Optimize your workout: a research on the influence of temperature on heart rate

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ABSTRACT

Due to the COVID-19 limitations, people need alternatives to stay healthy. One of the most common and easily accessible activities is walking. Little research was done on the beneficial influence of weather conditions on walking. Therefore, this research investigates how the weather could have potential influences on walking behaviours. The weather data was considered as the temperature variable collected through DHT sensors. The walking behaviour was examined with the heart rate data gathered with smartwatches. A two-week experiment of walking an average time of 15 minutes every day while collecting heart rate and temperature data was conducted among five participants. Although thorough data analysis did not show clear correlations between temperature and heart rate, this research informs the possibilities of better testing conditions and provides details on the experiment executions for improved future study settings.

Author Keywords

Heart rate; Temperature; Vitality; COVID-19; Walking

INTRODUCTION

The human body is built to move. So, exercising or being physically active has many health benefits. It helps to build and maintaining strong muscles and bones, it can reduce the risk of chronic diseases and it can make you feel happier and more energized [14]. Being inactive has negative impacts on the body. Instead of improving health, it decreases already existing symptoms and prevents complaints from becoming worse [8].

During COVID-19 people are stuck at home. Life went from biking to the working space every day and walking around naturally, to most of us do nothing more than sit in our room and study. This way, most of our regular physical activity is cancelled. On top of this, there are many regulations for sports and for a certain time the sports centers were closed. This all made being active a challenge.

To stay active during these times most people resort to walking and running since these are the most common sports to do [3]. The disadvantage of such activities is that they are outdoor and thus weather and temperature dependent. Even though it may portray that running and walking outside seems beneficial for our health, people are often unaware of how to optimize this type of workout. For example, considering the optimal heart rate for a workout. According to the American Heart Association [1], the target heart rate during a mild workout is about 50% to 70% of the maximum heart rate, while during more intense exercise it is about 70% to 85%.

With this target, the research opportunity of focusing on how the weather data influences the workout performance through tracking the average heart rate is taken. The research questions extracted from this sounds as following:

"How is the relation between temperature and heart rate an important factor when optimizing a workout?"

With the collected data using selected devices, an identification of the link between these factors is determined of best circumstances to work out. Depending on the outcome of the research, individuals can be informed on the influence of the temperature on their workout, which in the long term will improve their vitality.

RELATED WORKS

Before the research was conducted, related works were gathered concerning the topic. This helped when defining the research gap and finding research opportunities.

Heart rate

The normal heart rate range for adults from the age of 18 and over, is 60 to 100 beats per minute (bpm) at rest [12]. When exercising, the heart rate of a person depends on multiple factors [13]. First of all, just like heart rate at rest, it is age-dependent: the older an individual gets, the lower the maximum heart rate gets. Secondly, gender is also a factor: women tend to have higher heart rates than men in general. Following up, fitness level is also of importance on heart rate. People who exercise more, tend to have a lower heart rate than individuals who exercise on the regular. This, because the bodies beat volume increases with exercise. This explains the increase of heart rate when there is a gain in body weight. Further on, the intensity of training matters, since too intense or too often training, can increase heart rate. Also, type of movement influences heart rate: the walking heart rate is approximate of a range of 8 to

12 beats higher than when cycling. Next to that, eating larger meals can increase heart rate. Mental stress can increase heart rate. And last but not least, pregnancy can increase heart rate.

The other factors mentioned above might cause differences in heart rate. Heart rate at rest is expected to be between 60 and 100 bpm and considering the exercise that is done while measuring is walking, so the increase in heart rate should not be too big. A heart rate is expected as below 50% of the maximum heart rate since this is the heart rate when starting an exercise program [6].

Vitality during COVID-19

In a paper by Cheval, B. et al [4], an online survey (the 'International Physical Activity Questionnaire', IPAQ) has been conducted to measure physical activity before and during the lockdown. The results showed that the lockdown has influenced the vitality of people in two ways. It affected practical situations, considering the gyms were closed, public movement restrictions, and less ability to commute. Secondly, it affected people's vitality effectively: stress and anxiety of the risk of getting in contact with the virus made people stay at home. Therefore, the lockdown resulted in vigorous physical activity and an increase in sedentary behavior, time walking, and moderate physical activity.

Also, the paper by Puccinelli, P.J. et all [11] mentions the connection between physical activity, anxiety, and stress. The physical activity levels under social distancing were significantly lower than before: 69% of the research population were classified as very active before social distancing, but it dropped to 39% under pandemic. And those lower physical activity levels associated with higher levels of anxiety and depression. Because of these higher levels of anxiety and depression, there was a 147% increase in insufficiently active or inactive people.

Hargreaves, E.A. et al [5] claims that the changes in physical activity (PA) differed as a function of individuals' pre-lockdown PA levels. People who were highly active before the lockdown was less active in the lockdown. Their vigorous and moderate-intensity PA levels dropped during the lockdown and remained at this level post-lockdown. The people who were moderately active before the lockdown was more active in the lockdown. Their vigorous and moderate PA levels increased, thus resulting in a higher PA level after the lockdown compared to before. The reasons behind this, according to the paper, were less opportunity, since the indoor exercise facilities were closed, club and community sport were cancelled, and outdoor recreation was limited to local neighborhoods. On the other hand, there was a higher opportunity. People wanted to use the time to 'escape' from their homes and they knew being physically active was a permitted activity during the lockdown.

