular participant. We highlight this to illustrate that it is hard to compare different nights based on only temperature, humidity and light levels, as there are lots of other factors that affect heart rate and sleep. If a participant is not at home during the beginning of the night but still has a YODL kit running, this participant may have a high heart rate with a low temperature, causing discrepancies in the results.

In Figure 4, we find linear regression models of temperature and heat index against heart rate. We find similar results as those found in the statistical tests: a positive relationship between both of these variables and heart rate, with a slightly stronger relationship when using heat index. This could be the case because more variables are used in a single model, resulting in a more accurate prediction.

Finally, figure 5 shows light levels during different nights of one of the participants. We find that light levels during the night are often either zero or close to zero. As a result, few conclusions can be drawn on the effects of light on heart rate or deep sleep. While the Pearson correlation test does show a weak positive relation, the significance of this relationship is unclear and is likely based on the times our participants were still awake.

Chapter 6 | Conclusion

Within this Research project, the goal was to analyze the effects on deep sleep duration, by measuring humidity, temperature and light during sleep and comparing these with heart rate data

The analysis of the minutes of deep sleep, alongside the impact of heat index and light, has provided valuable insights into understanding the effects of heat index on deep sleep time and overall sleep quality. Our research showed correlations between these variables and sleep quality.

Firstly, looking at the weak positive Pearson correlation coefficient of 0.23 between heat index and heart rate, we can conclude that a lower heat index relates to a lower heart rate. Additionally, The Pearson correlation test also gave a very weak positive Pearson correlation coefficient of 0.10 between light level and heart rate.

Additionally, in t-tests that were conducted to test for the equality of means, we found statistically significant relations between lower heart rates and low heat index

The visualizations we generated, including the linear regression model, provided a representation of the correlations between deep sleep and heat index. The model demonstrates that a lower heat index results in a lower heart rate, supporting the idea that environmental conditions play a role in sleep quality. The relation between deep sleep and light levels was almost not visible as light levels were often zero or close to zero. Therefore our research cannot conclude a positive relationship between light levels and heart rate.

Looking back at our hypothesis we can conclude that while our findings support the hypothesis to some extent, indicating that lower heat index is associated with lower heart rates, other factors also influence heart rate during sleep.

However, it is important to acknowledge that the observed correlations are relatively weak. This suggests that there are additional factors beyond the ones examined in this study that contribute to variations in heart rate during sleep.

In conclusion, our research has shown some correlations between heat index, light levels, and heart rate during sleep. While confirming some aspects of our initial hypothesis, our research showed the complexity of sleep, researching sleep and the need for further research. Understanding these relationships can have important implications for eventually improving sleep quality. By considering environmental factors such as temperature and light, individuals can create optimal sleep conditions.

Chapter 7 | Discussion

Limitations

During our project, we also encountered several limitations that impacted our progress and outcomes. It is important to acknowledge these limitations to gain a comprehensive understanding of the challenges we face. In this discussion, we will highlight some of the key limitations that influenced our project's development and effectiveness.

No Go

During the project, we initially had ambitious plans and wanted to incorporate numerous variables and explore various aspects of sleep. We aimed to take on everything independently and may have been overly confident when developing our proposal. However, this approach led to our proposal being rejected, making us realize the need to reassess and adopt a more realistic perspective. As a result, we adjusted our goals and focused on challenging ourselves within feasible limits. By finding a balance between ambition and practicality, we were able to proceed with a more manageable and achievable plan.

Sleeping factors

Sleeping with other people can affect sleep quality. "Sleeping with a romantic partner or spouse shows to have great benefits on sleep health including reduced sleep apnea risk, sleep insomnia severity, and overall improvement in sleep quality," Brandon Fuentes, an undergraduate researcher in the Department of Psychiatry at the University of Arizona [2]. Some of the participants slept next to others and this could have influenced our data.

Another factor we examined was the difference in sleep quality between sleeping in different beds at home and in a student's house. Changes in the sleep environment, such as

different mattresses or sleeping arrangements, can influence sleep comfort and, consequently, sleep quality.

Alcohol use has been associated with disrupted sleep patterns and reduced sleep quality. Consuming alcohol before bedtime can lead to increased wakefulness during the night, fragmented sleep, and a decrease in the amount of deep sleep obtained [4].

The use of phones before sleeping can negatively impact sleep quality. The blue light emitted by electronic devices can suppress the production of melatonin, a hormone essential for sleep regulation. Additionally, engaging in stimulating activities or experiencing emotional responses while using phones before bed can contribute to difficulty falling asleep and reduced sleep quality [6].

Accuracy

During our research, we used the Mi-Band for our heart rate and activity data to determine our deep sleep time and data. However, it is important to acknowledge that the Mi-Band may not have consistently measured complete nights of sleep. Factors such as movement during sleep or the device disconnecting from your wrist which happened a few times could lead to incomplete or inaccurate data, potentially affecting the analysis of sleep patterns and deep sleep minutes. The measurement of heart rate may also have had small deviations in accuracy. Factors such as movement, the band not fitting correctly or issues with the sensor could result in slight inaccuracies in heart rate measurements. These deviations should be considered when analyzing the relationship between heart rate and sleep quality.

The temperature sensor used in our study had a 2-degree Celsius deviation. This deviation could introduce systematic errors when assessing the relationship between temperature and sleep quality. Additionally, the accuracy of humidity readings from the DHT11 sensor is reported as +/- 5%RH [1].

The accuracy of light measurements was also limited due to the positioning of the YODL device. The placement and orientation of the light sensor were not placed at our eyes and therefore may not have captured the precise light exposure experienced by individuals during sleep. During the night, the sensor often recorded a value of 0. As a result, there was no distinction between darkness and complete darkness.

While these factors can potentially influence sleep quality, it is important to note that our study aimed to explore their impact within the limitations of the available data and measurement devices. Future research could also address these limitations by implementing more advanced and accurate measurement methods, considering a longer study and a study with more people.

By acknowledging these factors and their potential impact, we can better understand the complexity of sleep quality and the need for comprehensive research to account for various variables that influence sleep patterns and subjective sleep experiences.

Chapter 8 | Future research

While this research focuses on the relationships between minutes of deep sleep time with various influencing factors, there are several considerations for future research to expand our understanding of our sleep and address the limitations within our research.

Longer-term data collection: we only took data for three weeks, looking over a longer period can provide better insights and stronger correlations.

Advanced Sleep Monitoring Techniques: Incorporating advanced sleep monitoring techniques and devices with higher accuracy and precision would enhance the reliability of sleep data collection. Utilizing better devices with higher accuracy and precision can provide a more comprehensive assessment of deep sleep, and enable a more precise analysis of the relationship between Heat index, light and deep sleep.

Personalized Sleep Interventions: Investigating individual differences in the response to environmental factors and developing personalized sleep interventions based on these differences can optimize sleep quality. Exploring factors such as chronotype, genetic variation, diseases, or stress can help tailor interventions to individual needs.

Larger Sample Sizes and Diverse Populations: Expanding the sample size and including a more diverse population in future studies can enhance the generalizability of findings and help identify potential variations in the effects of our variables on sleep quality.

Extremer conditions: Investigate sleep quality under more extreme temperatures and light conditions to establish a stronger correlation between these factors and sleep quality. Altering environmental conditions intentionally, such as creating temperature gradients and simulating different lighting scenarios, can provide valuable insights into the impact of the conditions on our sleep quality.

Through these future research directions, we can further advance our understanding of the complex relationship between sleep quality and the variables investigated, contributing to the development of more effective strategies for improving sleep health and overall well-being.

Chapter 9 | Acknowledgement

We would like to express our gratitude to those who have assisted us in the completion of this research paper. Firstly, we would like to thank our tutor, Rory, for his guidance and support throughout the research process. His expertise and insights helped us overcome challenges and navigate through the bottlenecks that we encountered.

We are also grateful to the publications support team and staff for providing us with the information and resources

necessary to conduct our research. Their assistance was instrumental for us to complete this paper.

In addition, we would like to extend our thanks to our peers, who provided us with constructive feedback and suggestions that helped us improve the quality of our work. Their contributions were greatly appreciated.

We would like to thank all those who have contributed to the success of this research paper.

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Appendix A

Dairy of a participant.