Temperature and heart rate

Related works about the relationship between temperature and heart rate are also implanted. In a paper by No, M. et al [9], the effects of environmental temperature on psychological responses during submaximal and maximal exercises in soccer players are researched. During the research, they concluded that the heart rate (and oxygen uptake) is lower in a moderate environment (22 ±1 ºC) than in a cool (10 ±1 ºC) or hot (35 ±1 ºC) environment at rest and during submaximal exercise and is higher during maximal exercise. Also, the psychological responses and endurance exercise capacity are impaired under cool or hot conditions, if compared to moderate conditions. The overall conclusion of the research was those physiological responses during rest, submaximal and maximal exercise were impaired under cold or hot temperature conditions compared with those under moderate conditions, suggesting that environmental temperature may play a key role in exercise performance. A temperature between three and 11 degrees Celsius could then be beneficial to maximal exercise performance.

Another study has been done concerning temperature and heart rate. In the paper by Madaniyazi, L. et al [7], the outdoor temperature is compared with the heart rate (HR) and blood pressure (BP) in Chinese adults. They examine whether the short-term effects of ambient temperature on heart rate are linear or non-linear. The results showed that the effect was non-linear. The effect was V-shaped with thresholds ranging from 22 degrees Celsius to 28 degrees Celsius, showing that both cold and hot effects were observed on the HR and BP. However, the associations of temperature with HR and BP were V-shaped except for people older than 65 years old, female, people who smoke, people with higher income, intellectual workers, and people with hyperlipidemia. Considering all participants in this study are female, this might be something to consider when reviewing the results of the study.

Temperature and burned calories

To verify the results from the study of the relationship between heart rate and temperature, the relationship between temperature and burned calories is also researched. In the paper by Ocobock, C.J. et al [2, 10], they researched the effects of cold on body fat. It is proven that during cold weather, bodies require more energy to stay warm. The process of the body creating heat when it's cold is called 'thermogenesis'. The study confirms that individuals were expanding an average of 3,500 calories a day while hiking in the mountains during the spring, whereas they burned over 4,700 calories per day while hiking in the mountains during the winter. However, it should be considered that exercising during colder weather already influences the initial body heat as it is higher. Therefore, the body contains enough heat to maintain exercise and does not burn calories.

Research gap

At this point, there are no studies found that research the effect of the outdoor temperature on heart rate when walking. Therefore, this research aims to find out how these two variables are correlated to create the optimal conditions to have a walk.

METHODS

Set up

The experiment consisted of daily 15-minute outside walks (later also referred to as 'workout'), done by every participant (in total 5 participants) for a period of 14 days. The participants were free to choose the time they walked. During the 15-minute workout, the outside temperature was measured by a YODL kit at the home of the participant the heart rate, step count and burned calories were measured by the smartwatches the participants wore throughout the walk.

Measuring

Devices

Two devices were used for measuring in this experiment: a smartwatch and a YODL kit. The smartwatch measured the heart rate, step count and burned calories during the 15-minute walk. During the experiment, participants either worn a Mi Band 5 or an Apple watch.

The other device used for data collection was the YODL kit. This kit measured the temperature during the whole workout. The kit was placed outside by all the participants at the start of the workout. Therefore, the only date during the walk was collected but not throughout the day. The kit consisted out of the following compartments (see the circuit in Figure 1):

- 3 x DuPont Jumper Male-Female 10cm wires
- 1 x RobotDyn Data Logging Shield
- 1 x DHT11 Temperature/humidity Sensor
- 1 x Uno R3 with USB Kabel
- 1 x Kingston Canvas Select Plus 16GB Class 10 UHS-I A1 microSD card with SD-card adapter

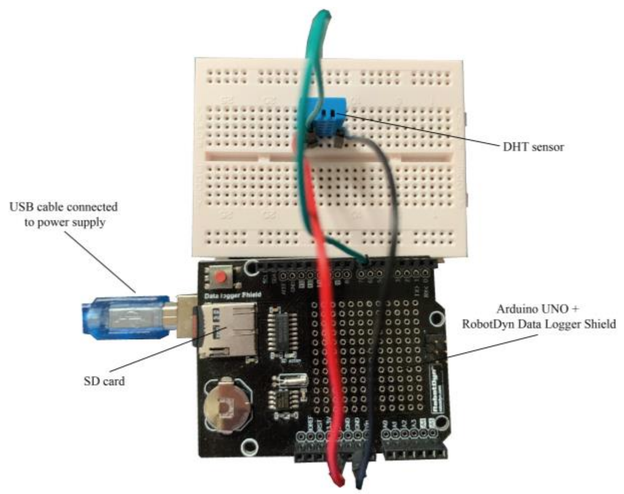


Figure 1: YODL Kit setup

Duration

This research contains an experiment consisting of data gathering. Starting on the 19th of May 2021 with a continuation of two weeks until the 2nd of June 2021. In these two weeks, a daily 15-minute walk is measured. When starting the workout, the participant selected the workout mode on the smartwatch, clicked on walking and started the walk. After 15 minutes of walking, the participant turned off the workout mode and the data were stored. As for the YODL kit, the participants connected the Arduino onto a power supply and ran the code (see appendix A.1) to measure the temperature (and humidity) the moment that they went for a walk. Some participants have measured an interval of longer than 15 minutes, but this extra time was filtered when analyzing the data.

Participants

The experiment was executed by the participants as the researchers who conducted this research. This was due to COVID-19 whereas it was not possible to include participants from outside. There was a total number of 5 participants. All participants lived at various locations in and around Eindhoven, the Netherlands. Because of this, the weather (temperature) data at the various locations could slightly differ. The participants were aged range from 19 to 20 years old, were all woman and were all not pregnant.

Analysis

After the data collection as described above, the data was analyzed. First, the data from the SD card of the YODL kit and the smartwatches was exported and stored on a shared folder on OneDrive, a protected platform by Technical University Eindhoven. This also made sure that the data was accessible to every researcher. After that, a code was written in Python (Jupiter Notebook, see appendix A.2) to carry out the next steps.

One issue found when exporting was that the YODL kit data from Participant 3 was not properly restored, resulting in a missing data set. Regardless, the data sets were analyzed independently for every participant. The finding would be presented in the results. A few steps were taken to reach there:

Cleaning and aggregating YODL kit data

The YODL kit data contained three columns: date/time, temperature, and humidity. First, the data collected by the YODL kit was cleaned. This included setting up columns for different variables, dropping the rows without values or with messed data points, and lastly, removing the extra letter 'T' from the column of date and time. This was done with a new data frame made in Python so that the originally collected datasets were obtained.

With the cleaned data for the YODL kit, the time frame of the first workout was selected. At the same time, the column with date and time was separated into four columns, namely date, hour, minute, and second. It was made sure that these columns were converted into datetime objects and as strings for future steps.

Afterwards, the variables of date, hour, minute, and temperature was stored in a new data frame. Here, the temperature data was grouped as the average value per minute. This was done purposely for easier comparison with the heart rate data.

Cleaning and aggregating heart rate data

The original heart rate dataset contained three columns: date, time, and heart rate. However, when converting the time data into datetime objects, it was noticed that a wrong date was read together with the time. To solve this problem, the column of the time was separated into two columns, one with the wrong date which was dropped in a later step and the other one with the correct time. The correct time was then divided into two: hour and minute. All in all, these led to a new data frame with the columns of date, hour, minute, and heart rate. The final step was grouping the heart rate data as the mean value for every minute.

Combining the datasets for the first day

Since the data for temperature and heart rate were in two data frames, and the relationship was the investigation point, the two data frames had to be combined.

To simplify the problem, individual days were looked at. A new data frame for the data of the first workout day was created including both temperature and heart rate data. One important process here was only choosing the data for the 15-minute workout and leaving out other data points. This was done by selecting the common variables of the date and time range of the workout. This time range was checked with the MiFit/AppleHealth mobile application and noted down. In this way, a cleaned dataset for the first workout was completed.

Combining the datasets for the other days

The same steps were followed for combining the datasets for the other individual days as the first day. In the end, it was expected to have in total 15 datasets for every participant.

Combining all the datasets per participant

Because the relationship between the temperature and heart rate was intended to be researched, it was decided to combine the data frames for all the workouts into one data frame per individual. In this way, the temperature and heart rate data could be used more easily.

Exploring and creating visualizations

The visualizations were created for every participant.

First, different types of plots including bar plot, line plot, and box plot were explored. It was found that a line plot could be used to show the differences in the average temperature and heart rate of every workout day. It also had an advantage that allowed both temperature and heart rate to be plotted on the y-axis. The x-axis in this case was the day number.

In addition, a box plot was created. Since the aim of using a box plot was to get a feel of the data range for every day per participant, the grouped average temperature and heart rate data were first ungrouped. This was done by resetting the index. Next, two plots were created and put next to each other. The left plot had a horizontal axis as the day number and a vertical axis as the temperature data. The right plot had a horizontal axis also as the day number and a vertical axis as the heart rate data. This made the comparison of the trends of temperature and heart rate more easily.

Finally, to research the relationship between temperature and heart rate more in-depth, linear regression models were made. It gave a clear picture of the spread of data with a visualization created. It also allowed for calculating the r-square value of the dataset.

Ethics

Considering the participants of the experiment are the researchers of this research, there is not too much about ethics (and FAIR principles) to take into consideration. The things we do consider are: All five researchers will be assigned to a participant number. Therefore, the data from the smartwatch which is shared amongst the group will be anonymous. Secondly, personal data, such as GPS, will not be gathered. Because of that, the data cannot be traced back to any participant. Lastly, the data gathered on the smartwatch will be safely stored in OneDrive folders. Only the researchers have access to these folders and will be deleted after the research has ended. This is around the 10^{th} of July 2021.

FAIR principles

Findable: the data collection is aimed to answer the variables of the research question.

Accessible: the protocol is universally implementable, with microcontrollers, data loggers, temperature, and moisture sensors in the YODL kit as well as a Mi Band 5 & Apple Watch.

Accessible: the metadata will always be accessible, as the results of this study will be presented in the final report. This means after the study, the findings will remain accessible.