Day	Sleeping situation	Speciality
25/May	togheter not at home	
26/May	alone at home	no data
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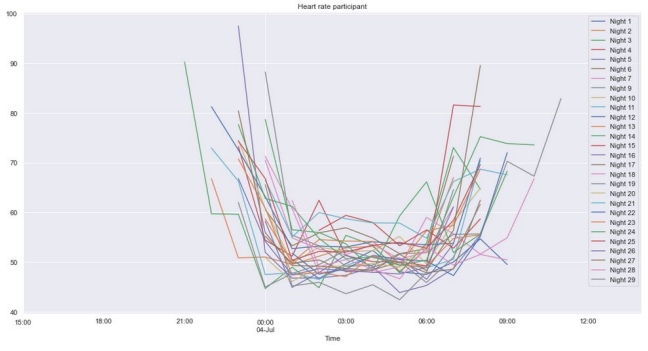
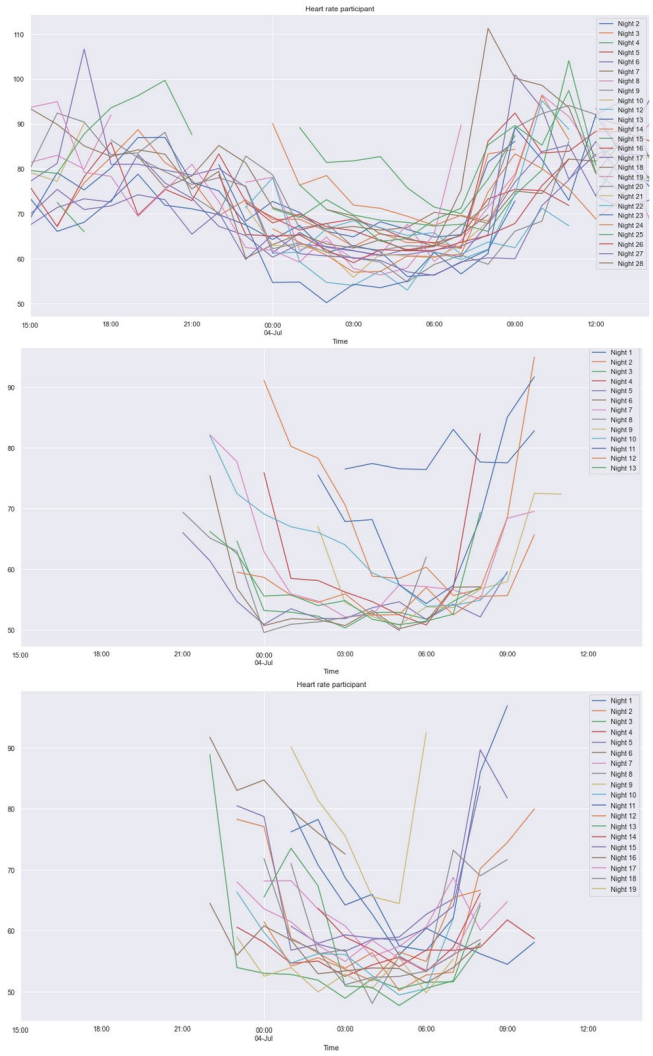
28/May	togheter at home	
29/May	togheter not at home	functioning light sensor
30/May	alone at home	
31/May	alone at home	
01/Jun	togheter not at home	
02/Jun	togheter not at home	MiBand did not update data
03/Jun	alone at home	MiBand registered unmeasured heart rate (not worn) and erroneous amount of sleep
04/Jun	togheter not at home	closed curtains from now on
05/Jun	alone at home	Again measured heart rate without wearing and exceptional room temperature (hot)
06/Jun	alone at home	
07/Jun	togheter not at home	
08/Jun	togheter not at home	
09/Jun	togheter not at home	
10/Jun	alone at home	
11/Jun	togheter not at home	
12/Jun	alone at home	
13/Jun	alone at home	
14/Jun	alone at home	
15/Jun	togheter at home	

Appendix B

Heart rate over time.





Appendix C

CONSENT FORM

Information sheet for research project "Predicting Deep Sleep with Heart rate, Temperature and Light"

1. Introduction

You have been invited to take part in research project "Predicting Deep Sleep with Heart rate, Temperature and Light", because you are an active member in the team that will conduct the research.

2. Purpose of the research

This research project will be managed by group 19 of the course 'Making Sense of Sensors' year 2022/2023.
The purpose of this research project is to find if there is any correlation between heart rate, temperature/humidity, light and the minutes of deep sleep.