Interpretable: data will be presented and analyzed in a way that could be easily understood by the outside.

Reusable: each attribute of the data will be described and explained precisely.

Reusable: the data collection and analysis are written into detail into the methods and results of this report.

RESULTS

To analyze the results from the 15-minute walks of the participants, multiple visualizations were made to look for relationships between different variables.

Boxplots

In the boxplots in figures 2 – 5, the temperature and heart rate of four participants are separately plotted against the days of the week to get a clear idea of the spread of data on every individual day. In the graphs, the temperature of the data is quite constant, with a few outliers. This makes sense considering the outside temperature usually does not change a lot within a 15-minute range. The big temperature differences reveal the fact that the participants did not walk at the same times during the day, and/or placed their YODL kits in different positions (North, South, East, West) to the sun.

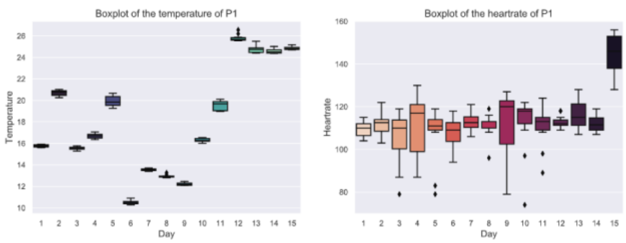


Figure 2: Boxplots participant 1

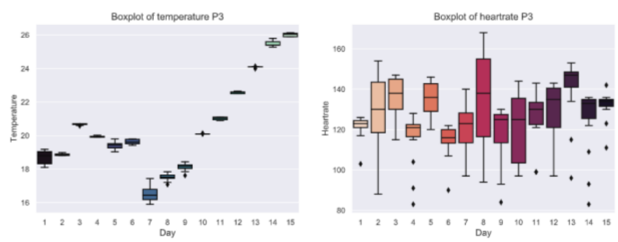


Figure 3: Boxplots participant 3

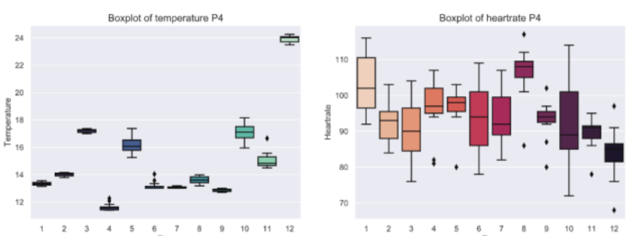


Figure 4: Boxplots participant 4

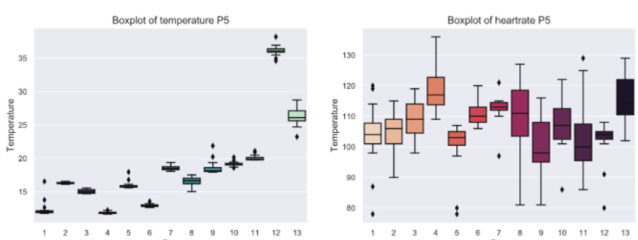


Figure 5: Boxplots participant 5

The heart rate plots present a great spread of data. Where the heart rate of participant 1 (figure 2) is very constant, the heart rate from participant 3 (figure 3) shows great differences when walking. These results, including the results from participant 2 (figure 6), indicate the big differences in heart rate per person.

When looking at the correlation between the two plots per participant, the following can be noticed. As mentioned before, the boxplot for participant 1 (figure 2) shows a relatively small spread of heart rate and about the same

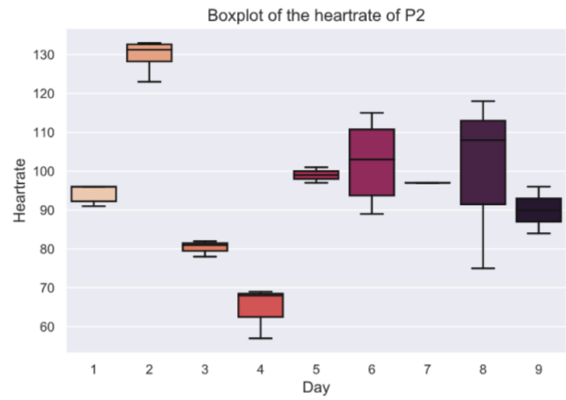


Figure 6: Boxplot heart rate participant 2

range for every day, even though the temperature data was quite different from day to day. For participant 5 (figure 5), the temperature was mostly below 20 degrees, whereas the data range of the heart rate was quite distinct for every day. The heart rate data of participant 4 (figure 4) did not follow the temperature pattern at all, sometimes it was even the opposite. For participant 3 (figure 3), the temperature shows an increase in temperature from day 7 till 15, but there is no pattern visible in the heart rate.

Line/bar chart

To see the relationship between the heart rate of the participants and the temperature measured while walking clearer, the data that was earlier plotted in the boxplots (figures 2-5) was combined. The line/bar plots (figures 7-10), containing both variables (temperature and heart rate) in a common graph, indicate the pattern for the temperature and heart rate data of every participant over the entire testing period.

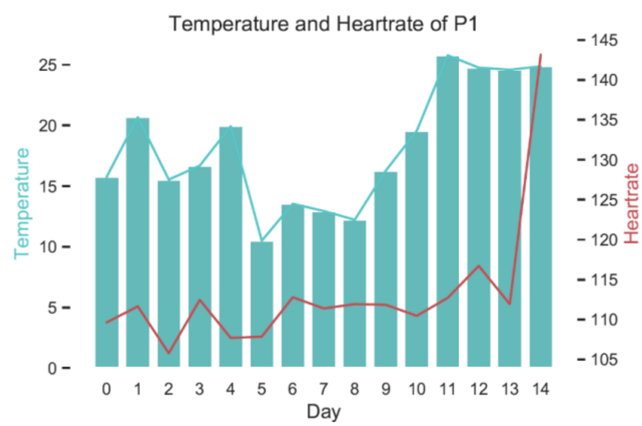


Figure 7: Line/bar chart participant 1

For all graphs, there is no clear pattern between the temperature and the heart rate. On some days, there is a small correlation visible. For example, the graph of the heart rate of participant 1 (figure 7) shows some peaks on warmer days. Looking at day 1 till 4 (plotted in the graph as day 0 – 3), the heart rate seems to rise with an increase in temperature and lower with a decrease in temperature.

However, this is not constant. In the second week of the research, where the temperatures were rising every day (over 20 degrees), the expected rise in heart rate is not visible. On day 13, a decrease in heart rate is visible, even though the temperature is the same as day 12.

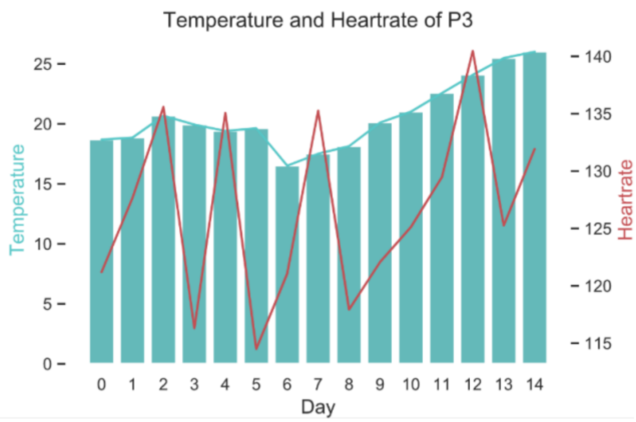


Figure 8: Line/bar chart participant 3

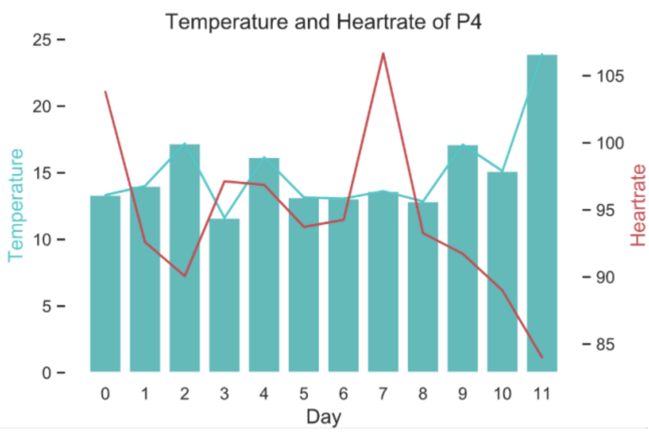


Figure 9: Line/bar chart participant 4

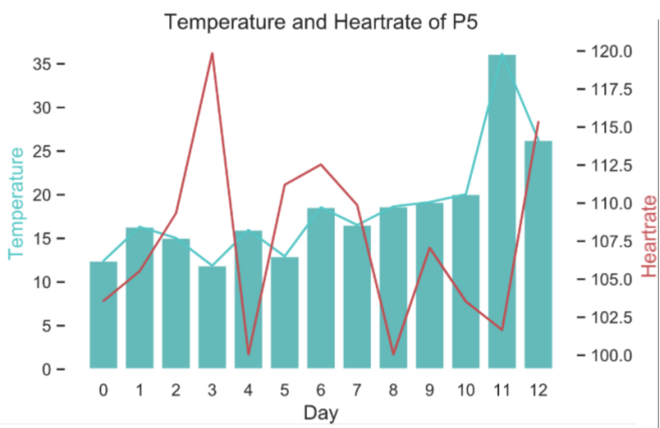
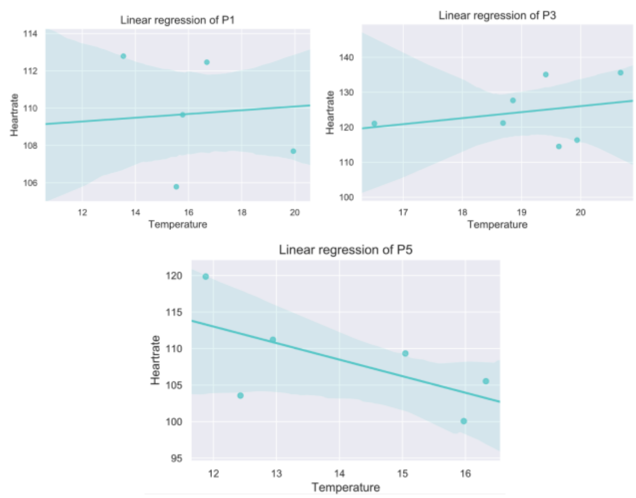


Figure 10: Line/bar chart participant 5

These kinds of results can be found in all graphs of the participants. On some days, where temperature rises, an increase in heart rate is visible, but on warmer days, where a peak in heart rate is expected, also very low heart rates are seen. On the hottest day, for example, day 11, there is a very small increase in heart rate visible for participants 1 (figure 7) and 3 (figure 8). However, the heart rates of participants 4 (figure 9) and 5 (figure 10) are close to the lowest values of heart rate of the week.