3. What will taking part in the research project involve?

You will be taking part in a research project in which we will gather information by: measuring heart rate with a MiBand, and measure light/temperature with sensors near your bed. The measurements will be conducted during the night and will continue for 21 days.

- Wearing a MiBand during sleep for 21 days
- Connecting sensors and keep them operatable for 21 nights
- Keeping a log of special events

For your participation in this research project you will not be compensated.

4. Potential risks and inconveniences

During your participation in this research you may be asked questions which you may find (very) personal in view of the delicate nature of the subject. These questions concern your sleeping patterns. We ask these questions exclusively in the interest of the research project. However, you do not need to answer questions you do not wish to answer.

5. Withdrawing your consent and contact details

Participation in this research project is entirely voluntary. You may end your participation in the research project at any moment, or withdraw your consent to using your data for the research, without specifying any reason. Ending your participation will have no disadvantageous consequences for you.

If you decide to end your participation during the research, the data which you already provided up to the moment of withdrawal of your consent will be used in the research. Do you wish to end the research, or do you have any questions and/or complaints? Then please contact Group 19 from the Making Sense of Sensors course 2022/2023.

6. Legal ground for processing your personal data

The legal basis upon which we process your data is consent.

7. What personal data from you do we gather and process?

Within the framework of the research project we process the following personal data:

Category	Personal data
Contact data	*Name, e-mail, home address, city of residence*
Medical data	*Heart rate, minutes of deep sleep*
Student data	*Student numbers*

Within the framework of the research project your personal data will be shared with yourself, the remaining members of group 19 and the assessors:

- *Storage solution: SURF ResearchDrive, Microsoft (Netherlands)*

8. Confidentiality of data

We will do everything we can to protect your privacy as best as possible. The research results that will be published will not in any way contain confidential information or personal data from or about you through which anyone can recognize you, unless in our consent form, you have explicitly given your consent for mentioning your name, for example in a quote.

The personal data that were gathered via data collection and storage and other documents within the framework of this research project, will be stored on the shared OneDrive of group 19 where all team members can get access.

The raw and processed research data will be retained for a period of 21 days. Ultimately after the expiration of this time period, the data will be either deleted or anonymized so that it can no longer be connected to an individual person. The research data will, if necessary (e.g. for a check on scientific integrity) and only in an anonymous form be made available to persons outside the research group.

This research project was assessed and approved by the ethical review committee of the Eindhoven University of Technology.

CONSENT FORM FOR PARTICIPATION BY AN ADULT

By signing this consent form I acknowledge the following:

1. I am sufficiently informed about the research project through a separate information sheet. I have read the information sheet and have had the opportunity to ask questions. These questions have been answered satisfactorily.

2. I take part in this research project voluntarily. There is no explicit or implicit pressure for me to take part in this research project. It is clear to me that I can end participation in this research project at any moment, without giving any reason. I do not have to answer a question if I do not wish to do so.

Furthermore, I consent to the following parts of the research project:

3. I consent to processing my personal data gathered during the research in the way described in the information sheet.

   YES ☒ NO☐

4. I consent to retaining research data gathered from me and using this for future research in the field of medical research in which recognized ethical standards for scientific research are respected, and for education purposes.

   YES ☒ NO☐

Consent filled in by participants (each participant gave consent for the YES and NO statements):

Name of Participant: Tomas Pieters

Signature: TOMAS PIETERS

Date: 25-05-2023

Name of researcher: Making Sense Of Sensors Group 19

Signature: -

Date: 25-05-2023

Name of Participant: Lot Vogels

Signature: LOT VOGELS

Date: 25-05-2023

Name of researcher: Making Sense Of Sensors Group 19

Signature: -

Date: 25-05-2023

Name of Participant: Jort Wiersma

Signature: JORT WIERSMA

Date: 25-05-2023

Name of researcher: Making Sense Of Sensors Group 19

Signature: -

Date: 25-05-2023

Name of Participant: Floris van Warmerdam

Signature: FLORIS VAN WARMERDAM

Date: 25-05-2023

Name of researcher: Making Sense Of Sensors Group 19

Signature: -

Date: 25-05-2023

Name of Participant: Euwe de Wilde

Signature: EUWE DE WILDE

Date: 25-05-2023

Name of researcher: Making Sense Of Sensors Group 19

Signature: -

Date: 25-05-2023

Appendix D

The code that was used, can be in the complementary delivered zip file.