Linear regression models

Next, linear regression models were created to take a more scientific approach when looking at the relationship between heart rate and temperature. In the linear regression models, there are fewer human errors when reading the graphs. In the graphs, the average temperature and heart rate of every individual day were plotted. The average temperature and heart rate of each day were used (instead of all data) because as could be seen in the boxplots (figures 2-5), the temperature measurements did not fluctuate a lot.



Figures 11, 12 and 13: Linear regression models participants 1, 3 and 5

The many outliers of the linear regression show that the spread of the data was large and show that the linear regression might not be totally reliable. However, looking at the linear regression, for participants 1 and 3, in general, there was a small increase of heart rate when the temperature increases. In the graphs of participants 4 and 5, an obvious decrease in heart rate is visible with an increase in temperature.

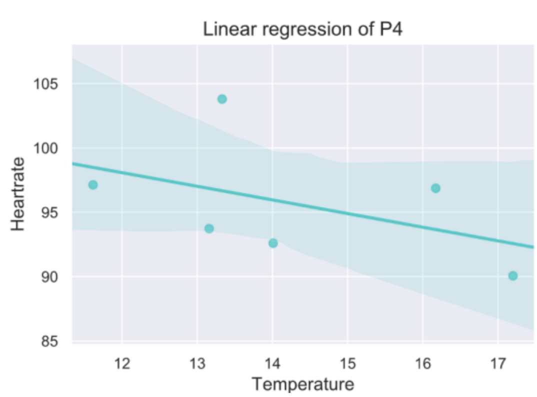


Figure 14: Linear regression model participant 4

R-squared values

Last but not least, the R-squared values were calculated and used to examine whether the temperature and heart rate data follow a linear regression model. The results can be found in table 1. The R-squared values for participants 1, 3, and 5 were negative, which means there is no clear correlation between the outdoor temperature and the heart rate measures of the participants. The R-squared value for participant 4 is positive, indicating a possible correlation between the temperature and the heart rate. However, this was not visible in the graphs (figures 4, 9 and 14).

Participant number	R-squared values of the linear regression models
1	-0.3179308162365299
2	not examined due to missing temperature dataset
3	-0.08989723837160035
4	0.4252306779942834
5	-16.892414641493744

Table 1: R-squared values

CONCLUSION

With the visualizations presented and discussed in the results, it can be concluded that there is no clear correlation between the temperature and the heart rate. This means that with the experiment set up in this study, the workout performance did not necessarily improve under certain temperature conditions. For this research, it could be concluded that individuals could walk whenever during the day, no matter for the weather conditions, the workout performance would not have a significant difference in terms of heart rate.

DISCUSSION

Checking collected data in the experiment

Initially, the heart rate and temperature data were intended to be measured for a 15-minute walk with a duration of two weeks. After every walk, some participants did not immediately check if these measures were correctly stored on the SD card or MiBand dataset. This, for instance, caused the complete YODL kit dataset of Participant 2 to be missing. When setting up the YODL kit, there were already some difficulties with testing the components. However, after some adjustments, they seemed to be working. Unfortunately, something went wrong along the way. Possible causes could be “broken” components such as the DHT sensor or loosen wiring, DHT sensor connected to a wrong pin by accident, no SD card inserted into the data logger shield, or not paying attention to the errors indicated in the Arduino software. In future, this could be prevented by paying more attention to checking the data; soldering the wires to make sure they are not loosened; double-checking the circuit when using the YODL kit every time including whether the sensor was connected properly, and the SD card was inserted.

In addition, when cleaning the data, it was noticed that some data was not properly stored in the CSV file. This resulted in some of the data points were cleaned since they could be not used easily for data aggregation. Thus, only 13 days of data were analyzed for Participant 4 and 5. By examining the datasets, it was noticed that the problem being either MiBand or YODL kit did not stream the data when the participant went for the walk. In addition, for Participant 2, there were only 9 days of data for heart rate that were properly collected and stored with the smartwatches. On top of that, no temperature data were analyzed. For future research, the experiment protocol could be designed better by including one more step as checking the data after every data collection. This could make sure that every participant obtaining an equal amount of data points.

The data used for Participant 4 was a bit different. It happened to be that quite a few datasets for Participant 4 were missing or incomplete in between the days of 19th May 2021 and 2nd June 2021. Because Participant 4 started the experiment earlier than 19th May, researchers decided to include the days before 19th May where the dataset was complete. However, even with using this method to include more data points, in total only the dataset of 13 days was analyzed. For future studies, it would be better to control the days of the experiment for every participant by making sure the data is stored properly.

Temperature measurements

During the experiment, participants noticed that the temperature sensor of the YODL kit was relatively sensitive. For example, when it was placed facing a window to the west during the evening and it was sunny, the temperature measured would be higher than placing the YODL kit in another position.

To compare data better, the YODL kit for every individual was put at a constant location during the testing period. This was also revealed in the visualizations as the temperature data for every participant over the testing period did not vary a lot. However, participants did not agree on an exact position (for instance facing north). Future investigations could control the direction of placing the YODL kit to raise the data reliability.

In addition, the data collection was done for only about 14 days in the spring. It might be interesting to research how the temperature in different seasons would influence heart rate. Thus, a larger range of data for the temperature would be taken into consideration. This would also help to draw a more valid conclusion for the research question.

Duration

Initially, the experiment was designed for a duration of 14 days continuously. However, unexpectedly, some malfunction occurred with streaming and storing the data collected from the YODL kit. This was the case for Participant 2, 4, and 5. Therefore, the dataset for two weeks was not completed, and the time span used for data analysis was slightly different for every participant. In future, it would be better to keep the days constant for every participant and ensure the data was collected properly by double-checking.

In addition, a long testing period could be helpful in better spotting the trend between the temperature and the heart rate. This would also reduce the cruciality of missing the data points or having bad points for a single day.

The study setup

First, it was clear that some participants walked longer than the exact 15 minutes for some days without turning the workout mode off. Initially, researchers hoped to also compare the calories burnt for the 15-minute walk. Since the calorie information was only available under the workout modes, and some participants did not turn off the workout mode right after fifteen minutes, the data of calories could be comparable. In future, the study setup could be designed better by for instance restricting the time frame.

In addition, for this study, participants chose when they walked during the day. In future, to better compare the datasets among individuals, it would be nice that every participant walked at the same time or even took the same route. This would control some external influences on the dataset as well, for example, the temperature is different in the morning and the evening. Additionally, it could help with simpler data analysis since the time frame could be chosen once and applied for every participant. It could also help with grouping the datasets for different participants.

Moreover, participants walked at different locations so that the route was different. Some participants also did not take the same route for the walk over the two weeks. By controlling the variable of the route, it might provide new insights into the pattern of the data collected over the 15 minutes.

All the participants wore smartwatches. However, 4 participants (Participant 1, 3, 4 and 5) used MiBand 5 whereas Participant 2 used an Apple watch. A difference in the use of the device might cause a systemic variance of the data. This could be a reason resulting in the dataset being less comparable. To limit this effect, future work could ensure that every participant uses the exact same model of the smartwatch.

Lastly, the participants did not walk at a constant pace every day, neither agreed upon a constant speed that everyone should be targeted at. This made the dataset of the heart rate to be less comparable since a slow walk could result in a lower heart rate. This could be improved by assigning a targeted speed before the experiment.

Reliability

Another interesting future research could be looking at data reliability. It was noticed by one of the participants who also worn a Garmin Venu during the workout, the steps collected with MiBand during a workout was > 400 more compared to the steps collected with a Garmin Venu. However, the burnt calories for one workout were detected as 247 calories on Garmin Venu but 186 on MiBand. Therefore, one possible future work is to examine the accuracy and precision of data collected with MiBand.

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APPENDIX

A.1 Arduino code

```
/*
  Simple program for Temperature / humidity datalogger. Uses Arduino UNO + DHT11 sensor + SD shield + Real Time CLock
  Part of TU/e course DAB100 "Making Sense of Sensors"
  Author: Aarnout Brombacher
  Basis: Public Domain examples from Arduino library

*/



/*
 * libraries and constants for SD card routines
 */

/*   The circuit:
   SD card attached to SPI bus as follows:
 ** MOSI - pin 11
 ** MISO - pin 12
 ** CLK - pin 13
 ** CS - pin 9 for Robodyn board
 *
 * This is different for other boards such as Arduino Mega
*/

#include <SPI.h>
#include <SD.h>

File myFile;

const int chipSelect = 9; // Important to check; this is Arduino dependent. Mega uses 53, Uno 9

/*
 * libraries and constants for Real Time CLock
 */

#include <Wire.h>
#include <TimeLib.h>
#include <DS1307RTC.h>

/*
 * libraries and constants for temperature/humidity sensor
 */

#include "DHT.h"

#define DHTPIN 7         // Digital pin connected to the DHT sensor
#define DHTTYPE DHT11    // DHT 11

// Connect pin 1 (on the left) of the sensor to +5V
```

```
// Connect pin 2 of the sensor to
whatever your DHTPIN is
// Connect pin 4 (on the right) of the
sensor to GROUND
// Connect, if necessary, a 10K resistor
from pin 2 (data) to pin 1 (power) of
the sensor

// Initialize DHT sensor.

DHT dht(DHTPIN, DHTTYPE);

#define Debug_mode true

// Define pin for signaling avctivity

#define debugled 8


void setup() {

  // Open serial communications and wait
for port to open:

  blink1();
  if (Debug_mode) {
    Serial.begin(9600);

    while (!Serial) {}

    Serial.println("DS1307RTC Read
Test");
    Serial.println("-------------------
");
    Serial.print("Initializing SD
card...");
  }
  delay(1000);
  pinMode(chipSelect, OUTPUT); // Set
Chip Select pin to "output" otherwise
the routine will not work
  delay(1000);

  if (!SD.begin(chipSelect)) {
    if (Debug_mode)
{Serial.println("initialization
failed!");}
    while (1);
  }
  if (Debug_mode)
{Serial.println("initialization
done.");}

  // open the file. note that only one
file can be open at a time,
  // so you have to close this one
before opening another.
  myFile = SD.open("data.csv",
FILE_WRITE);

  // if the file opened okay, write to
it:
  if (myFile) {
    if (Debug_mode)
{Serial.print("Writing to
data.csv...");}
    myFile.println("Date/Time,
Temperature, Humidity");
    // close the file:
    myFile.close();
    if (Debug_mode)
{Serial.println("done.");}
  } else {
    // if the file didn't open, print an
error:
    if (Debug_mode)
{Serial.println("error opening
data.csv");}
  }

  dht.begin();

  if (Debug_mode) {
    Serial.println("-------------------
");
    Serial.print("Initialzing
Temperature Humidity Sensor. ");

    Serial.println("done.");
    Serial.println("-------------------
");
    Serial.println("Starting data log");
    Serial.println("-------------------
");
  }

  pinMode(LED_BUILTIN, OUTPUT);
  blink1();
}

void blink1() {
  digitalWrite(debugled, HIGH);   //
turn the LED on (HIGH is the voltage
level)
  delay(500);                      //
wait for a second
  digitalWrite(debugled, LOW);    //
turn the LED off by making the voltage
LOW
  delay(500);                      //
wait for a second

}

void timestamp()
```

```
{
  tmElements_t tm;

  if (RTC.read(tm)) {
    // Block 1: write to serial
    if (Debug_mode) {
      Serial.print("Date (D-M-Y) = ");
      Serial.print(tm.Day);
      Serial.write('-');
      Serial.print(tm.Month);
      Serial.write('-');
      Serial.print(tmYearToCalendar(tm.Y
ear));
      Serial.print(" , ");
      print2digits(tm.Hour);
      Serial.write(':');
      print2digits(tm.Minute);
      Serial.write(':');
      print2digits(tm.Second);
      Serial.print(" , ");
    }

    //Block 2: write to file
    myFile.print(tm.Day);
    myFile.write('-');
    myFile.print(tm.Month);
    myFile.write('-');
    myFile.print(tmYearToCalendar(tm.Yea
r));
    myFile.print(" T "); // special
separator required for coupling with
data foundry
    print2digitssd(tm.Hour);
    myFile.write(':');
    print2digitssd(tm.Minute);
    myFile.write(':');
    print2digitssd(tm.Second);
    myFile.print(" , ");

  } else { if (Debug_mode) {
    if (RTC.chipPresent()) {
      Serial.println("The DS1307 is
stopped.  Please run the SetTime");
      Serial.println("example to
initialize the time and begin
running.");
      Serial.println();
    } else {
      Serial.println("DS1307 read
error!  Please check the circuitry.");
      Serial.println();
    }}
  }
}


void print2digits(int number) {
  if (number >= 0 && number < 10) {
    Serial.write('0');
  }
  Serial.print(number);
}

void print2digitssd(int number) {
  if (number >= 0 && number < 10) {
    myFile.write('0');
  }
  myFile.print(number);
}

void printtemp_humidity()
{ // Reading temperature or humidity
takes about 250 milliseconds!
  // Sensor readings may also be up to 2
seconds 'old' (its a very slow sensor)
  float h = dht.readHumidity();
  // Read temperature as Celsius (the
default)
  float t = dht.readTemperature();


  // Check if any reads failed and exit
early (to try again).
  if (Debug_mode) {
    if (isnan(h) || isnan(t) ) {
    Serial.println(F("Failed to read
from DHT sensor!"));
    return;
    }
    Serial.print(F("  Temperature: "));
    Serial.print(t);
    Serial.print(F("°C, Humidity: "));
    Serial.print(h);
    Serial.println(F("% "));
  }
  myFile.print(t);
  myFile.print(F(" , "));
  myFile.print(h);
  myFile.println(F("  "));
}

void loop() {

  // re-open the file for reading:

  myFile = SD.open("data.csv",
FILE_WRITE);
  blink1();
  if (myFile) {
    timestamp();
    printtemp_humidity();
    myFile.close();
    // close the file:
    delay(1000);

  } else {
```

```
    // if the file didn't open, print an
error:
   if (Debug_mode) {
Serial.println("error opening
data,csv");}
  }
  blink1();
  delay(8000); // one measurement cycle
every 10 (9000+500 + 500) seconds.



}
```

A.2 Jupiter Notebooks

The code in the Jupiter Notebook that was used to clean and visualize the data was too long and complicated to paste into this document. The notebook can therefore be accessed in the following OneDrive folder:

https://tuenl-my.sharepoint.com/:f:/g/personal/j_bergmans_student_tue_nl/Ekp7SG-TghhCnJA1y538es8BqMt3gVfoOofguZHdCYsZrA?e=5dOXtw